An exploration on the use of lung ultrasound by physiotherapists within the cardiac surgery population.

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ABSTRACT

Casey Juliet Farrell

Doctorate of Physiotherapy

An exploration on the use of lung ultrasound by physiotherapists within the cardiac surgery population

Background: Cardiac surgery places patients at a high risk of developing postoperative pulmonary complications (PPCs), some of which can have fatal consequences if not detected and treated in adequate time. Physiotherapists are an essential part of the postoperative team that aid in assessing for PPCs. Current diagnostic tools commonly used by physiotherapists postoperatively (e.g., chest x-ray and stethoscopes) lack reliability. Lung ultrasound (LUS) is a bedside diagnostic tool that has been shown to reliably detect PPCs when used by other healthcare professionals and may influence clinical decision-making. Physiotherapists use LUS, but to date, a paucity of research exists exploring experiences or influence of LUS on physiotherapy practice.

Aims: The aim of this thesis was to explore the use of LUS by physiotherapists within the cardiac surgery population through mapping the literature within a scoping review, empirically assessing the influence of LUS on pathology identification and management planning, exploring the perceptions and experiences of those engaging with LUS, exploring the current use of LUS with cardiac surgery patients, and exploring potential relationships between patient demographic and surgery details and changes in pathology identification and/or management.

Methods: This thesis first presents a scoping review that mapped the literature on the use of LUS within the cardiac surgery population. A fully integrated convergent mixed methods study was conducted, beginning with a quantitative phase that empirically assessed the influence of LUS on pathology identification, management planning, and confidence of physiotherapists assessing day one non-emergency cardiac surgery patients through paper-based questionnaires. The preliminary results from the quantitative phase informed the qualitative data collection, which consisted of semi-structured interviews analysed using the Framework approach. The data were integrated at the interpretation level using a statistics-by-themes joint display and through the construction of meta-inferences, with statistics and themes weaved further together through narrative discussion.

Key Findings: The scoping review found that while LUS has garnered significant attention in the field of cardiac surgery, further research is needed to establish best practices for LUS, particularly in standardising methods. Future research should explore use by non-medical professionals and explore experiences and perceptions of those engaging with LUS. The mixed methods study resulted in ten meta-inferences. In summary, the meta-inferences found LUS has an influence on pathology identification by improving confidence and certainty, particularly for pleural fluid. The meta-inferences also found LUS is seldom performed on, and changed management for, day one non-emergency cardiac surgery patients for several reasons. The qualitative phase resulted in three themes: (1) Views of physiotherapists on the use and impact of LUS in the cardiac surgery population, (2) Views of physiotherapists on skill development in LUS and importance within the field of respiratory physiotherapy, and (3) Barriers and facilitators to the use of LUS by physiotherapists within the cardiac surgery population.

Conclusions: This doctoral thesis has comprehensively explored the use of LUS by physiotherapists when assessing cardiac surgery patients. This exploratory thesis identified several areas for future research into the use of LUS by physiotherapists. Overall, LUS is viewed positively with numerous benefits and roles within physiotherapy practice, and therefore, further research is encouraged and considered worthwhile. The original knowledge generated from this doctoral thesis should be considered to guide the direction of future research. Lung ultrasound is showing the potential to be a valuable tool for physiotherapists working with cardiac surgery, as well as respiratory physiotherapy in general, and may assist in identifying PPCs early on to improve patient outcomes.

Key Words: lung ultrasound, ultrasonography, cardiac surgery, physiotherapy

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OUTPUTS

Presentations

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Lothian Health and Care Professions Conference – Oral Presentation; November 2023

CSP Conference, Glasgow – Rapid 5 Presentation; November 2023

Advancing Care, Advancing Practice Research Day – Oral Presentation; November 2023

The American Physical Therapy Association Combined Sections Meeting – Oral Presentation; February 2024; *Academy of Cardiopulmonary Physical Therapy Best Platform for CSM 2024*

Invited Commentary

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OUTPUTS IN PREPARATION

Publications

FARRELL, C. et al., TBD. Exploring the use of lung ultrasound by physiotherapists within the cardiac surgery population: a mixed methods study.

LIST OF ABBREVIATIONS

In alphabetical order:

ACPICR	Association of Chartered Physiotherapists in Cardiovascular Rehabilitation
ARDS	Acute respiratory distress syndrome
ARF	Acute respiratory failure
ASA	American Society of Anesthesiology
AVR	Aortic valve replacement
B5	Band 5
B6	Band 6
BLUE	Bedside Lung Ultrasound in Emergency
BMI	Body mass index
BSc	Bachelor of Science
CABG	Coronary artery bypass graft
CAQDAS	Computer-assisted qualitative data analysis software
CHF	Chronic heart failure
CITU	Cardiac intensive therapy unit
COPD	Chronic obstructive pulmonary disease
COVID-19	Coronavirus disease 2019
CPB	Cardiopulmonary bypass
CPD	Continuing professional development
CSP	Chartered Society of Physiotherapy
CT	Computerised tomography
CXR	Chest X-ray
D/C	Discharge
ED	Emergency Department
EVLW	Extravascular lung water
FiO2	Fraction of inspired oxygen
FRC	Functional residual capacity
FUSIC	Focused Ultrasound in Intensive Care
GDPR	General Data Protection Regulation
GP	General practitioner
I-AIM	Indication, Acquisition, Interpretation, Management
ICU	Intensive Care Unit
IPPB	Intermittent positive pressure breathing
IQR	Interquartile range
ITU	Intensive therapy unit
LUS	Lung ultrasound
MDT	Multidisciplinary Team
MIS	Minimally invasive surgery
MMR	Mixed methods research
MSc	Master of Science
MSK	Musculoskeletal
MVR	Mitral valve replacement
NA	Not applicable
NR	Not reported
OR	Odds ratios
OSF	Open Science Framework
PaO2	Partial pressure of oxygen in arterial blood

PI	Principal investigator
PIN	Patient identification number
PLAPS	Posterolateral alveolar and/or pleural syndrome
PMH	Past medical history
PoCUS	Point-of-care ultrasound
POD	Postoperative day
PPCs	Postoperative pulmonary complications
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PT	Physiotherapist
PTI	Physiotherapy technical instructor
R&D	Research & development
RCT	Randomised controlled trial
REC	Research Ethics Committee
Resp	Respiratory
RGU	Robert Gordon University
Rot	Rotational
SDA	Same Day Admissions
SpO2	Oxygen saturation
UK	United Kingdom
V/Q	Ventilation perfusion
VF	Ventricular failure

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

LIST OF APPENDIX FIGURES

1. INTRODUCTION

1.1 Introduction

This thesis evolved from a collaboration between the university and a clinical centre. The researcher and supervisory team worked closely with a cardiothoracic physiotherapy department in the United Kingdom (UK) that had begun to regularly use a diagnostic tool called lung ultrasound, a device that is new to the profession both in clinical practice and in research. At the time of planning this thesis, it was uncommon to find a physiotherapy department which had already integrated lung ultrasound into practice due to the novelty of the concept. The opportunity to explore the influence of lung ultrasound on the physiotherapy practice of this unique department became the basis of this thesis.

The aim of this thesis was to explore the use of lung ultrasound by physiotherapists within the cardiac surgery population. This chapter provides the context and background for the doctoral research. The chapter begins by discussing cardiac surgery and the risks of postoperative pulmonary complications. The role of respiratory physiotherapy in the identification and management of postoperative pulmonary complications is explained, as well as the clinical reasoning process. Next, point-of-care ultrasound and lung ultrasound are introduced, comparing lung ultrasound to other diagnostic tools. The current literature on the use of lung ultrasound by physiotherapists is then reviewed. The chapter concludes by justifying the direction of the thesis and leads into the next chapter, which presents a scoping review of the literature.

1.2 Cardiac Surgery

Cardiac surgery is the surgical treatment of pathologies relating to the heart and aorta, a speciality of medicine that was developed in the 19th century (Senst, Kumar and Diaz 2022). Over 35,000 cardiac surgeries are typically performed on adults every year in the United Kingdom (UK) (Grant et al. 2021). The prevalence of cardiovascular disease is increasing, and cardiac surgery serves an important role in managing cardiovascular health (Senst, Kumar and Diaz 2022). Atherosclerosis, the thickening or hardening of arteries due to a build-up of plaque, is becoming a more common cause of cardiovascular disease. A coronary artery bypass graft (CABG) is the most common type of cardiac surgery performed for blocked or narrowed arteries (Hough 2018; Grant et al. 2021) and uses a native blood vessel to bypass the affected arteries by connecting the aorta directly to the coronary artery (Hough 2018). Valve surgeries are also a common type of cardiac surgery; when heart valves become too rigid or loose, the blood flow through the heart can be affected requiring the patients to undergo surgery to repair or replace the aortic, mitral, or tricuspid valve with either a tissue or mechanical valve.

Over the last decade, there has been a steady improvement in patient outcomes following cardiac surgery (Grant et al. 2021). However, this progress was halted by the coronavirus disease 2019 (COVID-19) pandemic (National Institute for Cardiovascular Outcomes Research (NICOR) 2023). According to the 2023 UK National Adult Cardiac Surgery Audit, adult cardiac surgeries reduced to 19,333 within the first year of the COVID-19 pandemic and about 10,000 scheduled cardiac operations were not performed (NICOR 2023). Operations have slowly recovered over the past few years, with 24,807 cardiac surgeries performed in the 2021/2022 year. Due to the slowing of operations, the wait list for surgery has increased. Elective CABG waiting times have increased by 11.7% and urgent CABG waiting times are two days longer than pre-pandemic levels, with no hospital achieving the seven-day target since before the pandemic. Since 2013, there has been a 68% increase in the number of emergency aortic procedures. The mortality rate is higher than pre-pandemic levels (NICOR 2023) and requires all healthcare professionals involved in post-surgical care to actively work towards improving patient outcomes and reducing mortality rates.

1.3 Cardiac Surgery & Postoperative Pulmonary Complications

Cardiac surgery comes with many risks, including the risk of postoperative pulmonary complications. Postoperative pulmonary complication (PPC) is an umbrella term that includes a wide range of pulmonary complications that can occur following an operation and have the potential to be life-threatening if not caught early due to the relationship between the respiratory and circulatory system (Miskovic and Lumb 2017). To understand how PPCs develop and impact patients, it is important to understand these systems and how they connect.

1.3.1 The Respiratory and Circulatory Systems

The purpose of the lungs and the respiratory system is to oxygenate the blood by bringing inspired air close to the blood stream. The respiratory system can be divided into airways and lung parenchyma. The airways comprise the bronchial tree; the bronchus bifurcates off the trachea (windpipe), dividing into the left and right main bronchus. Each bronchus enters the lung and further divides into lobar bronchi, segmental bronchi, and eventually end with the terminal bronchioles and small air sacs called alveoli (Shier, Butler and Lewis 2018). The terminal bronchioles, alveoli, and the passageways connecting them (alveolar ducts) comprise the parenchyma, which is responsible for gas exchange (Figure 1.1).

Gas exchange is when the respiratory system and the pulmonary circulatory system meet. The pulmonary circulatory system consists of pulmonary arteries, veins, and capillaries. Pulmonary arteries are blood vessels which leave the heart through the pulmonary trunk, branching into smaller arteries (arterioles) the farther they get from the heart (Betts et al. 2022). The arterioles connect to capillaries, which are fine branching blood vessels that line the walls of the alveoli. The capillaries have thin walls to allow for perfusion, which is the passage of oxygen and other molecules between our lungs and the blood stream. The capillaries then continue to the venules (small veins) which lead into the pulmonary veins, returning oxygenated blood to the heart to be dispersed into the systemic circulatory system, and providing oxygen to the rest of our body's organs (Shier, Butler and Lewis 2018) (Figure 1.1). The parenchyma plays a vital role in connecting the two systems; impairment of the parenchyma can lead to widespread systemic issues if gas exchange at the alveoli is compromised. The pulmonary circulatory system is able to respond to changes in blood flow by reducing resistance through dilation, recruiting closed capillaries, and shifting blood to the circulatory system, ensuring consistent and adequate supply (Hough 2018).

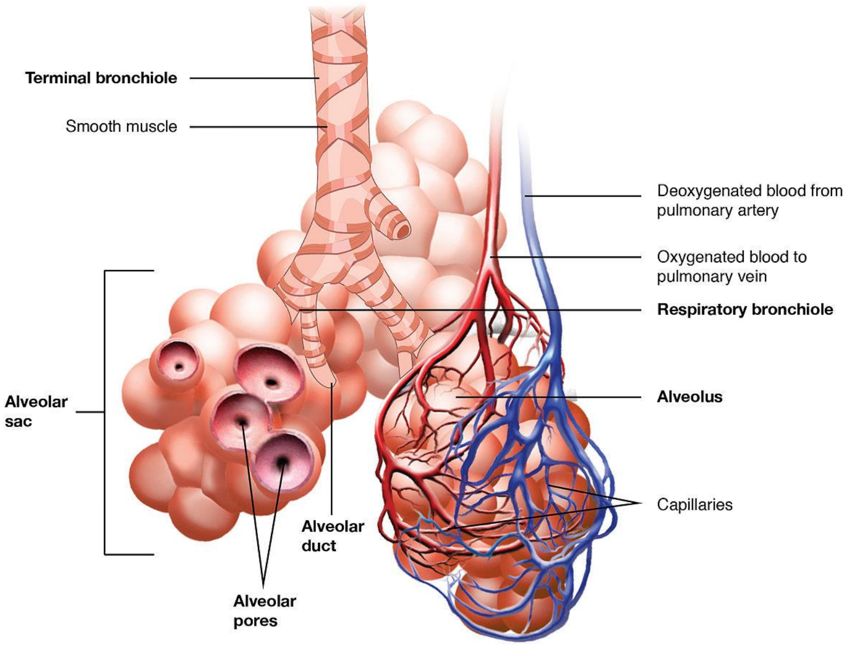


Figure 1.1 The Parenchyma and Gas Exchange. *The parenchyma comprises all the alveoli and is responsible for gas exchange. The deoxygenated blood from the pulmonary arteries travels to the alveoli where gas exchange occurs through the capillaries, allowing oxygen to be picked up and transported back to the heart through the pulmonary veins. (Source: Betts et al. 2013)*

All of the parenchyma is covered by a pleura (visceral/pulmonary pleura) which is continuous and folds onto itself to then cover the thoracic cavity (parietal/costa pleura). The space between the pleura forms the pleural cavity; the pleural cavity contains a tiny amount of serous fluid which allows the pleural surfaces to slide easily over one another during inhalation and exhalation (Betts et al. 2022). This serous fluid also generates a tension that aids the thoracic cavity in expanding during inspiration (Shier, Butler and Lewis 2018) (Figure 1.2). Disruption to the pleura may result in reduced inspiration which could lead to reduced tidal volume, the amount of air that is inhaled or exhaled during one respiratory cycle (Shier, Butler and Lewis 2018), making it difficult for oxygen to reach the alveoli for gas exchange.

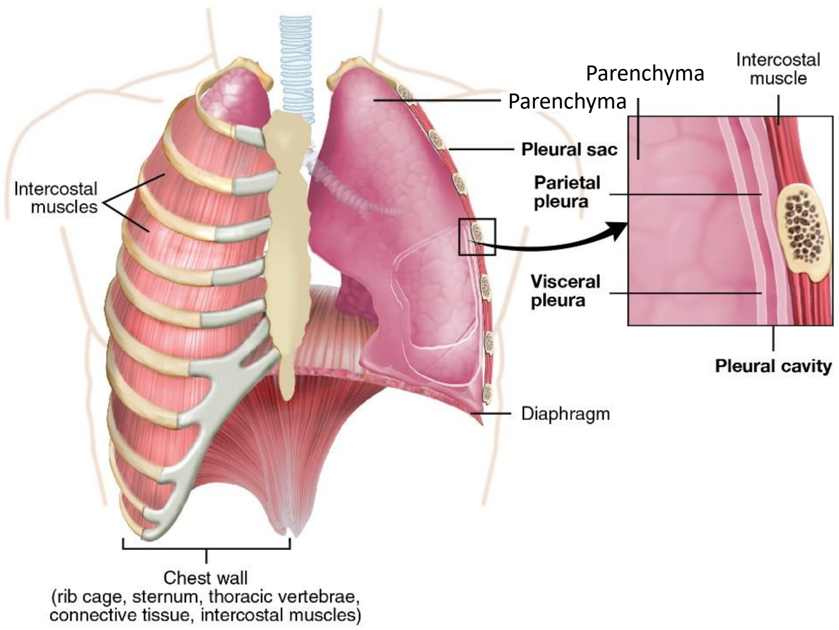


Figure 1.2 Parietal and Visceral Pleura of the Lungs. *The pleura is a serous membrane that lines the lungs. The pleural cavity between the two pleura is a region where many postoperative pulmonary pathologies originate. (Source: Betts et al. 2013)*

1.3.2 Common Postoperative Pulmonary Complications

When defining PPCs in the literature, authors include a combination of an extensive range of pulmonary complications, such as atelectasis, pleural effusion, pneumothorax, pneumonia, acute respiratory distress syndrome (ARDS), acute respiratory failure (ARF), bronchospasm, respiratory infection, aspiration pneumonitis, pulmonary oedema, and several others. This section will discuss three common PPCs that may occur after cardiac surgery: atelectasis, pleural effusion, and pneumothorax. A summary of these pathologies and their clinical presentations are found in Table 1.1.

Table 1.1 Common Postoperative Pulmonary Complications – Definitions & Presentation. *As seen in the table, the clinical presentation for these three pathologies are similar, making it challenging to differentiate. Key: PPC=postoperative pulmoanry complication.*

PPC	Definition	Clinical Presentation
Atelectasis	A partial or complete collapse of the lung	• Breathlessness • Decreased or absent breath sounds • Fine crackles on inspiration
Pleural Effusion	An excessive accumulation of fluid in the pleural cavity	• Breathlessness • Dull, decreased, or absent breath sounds • Dry cough
Pneumothorax	An accumulation of air in the pleural cavity	• Breathlessness • Decreased breath sounds

Atelectasis is when there is partial or total collapse of the alveoli. This can cause an intrapulmonary shunt, which is when the blood bypasses the alveoli because they collapse, resulting in less oxygen returning to the heart for systemic distribution. Too large of a shunt due to a large amount of collapse can cause hypoxaemia, which is low levels of oxygen in the blood. Hypoxaemia can destablise the cardiovascular system, which is already vulnerable for patients who are post-cardiac surgery. Hypoxaemia can also cause infection, slow down wound healing, and impair cognition (Hough 2018).

While atelectasis is a primary pathology itself, it can also be secondary to other pathologies. A pleural effusion occurs when excessive fluid accumulates in the pleural cavity (Hough 2018). The excess fluid can put pressure on the parenchyma, reducing the functional residual capacity (FRC), or the residual air in the lungs after exhalation (Shier, Butler and Lewis 2018). The patient's FRC provides pressure within the alveoli which keeps them open during exhalation. Reduction in the patient's FRC may bring pressure levels low enough to the point of collapse, therefore causing atelectasis. A pneumothorax may cause similar problems to that of pleural effusion, except it is from accumulation of air in the pleural cavity rather than fluid (Hough 2018) (Figure 1.3).

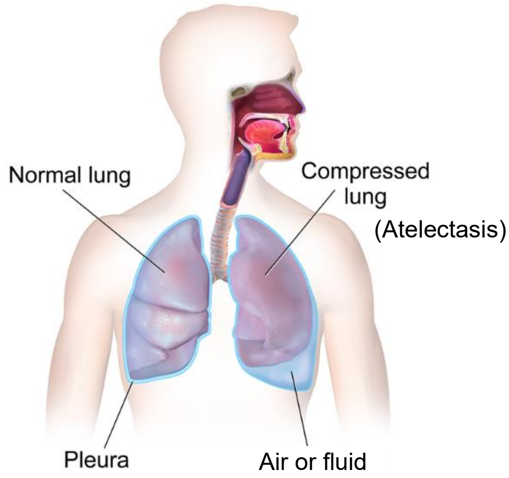


Figure 1.3 Common PPCs. *Atelectasis, a partial or complete collapse of the lung, can occur from excessive fluid (pleural effusion) or air (pneumothorax) accumulating in the pleural cavity and compressing the lung.*

1.3.3 Risk Factors for Development of PPCs after Cardiac Surgery

There are several preoperative, intraoperative, and postoperative factors that can increase the risk of the patient developing PPCs after cardiac surgery, particularly due to the proximity of the heart to the lungs (Figure 1.4). Preoperatively, the patient's overall health can impact the development of complications (Canet and Mazo 2010). Some risk factors associated with the development of PPCs after cardiac surgery include pre-existing pulmonary and cardiovascular conditions (e.g., congestive heart failure), low PaO2 (Ji et al. 2013), pulmonary hypertension (Naveed et al. 2017), and older age (Ji et al. 2013; Naveed et al. 2017).

The intraoperative period poses many risks of developing PPCs in the lungs (Figure 1.5). From the moment general anaesthesia is induced, FRC reduces, causing immediate atelectasis in the dependent regions of the lung through the compression of lung tissue, absorption of air, and impact on surfactant function (Canet and Mazo 2010). Anaesthesia and other perioperative drugs change and depress the neural respiratory drive, contributing further to the development of PPCs (Canet and Mazo 2010; Miskovic and Lumb 2017).

Cardiopulmonary bypass (CPB) is when the heart is stopped to allow surgery on the heart without excessive blood, and is commonly used during operations. During CPB, the lungs are also nonfunctioning, resulting in the lungs being partially collapsed. The resulting atelectasis can cause an intrapulmonary shunt of 25% following CPB (Hough 2018), increasing the risk of hypoxaemia. While blood is normally delivered to the lungs by both pulmonary and bronchial arterial systems, during CPB, perfusion is only provided to the bronchial system, placing the lungs in a relative state of ischemia. Once perfusion is reinstated, this can cause ischemia-reperfusion injury which leads to swelling of the vessel walls, obstructing blood flow (Tanner and Colvin 2020). The effect of CPB on capillary permeability may also lead to cardiogenic pulmonary oedema (water in the lungs), as well as miscalculated fluid replacement treatments (Hough 2018).

The patient's position in a prolonged recumbent position also impacts the patient's respiratory muscle function due to the increase curvature of the spine, cephalad diaphragm displacement in dependent regions, and reduced cross-sectional chest wall (Miskovic and Lumb 2017). The replacement of natural breathing with intermittent positive pressure ventilation, reduced cardiac output, and prolonged position lead to ventilation perfusion (V/Q) mismatch due to areas of both low and high V/Q ratios (Canet and Mazo 2010). Fluid disturbances, internal mammary artery harvesting, diaphragm dysfunction, and/or surgical techniques can lead to pleural effusion following bypass (Özülkü and Aygün 2015; Hough 2018).

There are two main surgical approaches: open surgery through sternotomy, or minimally invasive (Hough 2018). Sternotomy is the more common approach used in adult cardiac surgery and comes with more risks than minimally invasive surgery. Incisions can cause functional disruption of respiratory muscles and the pain from this can limit respiratory motion postoperatively, further contributing to PPCs. Surgery trauma may also cause reflex inhibition of respiratory muscle nerves, particularly the phrenic nerve which can cause diaphragm dysfunction postoperatively, which again may lead to PPCs (Canet and Mazo 2010; Ji et al. 2013; Naveed et al. 2017).

Following surgery, lingering sedation from residual anaesthetic and other drugs can contribute to continued depression of the respiratory system (Miskovic and Lumb 2017). Pain can contribute to atelectasis and sputum retention (phlegm or mucus) by discouraging the patient to cough and/or breathe deeply (Hough 2018) (Figure 1.5). An acute kidney injury can occur in up to 30% of cardiac surgery patients due to hypoxaemia and/or hypotension (low blood pressure) postoperatively, further increasing the risk of PPCs (Ji et al. 2013) and can even increase the risk of death fivefold (O'Neal, Shaw and Billings 2016; Hough 2018).

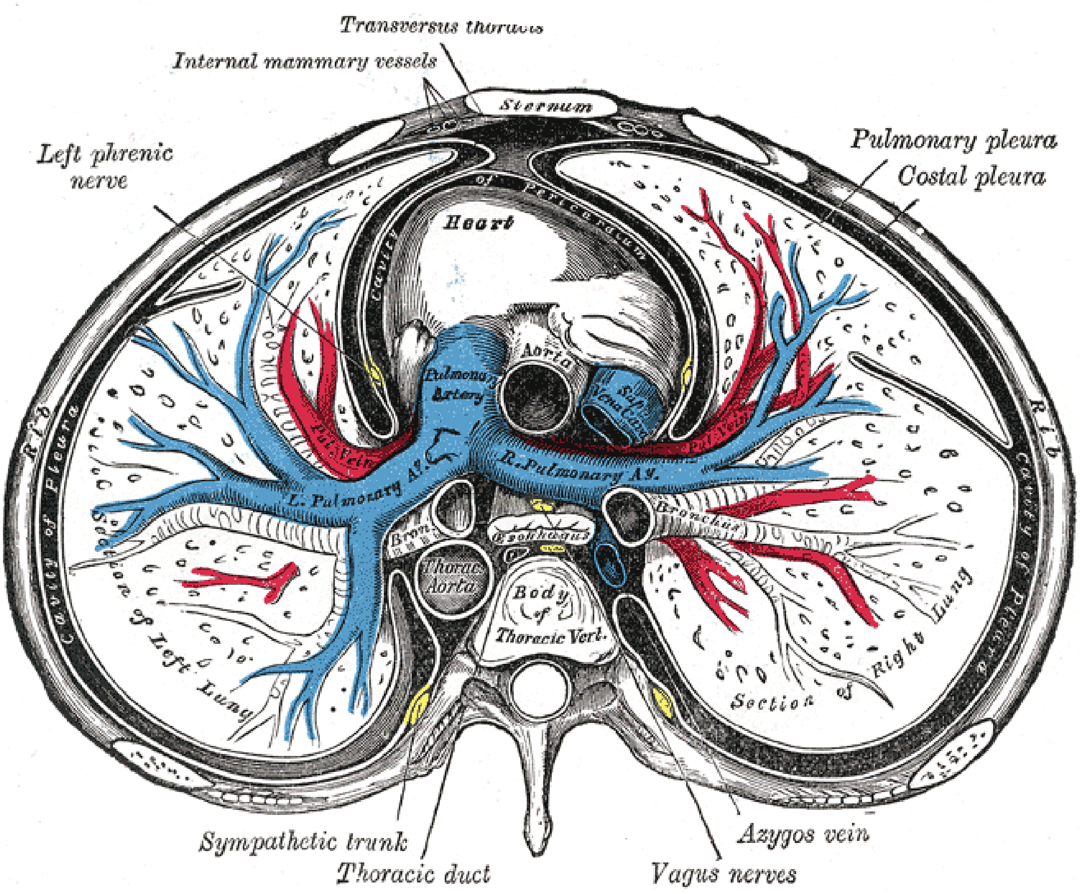


Figure 1.4 Transverse section of the thorax. *Postoperative pulmonary complications (PPCs) are common after cardiac surgery due to the proximity of the heart to the lungs, as seen above. In this image, the pleural cavity is the black space between the pleural linings of the lung, and where many PPCs occur. The proximity of the phrenic nerve to the heart shows how cardiac surgery may cause damage to the nerve, resulting in diaphragmatic dysfunction. (Source: Gray 1918).*

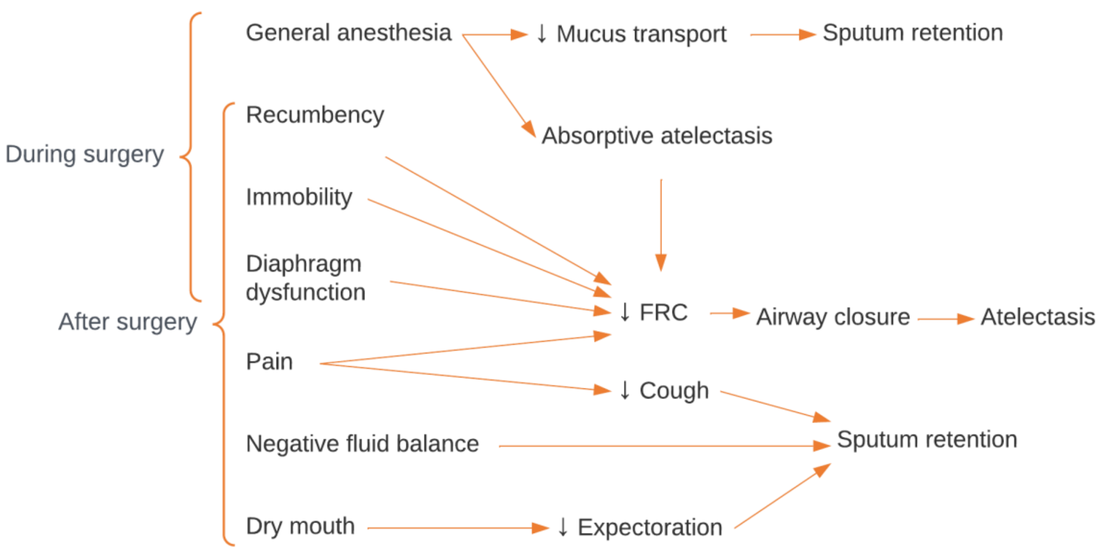


Figure 1.5 Surgical risk factors for physiotherapy problems. *Adapted from Hough (2018). Key: FRC = functional residual capacity.*

1.3.4 Incidence and Consequences of PPCs after Cardiac Surgery

The incidence of PPCs after major surgery, depending on the definition and inclusion of the different types of PPCs, ranges from 6.2% to 55% (Chumillas et al. 1998; Al-Qubati, Damag and Noman 2013; Naveed et al. 2017; Fischer et al. 2022). Chumillas and colleagues (1998) found only a 6.2% incidence rate of PPCs, which included atelectasis, respiratory failure, ARDS, and pneumonia. However, the prospective observational study had a mean age of 49 years and found an age over 60 years to be their main risk factor for PPCs; the mean age of cardiac surgery patients has been increasing over the years, with a mean age of 66.4 years in the UK in 2010/2011 (Grant et al. 2021). Meanwhile, a more recent cohort study by Fischer et al. (2022) found a 55% incidence of PPCs after cardiac surgery, defining PPCs as pleural effusion, respiratory failure, atelectasis, respiratory infection, pneumothorax, bronchospasm, and aspiration pneumonia. There are several factors to consider when determining incidence (e.g., setting, type of surgery, country), however, PPCs do occur after surgery and can be life-threatening. A patient can develop multiple PPCs, but the development of just one PPC, even if presumed mild (Fernandez-Bustamante et al. 2017), is significantly associated with increased admission into the intensive care unit (ICU) (Fernandez-Bustamante et al. 2017; Tanner and Colvin 2020), prolonged length of stay (LOS) (Fernandez-Bustamante et al. 2017), and most critically, early postoperative mortality (Canet and Mazo 2010; Al-Qubati, Damag and Noman 2013; Fernandez-Bustamante et al. 2017; Miskovic and Lumb 2017). Therefore, there is an urgency to identify PPCs and begin treatment early to prevent pathologies from developing to a lethal level.

1.4 Cardiothoracic Physiotherapy

Cardiothoracic physiotherapists are an integral part of the postoperative team that help to detect PPCs early after cardiac surgery. Common PPCs seen in the first few days after cardiac surgery are atelectasis, pleural effusion (Weissman 2004; Özülkü and Aygün 2015; Cantinotti et al. 2016; Hough 2018) and pneumothorax (Cantinotti et al. 2016). While physiotherapists can treat atelectasis, they cannot directly treat pleural effusion or pneumothorax. Pleural effusion is treated by fluid management (e.g., diuretic medications to reduce fluid load), thoracentesis (needle aspiration), or the insertion of a chest drain, all of which are medical interventions. Pneumothorax can either be left alone if it is minor or may also require thoracentesis or a chest drain to remove excess air if severe (Hough 2018). Although physiotherapists cannot directly treat a pneumothorax, it is important for them to know whether it is present; tension pneumothorax is a contraindication for intermittent positive pressure breathing (IPPB) (AARC 2003) which is common treatment used in physiotherapy to treat atelectasis after cardiac surgery, making it essential to be able to ensure there is no pneumothorax present prior to treatment. Regardless, physiotherapists who assess patients day one after cardiac surgery are in a prime position to detect these pathologies early and refer the patient to medical staff who can initiate appropriate treatment. It is important for physiotherapists to be able to differentiate between PPCs, as delayed treatment of a pneumothorax or pleural effusion could increase risk of mortality (Miskovic and Lumb 2017).

1.4.1 Physiotherapy Assessment

Physiotherapists detect PPCs through clinical assessment. An assessment begins by first collecting background information. This involves receiving a handover from the nursing staff and/or ward rounds and meetings, reading the notes, and reviewing the patient's charts. During this process, the physiotherapist considers charted observations (e.g., heart rate, blood pressure), oxygen therapy (e.g., ventilation settings, type of oxygen delivery), and investigations (e.g., arterial blood gases, chest x-rays, biochemistry reports). After reviewing the background information, the physiotherapist then approaches the patient and conducts a subjective and objective assessment. A subjective assessment involves speaking with the patient and discovering what is important to them. This may involve asking the patient about their pain, their breathing, their ability to clear their chest independently, sleep levels, and/or oral intake (Grillo et al. 2023). The objective assessment begins from the moment the physiotherapist sees the patient through observation of the patient's breathing, positioning, and general appearance. The physiotherapist will palpate the patient's chest, feeling for any crackling that may indicate sputum and feel how the thoracic cavity moves during inhalation and exhalation. Auscultation (listening via stethoscope) is then performed to verify observed and palpated findings (Grillo et al. 2023).

1.4.2 Clinical Reasoning and Impression

The complex and contextual nature of physiotherapy service has resulted in difficulties in conducting physiotherapy effectiveness studies. Therefore, physiotherapists must attempt to perform best practices using evidence that is either largely unavailable or incomplete, which requires comprehensive clinical reasoning and judgement. Every piece of information taken into consideration during the assessment becomes part of the physiotherapist's clinical reasoning. Clinical reasoning, a term often used interchangeably with clinical decision-making, has been defined as "the cognitive and noncognitive process by which a healthcare professional consciously and unconsciously interacts with the patient and environment to collect and interpret patient data, weigh the benefits and risks of actions, and understand patient preferences to determine a working diagnostic and therapeutic management plan whose purpose is to improve a patient's well-being" (Trowbridge, Rencic and Durning 2015). Clinical reasoning comprises multiple layers and components that are context-dependent; there is no single model of clinical reasoning that is applicable across professions and settings (Higgs et al. 2019). The method of assessment described in the previous section closely resembles the hypothesis categories framework, a framework of clinical reasoning which requires the physiotherapist to recognize patient cues and information that should trigger hypotheses in one or more categories of clinical judgements (Higgs et al. 2019). The physiotherapist will identify a number of physiotherapy problems from their assessment. Common respiratory physiotherapy problems post-cardiac surgery are breathlessness, loss of volume, sputum retention, reduced exercise tolerance, and/or V/Q mismatch. Based on these problems, the physiotherapist will begin to form hypotheses on the cause of the problems, which may include one or more PPCs.

As each hypothesis is considered, clinical judgements should be tested for remaining requirements of the hypothesis using common clinical patterns until ultimately a clinical impression is formed and a decision is made for intervention (Higgs et al. 2019). A clinical impression is a working informed opinion of the patient's condition based on the physiotherapist's assessment. From initial assessment to management planning, the process can be complex; this process is made more complex by the lack of reliability of the available tools that physiotherapists are using and have access to when assessing cardiac surgery patients.

1.4.3 Differential Diagnosis

The two main diagnostic tools used by physiotherapists to differentiate between pathologies are auscultation and chest x-ray (CXR). Although physiotherapists do not perform CXR, they are trained to interpret CXR images and use this information as part of their clinical reasoning. Physiotherapists, however, have difficulty differentiating between atelectasis, pleural effusion, and pneumothorax with these standard diagnostic tools (Leech et al. 2015; Hayward and Hayward 2019). Therefore, physiotherapists must incorporate other information to differentiate between them, such as with predictor values associated with the diagnostic tools. Commonly used predictor values in the literature are sensitivity and specificity: sensitivity is how well a test identifies a true positive; specificity is how well the test identifies a true negative (Monaghan et al. 2021). Physiotherapists, as well as other healthcare professionals, often use a 'rule in' or 'rule out' approach, which aligns with the hypothesis categories framework (Higgs et al. 2019). It is common to use the acronyms SpPin and SnNout, SpPin meaning when a test has high specificity, a positive test 'rules in' the pathology, and SnNout meaning when a test has high sensitivity, a negative test 'rules out' the pathology (Sackett and Straus 1998). Another statistical tool to understand diagnostic ability is likelihood ratios. A likelihood ratio is calculated from the sensitivity and specificity and provides how much more likely a particular test result will show in patients with the disease than without. The overall diagnostic accuracy is calculated from the sum of the true positive and negatives divided by all tests and is a summary of the correct diagnostic yield of the tool being tested. Physiotherapists may take sensitivity, specificity, likelihood ratios, and diagnostic accuracy of different diagnostic tools into consideration to test their hypotheses created during the clinical reasoning process.

There are several reasons why physiotherapists may struggle to differentiate between atelectasis, pleural effusion, and pneumothorax with the tools currently available for use. Auscultation has poor accuracy and intra-rater reliability (Allingame et al. 1995; Brooks and Thomas 1995; Hanekom, Faure and Coetzee 2007). Diminished or absent breath sounds could be caused by pneumothorax, pleural effusion, airway obstruction, shallow breathing, or hyperinflation, which can be difficult to differentiate without more information (Sarkar et al. 2015) (Table 1.1). While an erect CXR has 92% sensitivity for pneumothorax, a supine CXR (common postoperatively) has only 50% sensitivity (Omar et al. 2010). Although computerised tomography (CT) is the gold standard for diagnosing PPCs, it cannot be routinely used due to cost, exposure to radiation, and transportation difficulties within the post-cardiac surgery population (Cantinotti et al. 2016). Chest x-ray has a low sensitivity for diagnosing pleural effusion (42%) and consolidation (53%) (Hansell et al. 2021); these low sensitivities make it challenging for physiotherapists to differentiate between a pathology they can treat (consolidation) and one they cannot treat that requires medical intervention (pleural effusion). Occasionally, physiotherapists may come across a 'whiteout' on a CXR, which is a hemithorax opacification or a complete whitening of one half of the thorax (Figure 1.6). A 'white-out' often results in a referral for physiotherapy intervention due to a suspicion of total lung collapse, but a 'whiteout' on a CXR could indicate atelectasis or 15 other causes (Hayward and Hayward 2019). If the standard tools are unable to reliably differentiate between pathologies, physiotherapists might be misguided and initiate inappropriate or ineffective management, further delaying essential treatment and recovery for patients.

Figure 1.6 Hemithorax Opacification ('whiteout'). *A 'whiteout' on a chest x-ray can be a pleural effusion, atelectasis, mucus plugging, or 13 other differentials. This makes differential diagnosis difficult for physiotherapists. (Source: Dawes et al. 2022)*

1.5 Point-of-Care Ultrasound

Due to concerns of using tools with low reliability, respiratory physiotherapists are investigating alternative diagnostic measures. Point-of-care ultrasound (PoCUS) has gained popularity over recent years as it is highly accurate, portable, and emits no radiation (Lichtenstein 2014; Cantinotti et al. 2016; Hew and Tay 2016). PoCUS is seen in literature within the fields of musculoskeletal (MSK) and pelvic health physiotherapy (Smith et al. 2022, 2023). Respiratory physiotherapists, however, are particularly interested in a type of PoCUS that focuses on the pleura and parenchyma called lung ultrasound (LUS).

1.6 Lung Ultrasound

Lung ultrasound (LUS) is a diagnostic tool used at the bedside that is easy to use, emits no radiation, and is studied globally within the medical field. Lung ultrasound is a form of sonography, which uses sound waves to produce images. Lung ultrasound differs from other ultrasound examinations; most of the ultrasonic waves reflect off the pleura in a normally air-filled lung causing a hyperechoic pleural line, and the parenchyma cannot be directly visualised any deeper (Marini et al. 2021). Instead, operators of LUS use artefacts, something seen on the image that is not there in reality but appears due to the physics of the ultrasonic waves. When the ultrasound probe is placed between the ribs, horizontal reverberation artefacts of the hyperechoic pleural line are reflected from the air-filled lung and appear equally spaced down the image (A-lines), ensuring the operator the lung is properly aerated (Figure 1.7). When there is anything other than normal air in the lungs, different artefacts are found that suggest the existence of pathology. Lung ultrasound is commonly performed in each hemithorax over the anterior, lateral, and posterior lung zones (Marini et al. 2021).

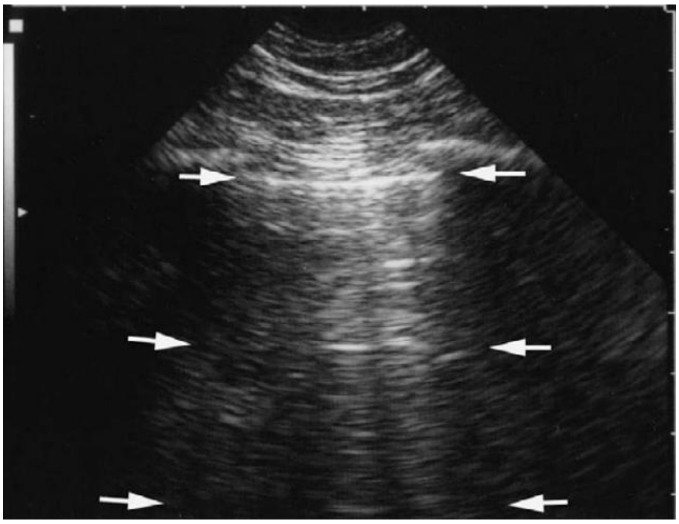


Figure 1.7 The Normal Lung Visualised by Lung Ultrasound. *In a normal lung, most of the image comprises artefacts as the ultrasonic waves bounce off air. Only when there is pathology which reduces air can we begin to see true images with the ultrasonic waves. The shadows underneath the arrows are caused by the ribs blocking the ultrasonic waves. The hyperechoic white line between the top arrows is the pleural line. The subsequent hyperechoic lines indicated by the other arrows are reverberations of the ultrasonic waves off the pleural line and are artefacts called A-lines. (Source: Lichtenstein 2009)*

A LUS score, a score based on aeration levels determined by the presence of certain LUS artefacts (Mojoli et al. 2019), can be used to predict death, ICU admission, endotracheal intubation, and weaning failure with moderate accuracy (Le Neindre et al. 2021). These abilities have recently increased the presence of LUS in research for COVID-19 management (Smith et al. 2020; Gil-Rodriquez et al. 2022). Arguably, the most important feature of LUS for this context is its ability to detect common pulmonary pathologies, such as pneumothorax, pleural effusion, lung consolidation, atelectasis, and pneumonia (Cantinotti et al. 2016; Karthika et al. 2019; Chan et al. 2020).

1.6.1 LUS and Common Assessment Tools

Although CT is considered the gold standard for diagnosing PPCs, CXR is still one of the most common investigations available for physiotherapists to use as part of their respiratory assessment of cardiac surgery patients. Senniappan and colleagues (2019) compared LUS results to the CXR results of 250 elective cardiothoracic and vascular surgery patients with blinding of the interpretation of both tools using Cohen's Kappa value (k) to assess agreement. Lung ultrasound was comparable to CXR both immediately postoperatively (k=0.65) and one day postoperatively (k=0.74), with moderate agreement in the diagnosis of pleural effusion (k=0.561), substantial agreement for atelectasis (k=0.68) and near-perfect agreement for pneumothorax (k=0.93). Although this study did not compare LUS to the gold standard (CT), the purpose of this study was to compare LUS with CXR directly. The study suggests LUS could replace CXR in the cardiothoracic surgery population in terms of accuracy. Medical imaging is an increasing source of radiation exposure (Williams et al. 2019); chest x-rays produce ionising radiation which is a proven carcinogen that increases the risk of cancer, with CT scans producing even more radiation than CXR (Picano et al. 2014). Cardiac imaging and interventional procedures were responsible for 40% of the cumulative effective dose due to medical imaging in the United States (William et al. 2019). Due to high exposure to radiation in cardiac patients, especially in comparison to other populations, it is recommended not to perform tests with ionising radiation when a non-ionising test with comparable accuracy is available (Picano et al. 2014). Therefore, LUS is a preferable alternative to CXR due to its non-ionising nature and comparable accuracy.

The accuracy of CXRs, particularly CXRs taken from the front with the patient semi-erect in bed, has been questioned (Leech et al. 2015; Le Neindre et al. 2016; Hansell et al. 2021). Several studies and experts in the field have concluded LUS as superior to CXR in diagnosing specific pulmonary pathologies (Leech et al. 2015; Le Neindre et al. 2016; Buda et al. 2020; Hansell et al. 2021; Girona-Alarcón et al. 2022). For example, a recent systematic review by Hansell et al. (2021) compared the accuracy of the two standard diagnostic tools used by physiotherapists (CXR and auscultation) and LUS for diagnosing pleural effusion and consolidation with CT as the reference standard; the review concluded LUS was significantly higher in sensitivity and specificity than either CXR or auscultation.

1.6.2 LUS and the Gold Standard

Lung ultrasound has also been tested against CT, the gold standard. Several studies have concluded LUS to have high sensitivity, specificity, and diagnostic accuracy (Yu et al. 2016; Wang et al. 2020; Xie et al. 2020; Hansell et al. 2021). Both Yu et al. (2016) and Xie et al. (2020) recognised a limitation in their studies of a one-hour gap between LUS and CT scans which may have compromised the sensitivity of LUS if PPCs developed within this time gap. Considering this limitation potentially negatively affecting reported results, LUS may have even higher sensitivity.

LUS is comparable to the gold standard reference of CT and has higher accuracy, specificity, and sensitivity for PPCs than either CXR or auscultation. With the added benefits of its portable nature and absence of radiation, LUS is showing potential to be a superior diagnostic tool for physiotherapists to detect PPCs after cardiac surgery. Introducing LUS may provide physiotherapists with the ability to differentiate between pathologies that either will or will not respond to physiotherapy interventions, allowing for more targeted and effective physiotherapy treatment (Leech et al. 2015; Le Neindre et al. 2016).

1.7 Physiotherapy & Lung Ultrasound

Following the assumption that LUS is superior to CXR in diagnosing specific pulmonary pathologies, researchers have begun investigating and theorising how LUS may affect the field of respiratory physiotherapy specifically. Physiotherapist-operated thoracic ultrasound was first investigated in 2013 for the diaphragm and 2014 for the pleura and parenchyma. More literature has been published on thoracic ultrasound-use by physiotherapists in the last three years than in the preceding sixteen, showing the assessment tool is gaining popularity within the discipline (Hayward and Janssen 2018). The role of LUS within the COVID-19 pandemic further propagated respiratory physiotherapists' interest in the tool. Several training programmes and protocols are being piloted for training physiotherapists (Hayward and Kelly 2017; Ntoumenopoulos et al. 2017; Ntoumenopoulos, Parry and Neindre 2018). A recent survey of the use of LUS by therapists within the ICU environment received responses from 30 different countries showing widespread interest in LUS by physiotherapists (Lau, Hayward and Ntoumenopoulos 2023).

1.7.1 Current Literature

A scoping review by Hayward and Janssen (2018) aimed to understand the emerging evidence around physiotherapy use of thoracic ultrasound, a type of PoCUS that investigates the pleura, parenchyma, and the diaphragm. Overall, the evidence base included a wide range of scanning techniques, methodologies, and populations with little overlap, making it challenging to synthesise evidence to inform clinical practice. Of the 26 papers included in the review, 26% of participants were healthy with most of the unwell patients either chronic obstructive pulmonary disease (COPD) patients (5 out of 26) or in critical care (4 out of 26). None of the papers included the cardiac surgery population. Thoracic ultrasound is currently used to assess the diaphragm (23 out of 26) with only three studies involving the lung (Hayward and Janssen 2018). This further shows the need for research concerning the role of LUS within physiotherapy to detect PPCs following cardiac surgery. Looking closer at Hayward and Janssen's review (2018), only one paper was from the United Kingdom (UK) showing the country is underrepresented within the literature surrounding physiotherapy and LUS.

Within recent years, LUS has become a popular tool to assess COVID-19 patients. Clinical practice recommendations, guidance, and narrative reviews have been published for physiotherapists performing LUS on COVID-19 patients since the start of the pandemic (Smith et al. 2020; Thomas et al. 2020; Thomas et al. 2022). The use of a LUS score by physiotherapists has also become a research area of interest in recent years (Battaglini et al. 2021; Hansell et al. 2023b, 2023c); a LUS score as been shown to have substantial interrater reliability between physiotherapists in assigning a LUS score in mechanically ventilated patients (Hansell et al. 2023b), as well as detecting changes in lung aeration due to respiratory physiotherapy treatment for lobar atelectasis in mechanically ventilated patients (Hansell et al. 2023c).

The rise in popularity of LUS-use among physiotherapists has resulted in a proposed framework for point-of-care LUS by respiratory physiotherapists endorsed by the Chartered Society of Physiotherapy, a professional body and trade union for physiotherapists in the UK (Smith, Hayward and Innes 2022), with published research assessing LUS training courses for physiotherapists beginning to emerge (de Souza et al. 2022; Hansell et al. 2023a). LUS-use by physiotherapists is growing rapidly in the field despite the limited knowledge base.

1.7.2 Potential Uses for LUS

Although there is a lack of empirical research on the use of LUS by physiotherapists, there are several proposed uses for LUS presented in narrative reviews and text and opinion pieces. Due to the high specificity and sensitivity of LUS in detecting atelectasis, LUS has favourable features for assessing lung recruitment manoeuvres (RM) to address reduced lung volume and atelectasis. Lung ultrasound can also assist in diagnosing haemodynamic status using measures simple to use without specialised training, which can aid in enhancing patient safety during RM (Tusman, Acosta and Costantini 2016). Leech et al. (2015) suggest that using LUS to monitor lung recruitment may increase the influence physiotherapy can have on key lung pathologies, potentially impacting major patient outcomes such as mortality, time on mechanical ventilation, or ICU length of stay. This is demonstrated in the prospective cohort study by Wang et al. (2020) where researchers used LUS to monitor patients during RM and saw a decrease in the patient's lung ventilation score in real-time. Le Neindre et al. (2016) and Leech et al. (2015) argue there is a lack of research assessing LUS as an outcome measure. Lung ultrasound has yet to be investigated as an assessment tool, treatment aid, or outcome measure within physiotherapy; these potential uses should be considered for exploration in future studies.

1.7.3 Potential Impact on Clinical Reasoning

Heldeweg et al. (2022) conducted a systematic review on the impact of LUS on clinical decision-making across clinical departments and found LUS resulted in a large proportion of diagnosis changes in the emergency department (ED) and intensive care unit (ICU), as well as substantial management changes in the ED, ICU, and general ward. Le Neindre et al. (2016) called for investigation of the impact LUS may have on the clinical decision-making of physiotherapists and recently conducted an observational study finding thoracic ultrasound to have an impact on the clinical decision-making process of critical care physiotherapists (Le Neindre et al. 2023). Based on these results, the question arises of whether LUS could potentially have a role in assisting clinical decision-making for cardiothoracic physiotherapists who are assessing and treating cardiac surgery patients.

1.7.4 Potential Impact on Practitioner Autonomy

Leech and colleagues (2015) recognised physiotherapy has been ordered as a noninvasive treatment by physicians in published studies and asked the question of why physiotherapists themselves are not using LUS to decide whether physiotherapy could benefit the patient. This is a common sentiment among many key respiratory physiotherapists in the field (Hayward and Janssen 2018, Leech et al. 2015, Le Neindre et al. 2016).

The I-AIM model is a novel model used for teaching and performing focused sonography by physicians (Bahner, Hughes and Royall 2012). I-AIM stands for (1) indication, (2) acquisition, (3) interpretation, and (4) medical decision-making. If we reconsider (4) to stand for "management" to place this model in the context of physiotherapy, this model helps to explain the potential benefit of autonomy LUS can bring the profession (Figure 1.8). Currently, physiotherapists can determine indication for imaging (1) and decide on management based on the findings (4), the outside ends of the I-AIM model. After the physiotherapist's initial assessment, the physiotherapist requires a member of medical staff to order diagnostic assessment (CT or CXR) and an external operator or radiographer to acquire the image (2) and interpret the findings (3) prior to the physiotherapist being able to consider the imaging findings for their management. This process can take time and delay the physiotherapist's management plan. If a physiotherapist can operate LUS, this eliminates the need for other members of the team, improving autonomy, allowing for the initial assessment for indications, acquisition, interpretation, and management planning to occur all at once at the bedside with results available instantly and allow the physiotherapist to carry on with treatment straight away.

Figure 1.8 I-AIM Model for Teaching and Performing Focus Sonography. *Currently, physiotherapists can assess for indications and decide management based on the results of imaging. Implementing LUS gives physiotherapists the autonomy to complete the full I-AIM framework in their clinical practice. Adapted from Bahner et al. (2012).*

1.7.5 Current Gaps in the Literature

Researching LUS within the field of respiratory physiotherapy is proving difficult due to a lack of LUS-trained physiotherapists. In both Szabó et al. (2021) and Xirouchaki et al's studies (2014), availability of LUS operators limited data collection. In addition, Xirouchaki et al. (2014) had potential bias due to the same LUS-operator being used in the same hospital for a prior study. The lack of trained LUS operators and expense of implementing LUS in other hospitals may be affecting results and quality of research being published, which in turn may influence the decision to train physiotherapists in LUS for research purposes. Hayward and Janssen (2018) consider the training of physiotherapists in LUS to be essential for research to progress in the field. The lack of training protocols and programmes is recognised by many researchers (Ntoumenopoulos and Hough 2014; Leech et al. 2015; Le Neindre et al. 2016; Hayward and Janssen 2018; Szabó et al. 2021). Determining the feasibility of physiotherapy-operated LUS also requires investigation, as this challenges clinical governance in terms of scope of practice and resources (Ntoumenopoulos and Hough 2014; Leech et al. 2015; Hayward and Janssen 2018; Hansell et al. 2021).

The knowledge base on the use of LUS by physiotherapists remains limited and there are numerous gaps to address. Something that remains unclear in the LUS protocol is indications for scanning after cardiac surgery. Indications are still widely unknown and needs further research, especially for physiotherapy purposes (Ntoumenopoulos and Hough 2014). Some studies have begun to explore this question. In a prospective cohort study by Bosch et al. (2021), the PPC positive group presented with American Society of Anesthesiology (ASA) scores higher than 2 and higher body mass index (BMI) than the PPC negative group. Similarly, in another prospective cohort study, Szabó et al. (2021) found that an ASA score of 3 was more significantly represented in the PPC positive group than the PPC negative group. Xirouchaki et al. (2014) set their indications for LUS as unexplained deterioration of arterial blood gases (which commonly links to the five common lung pathologies they studied) or general suspicion for one of the studied pathologies. Recommendations from Buda et al. (2020) suggest dyspnoea, pleuritic chest pain, and acute cough are indications for LUS. There is no compelling evidence to determine whether LUS should be used only when indicated or routinely for all post-cardiac surgery patients; this makes it difficult for physiotherapists to complete the first step of the I-AIM model and determine the indication (1) for LUS.

Another question is when to perform LUS in relation to surgery. There are several combinations of time windows in the literature: preoperatively, perioperatively, one hour postoperatively, 24 hours postoperatively, and the following consecutive days. The only common time window for LUS across studies was within one hour postoperatively (Yu et al. 2016; Senniappan et al. 2019; Xie et al. 2020; Bosch et al. 2021; Szabó et al. 2021). A scoping review by Hayward and Janssen (2018) found the evidence base surrounding physiotherapy and LUS to be heterogeneous with varying scanning techniques, methodologies, and populations, making it difficult to determine applicability of LUS in clinical and research practices. Hansell and colleagues (2021) had a similar problem in their systematic review, as LUS data collection and presentation was heterogeneous, making comparisons between studies difficult. Both reviews call for a single standardised protocol for conducting LUS to allow for greater ability to compare future studies.

1.7.6 Current Use

Despite there being a paucity of research surrounding LUS-use in physiotherapy, physiotherapists had begun to train and gain accreditation in LUS. The Intensive Care Society launched FUSIC, a comprehensive ultrasound training and accreditation pathway with an option for allied health professionals to gain ultrasound accreditation for the lung (The Intensive Care Society 2024), providing a formal pathway for physiotherapists to become accredited in LUS. A 2020 survey within the UK of 133 respiratory physiotherapists revealed 58 (44%) completed introductory training, 31 (23%) reported using thoracic ultrasound in their practice, but only ten reported completing further formal accreditation training (Hayward, Smith and Innes 2020). The survey reveals physiotherapists are beginning to train in and perform LUS as part of their practice. However, it remains unknown what influence LUS has on their practice and on patient outcomes.

The growth in numbers of LUS-accredited physiotherapists opened an opportunity to begin to measure the influence it may be having on practice. There was no formal register of LUS-accredited physiotherapists in the UK at the time of completing this thesis, which would have posed difficulty in recruiting. Anecdotally, there was steady growth in the number of physiotherapists gaining accreditation to use LUS, but there remained less than 40 physiotherapists known to be LUS-accredited throughout the whole of the UK in 2021 at the time of planning this thesis (Hayward 2021). Fortunately, through the collaboration with a cardiothoracic physiotherapy department with several LUS-accredited physiotherapists, there was a unique opportunity to begin to study the influence of LUS on physiotherapy practice despite the low numbers of accredited physiotherapists across the UK at the time.

1.8 Summary

This chapter has discussed the risks of patients developing PPCs after cardiac surgery, some of which could be fatal if not identified and treated quickly. Cardiothoracic physiotherapists are one of the healthcare professionals which can help to identify PPCs early after surgery, but the tools currently used by physiotherapists lack reliability, making it challenging to differentiate between pathologies. Lung ultrasound is a diagnostic tool that is comparable CT (the gold standard) for assessing many of the common PPCs seen after cardiac surgery and can be performed at the bedside, eliminating the need to transport a patient for a CT scan. The literature demonstrates LUS is superior to the standard assessment tools used by physiotherapists (CXR and auscultation). Unlike both CXR and CT, LUS emits no radiation, making it a safer option. The growing interest in and use of LUS by respiratory physiotherapy begs the question of how it may impact practice and whether cardiothoracic physiotherapists should implement LUS to better detect PPCs early after cardiac surgery in the hopes of improving patient survival. The next chapter will further explore the literature surrounding the use of LUS within the cardiac surgery population.

2. SCOPING REVIEW

Chapter 1 discussed the rise in popularity of LUS within respiratory physiotherapy due to its high accuracy, lack of radiation, and portable nature. There was a need to develop a current map of literature on the use of LUS to assess cardiac surgery patients across disciplines to better understand what the use by cardiothoracic physiotherapists may entail. This chapter presents a scoping review on LUS use within the cardiac surgery population. The review methodology and approach will be discussed and justified, and the findings and implications will be presented and discussed. This chapter is based on the publication (FARRELL, C. et al. 2023. Exploring the Use of Lung Ultrasonography to Assess Cardiac Surgery Patients: A Scoping Review. *Journal of Diagnostic Medical Sonography.* doi:10.1177/87564793231198521).

2.1 Background

As highlighted in Chapter 1, patients undergoing cardiac surgery are subjected to numerous factors preoperatively, intraoperatively, and postoperatively that increase their susceptibility to developing PPCs such as atelectasis, pleural effusion, and pneumothorax (Weissman 2004; Cantinotti et al. 2016; Miskovic and Lumb 2017; Naveed et al. 2017). Up to 30% of patients who develop PPCs die within 30 days of major surgery – a considerably higher mortality rate than those without such complications (0.2-3.0%) (Miskovic and Lumb 2017). Consequently, timely identification of PPCs is crucial for effective management and improved patient outcomes. Although physiotherapists play an integral role within the postoperative multidisciplinary team (MDT) in identifying PPCs, the responsibility to identify PPCs early and decrease mortality rates remains on the whole MDT. The tools commonly used by physiotherapists and the wider MDT (CXR and auscultation) lack reliability, therefore all professions should have an interest in finding a solution.

In recent years, point-of-care ultrasound (PoCUS) has become increasingly popular due to its high accuracy, portability, and lack of radiation emissions (Lichtenstein 2014; Cantinotti et al. 2016; Hew and Tay 2016). The first mention of thoracic ultrasound in the literature, however, was in 1946 (Lichtenstein 2009), suggesting lung ultrasound has been used by other professionals for significantly longer than physiotherapists, who began publishing literature on LUS in 2013 (Hayward and Janssen

2018). Understanding how other professions have been using LUS in the cardiac surgery population would assist in understanding what LUS-use by cardiothoracic physiotherapists may involve and how it could be integrated into the wider MDT practice.

There is a growing body of evidence on the use of LUS in the cardiac surgery population. Lung ultrasound's comparability to CT and superiority to CXR in addition to its lack of radiation has made it a tool of interest within cardiac surgery research to reduce patient exposure to radiation while maintaining quality imaging, particularly for paediatric patients. It was deemed useful to both the clinical and research community to map that body of evidence, in order to identify what is currently known about LUS in the cardiac population, and to guide future research investment in the field. A preliminary search of PROSPERO, Open Science Framework, the Cochrane Database of Systematic Reviews, JBI Evidence Synthesis, Medline and CINAHL was conducted, and no planned, underway, or completed systematic reviews or scoping reviews on the use of LUS in the cardiac surgery population were identified.

2.2 Methodology

2.2.1 Literature Review Types

Over the span of ten years, the number of review types expanded from 14 (Grant and Booth 2009) to 48 (Sutton et al. 2019). Sutton et al. (2019) divided the 48 identified review types into seven review families. Table 2.1 describes each type of review family and provides examples.

This review aimed to be rigorous and thorough; therefore, some review families were not considered for the following reasons: The traditional review family often does not clearly report or follow a rigorous method which puts into question the trustworthiness of the conclusions; the rapid review family often abbreviates a part of the systematic process which is required to ensure rigour; a review solely on qualitative research would not have captured the breadth of literature desired to answer the current review's questions. Therefore, review types from the traditional, rapid review, and qualitative systematic review families were rejected as potential methodologies, and the remaining review families were considered in more detail and are discussed in the following section.

Table 2.1 Review Families. Reproduced from Sutton et al. (2019).

Review Family	Methodology
Traditional Review Family *E.g., critical review, integrative review, narrative review, narrative summary, state-of-the-art review*	Uses a purposive sampling approach. Traditional reviews involve bibliographic database searching, but the methods are not always clear.
Systematic Review Family *E.g., systematic review, diagnostic systematic review, comparative effectiveness review, meta-analysis, Cochrane review of effects*	The defining feature of a systematic review is a comprehensive search approach, often including a search across multiple databases with well-established reporting standards and guidance.
Review of Review Family *E.g., review of reviews, overview, umbrella review*	Generally, has the same methodology and standards of a systematic review, but prioritises systematic reviews and evidence synthesis over primary studies. Database searching will commonly filter for only systematic reviews.
Rapid Review Family *E.g., rapid review, rapid evidence assessment, rapid realist synthesis*	The methodology is flexible and defined by the client and review team. Some part of the systematic review process is abbreviated, and the limitations should be declared clearly.
Qualitative Systematic Review Family *E.g., qualitative evidence synthesis, qualitative interpretive meta-synthesis, framework synthesis, meta-aggregation, meta-ethnography, thematic synthesis*	Aggregative reviews resemble the methodology of quantitative systematic reviews, but interpretative reviews may use theoretical sampling. Depending on the type of review, there may also be a need to include a search for theory or a more thorough search to understand the influence of context.
Mixed Methods Review Family *E.g., mixed methods synthesis, Bayesian meta-analysis, EPPI-Centre review, critical interpretive synthesis, narrative synthesis, realist synthesis*	Most commonly aims to integrate both quantitative and qualitative data or involve only mixed methods primary studies. Guidance has been developed to assist database searching for mixed methods studies but is not yet validated.
Purpose Specific Review Family *E.g., concept synthesis, content analysis, expert opinion/policy review, technology assessment review, scoping review, mapping review, methodological review, systematic search and review, systemised review*	Methodologies are tailored by such a degree, that it is difficult to adapt the specific review type for use beyond that purpose. The search process requires alignment between the purpose of the review, the type of studies sought, and the individual search strategies required.

The first review family considered was the systematic review family. JBI defines systematic reviews as aiming to provide "a comprehensive, unbiased synthesis of many relevant studies in a single document using rigorous and transparent methods" (Aromataris and Munn 2020). There are systematic reviews on the use of LUS for pulmonary pathologies in varying populations, such as the trauma and critically ill populations (Ebrahimi et al. 2014; Winkler et al. 2018; Hansell et al. 2021), but not yet one done on the cardiac surgery population. Munn et al. (2018) describes ten types of systematic reviews (Munn et al. 2018), however there are three types of systematic reviews that could have been considered for this topic. Effectiveness reviews assess the effectiveness of a certain intervention and are the most commonly conducted systematic review (Munn et al. 2018). Research is still exploring the role of LUS within intervention, so this type of review was not yet appropriate. A diagnostic test accuracy review, which provides a summary of test performances, would be more appropriate considering the more established role of LUS as a diagnostic tool. Due to the amount of research done on the diagnostic accuracy of LUS, summarising the accuracy for this specific population was not seen as a main priority. Methodology reviews examine methodological issues in the conduction or reviewing of research. As LUS remains on the rise in popularity, there may be methodological issues to identify and address to progress the research on the topic; while some reports state heterogeneity in methods, it was unclear if this was an issue enough to address with a methodology review. Overall, it was unclear what specific question to pose, and as a systematic review is conducted with a specific question, this review family was deemed not best suited for this review. Considering the mixed methods review family and review of review families are more targeted systematic reviews (Sutton et al. 2019), these were also rejected.

The purpose specific review family is a collection of review types which have methodologies tailored for a specific purpose and are difficult to adapt for use beyond this purpose (Sutton et al. 2019). This group of review types are pragmatic in nature. This doctoral thesis was conducted with a pragmatic approach (discussed further in Chapter 3), therefore this review family seemed most appropriate.

The two review types considered within the purpose specific review family were a scoping review and mapping review. The terms scoping review and mapping review are often used interchangeably. Sutton et al. (2019) distinguish between the two stating that scoping reviews aim to inform future predetermined research, whereas a mapping review identifies research gaps which may be addressed by future research yet to be specified (Sutton et al. 2019). As this thesis involved predetermined primary research, a scoping review was felt to be most appropriate based on this distinction.

Scoping reviews are advantageous when it is unclear what specific questions could be posed that could be valuably addressed through evidence synthesis (Peters et al. 2020). A scoping review, also referred to in some literature as scoping studies (Arksey and O'Malley 2005) or systematic scoping reviews (Peters et al. 2015), was therefore more closely considered. Scoping reviews were introduced in 2005 by Arksey and O'Malley with a spike in scoping reviews published between 2009 and 2012 (Tricco et al. 2016). JBI added a guidance chapter in their reviewer's manual in 2015 (Peters et al. 2015) which was subsequently updated in 2020 (Peters et al. 2020). There have been several definitions of a scoping review; Peters et al. (2021) described six indications for conducting a scoping review; (1) as a precursor to a systematic review, (2) to identify the types of evidence available in a given field, (3) to identify and analyse knowledge gaps, (4) to clarify key concepts or definitions in the literature, (5) to examine how research is conducted on a certain topic, and (6) to identify key characteristics or factors related to a concept.

The desired topic area for this scoping review was initially the use of LUS within physiotherapy. A preliminary search was conducted to ensure there was adequate literature to include in a review and no similar reviews had been published. At the time of the search, there were no systematic reviews considering the use of LUS within physiotherapy. There was, however, one scoping review identified on the use of thoracic ultrasound within physiotherapy. This was completed in 2018 and found only three reports where physiotherapists used ultrasound to assess the lungs (Hayward and Janssen 2018). Correspondence with the lead author of this review confirmed that an update for this scoping review was in-progress. Due to the paucity of research on the use of lung ultrasound within physiotherapy as well as having a recent scoping review completed, another scoping or systematic review on the same topic was not indicated. Therefore, the review aim was broadened to the use of LUS within healthcare with a focus on the cardiac surgery population – the population of the primary research. Understanding the scope of literature on the use of LUS by the wider MDT involved with the cardiac surgery population can help us to understand what the use of LUS by cardiothoracic physiotherapists may resemble. This review aimed to examine the extent, range and nature of research activity on the use of LUS in the cardiac surgery population encompassing several disciplines, settings, methods, and types of reports. Due to the interest in how LUS is used, there was a particular methodological focus. The aims of the review did not have one specific question and aligned with the indications for a scoping review as described by Peters et al. (2021), including: to identify the types of evidence available on LUS, to identify and analyse knowledge gaps, to clarify key concepts/definitions of LUS-use in the literature, to examine how research is conducted on LUS, and to identify key characteristics or factors related to LUS. Therefore, a scoping review was conducted.

2.2.2 Scoping Review Methodology

This scoping review was conducted in accordance with the updated JBI methodology for scoping reviews (Peters et al. 2021) and followed an *a priori* open access protocol registered on Open Science Framework (OSF) in March 2022 (Farrell et al. 2022). The results are reported in accordance with the PRSIMA Extension for Scoping Reviews (PRISMA-ScR) (Tricco et al. 2018). The JBI methodology was chosen as it is a well-known and accepted methodology that recently utilised user-feedback in the most recent update (Khalil et al. 2020), demonstrating a commitment to consistency and rigor (Peters et al. 2021).

2.3 Review Questions

The objective of this scoping review was to map the evidence base on the use of LUS within the cardiac surgery population. The primary review question was: What has been reported on the use of lung ultrasound in the cardiac surgery population?

The following sub-questions were explored:

1) What type of studies have been published on LUS and cardiac surgery?
2) How and why has LUS been used within the cardiac surgery population?
3) What anatomical structures and artefacts have been investigated with LUS within the cardiac surgery population?
4) Which professionals are reportedly using LUS in the cardiac surgery population?
5) What LUS protocols are reportedly being used by professionals undertaking LUS in the cardiac surgery population?

2.4 Inclusion Criteria

2.4.1 Participants

This scoping review considered literature including or concerning both adult and paediatric populations undergoing cardiac surgery irrespective of participants' demographic profile. Types of cardiac surgery included, but were not limited to:

- Coronary artery bypass grafting
- Heart valve repair or replacement
- Coronary angioplasty and stenting
- Atherectomy
- Cardiomyoplasty
- Heart Transplant
- Catheter Ablation

Literature that included a mixed surgical population of cardiac and non-cardiac surgery was considered if cardiac surgery patients contributed 75% or more of the total population or the cardiac surgery patient outcomes could be extracted separately.

2.4.2 Concept

This scoping review considered literature concerning LUS use by any qualified healthcare professional on a cardiac surgery patient. Lung ultrasound could have been used as an assessment tool, outcome measure, during treatment or for any other purpose. For this review, LUS was defined as a tool for investigating the pleura and parenchyma ultrasonically. For this reason, literature sources investigating the diaphragm were excluded.

2.4.3 Context

This scoping review considered literature from any healthcare setting where cardiac surgery is conducted. Studies were not limited by geographical location. Non-English records were considered if they could be translated using Google Translate.

2.4.4 Types of Sources

This scoping review considered: primary research of any type (e.g., qualitative, quantitative, case reports); literature reviews of any type (e.g., systematic, narrative); narrative, opinion and text (e.g., editorials, opinion pieces, commentaries); and conference abstracts reporting any of these types. Trial registrations and protocols were excluded; however, they were retrieved in order to identify additional published studies from their reference lists. Grey literature was also considered.

2.5 Methods

2.5.1 Search Strategy and Information Sources

The search strategy aimed to locate both published and unpublished studies. An initial limited search of Medline and CINAHL (EBSCOhost) was undertaken using the keywords (TX lung ultrasound) AND (TX cardiac surgery) to identify articles on the topic. The text words contained in the titles and abstracts of relevant articles, and the index terms used to describe the articles were used to develop a full search strategy for Medline. The search strategy, including all identified keywords and index terms, was adapted for each included database and information source (Appendix 1). A database search update was undertaken on 6 April 2022 and for grey and unpublished literature on 3 August 2022.

The databases searched included: Medline, CINAHL (via EBSCOhost), Embase (via Ovid), Cochrane Reviews and Trials, Scopus, and Web of Science. Sources of unpublished studies and grey literature included: Google Scholar and e-theses online service (ETHoS). The full search strategy including the search terms and hits from each database and grey literature source are provided in Appendix 1.

2.5.2 Source of Evidence Selection

Following the searches, all identified records were collated and uploaded into the reference manager Zotero (v6.0.13; Roy Rosenzweig Center for History and New Media, Fairfax, VA, USA) and duplicates removed. Remaining records were uploaded into Covidence (Veritas Health Innovation, Melbourne, Australia) with further duplicates detected and removed. Titles and abstracts were initially screened against the inclusion criteria independently by two reviewers (two of CF, CW, KC) against the inclusion criteria for the scoping review as per the JBI methodological guidance for scoping reviews (Peters et al. 2021). Excellent agreement (90%) was demonstrated after 10% of title and abstract screening, and as this scoping review formed part of an unfunded doctoral research programme, one reviewer (CF) conducted the remainder of title and abstract screening, with regular review and discussion with members of the review team (CW, KC). This process was repeated for full-text screening, with 90% agreement following screening of 20% full-texts.

2.5.3 Data Extraction

A data extraction form was constructed prior to the search update based on the Covidence Data Extraction Form 2.0 and extraction from 10% of reports was piloted independently by two reviewers (CF, KC) to reduce the chance of error and bias (Peters et al. 2021). Minor amendments were made to the data extraction form to focus more on LUS methods and characteristics. After good agreement was reached on independent data extraction by two reviewers (85%), one reviewer (CF) extracted data from the remaining reports, with regular review and discussion with the review team (CW, KC). Data were extracted on the aim, study design, setting, participant characteristics, and key findings. Lung ultrasound methods were also extracted regarding the profession of the operator, the number of operators, the reason for use, time of use in relation to surgery, anatomical features or artefacts of interest, LUS findings, and any protocols used.

2.5.4 Data Analysis and Presentation

Search results and included reports are summarised in a Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) flow diagram in Figure 2.1 (Tricco et al. 2018). Summary data from all the included reports is presented in tabular form and displayed in Appendix 2. Research questions are displayed graphically. A narrative summary accompanies each of the display graphs.

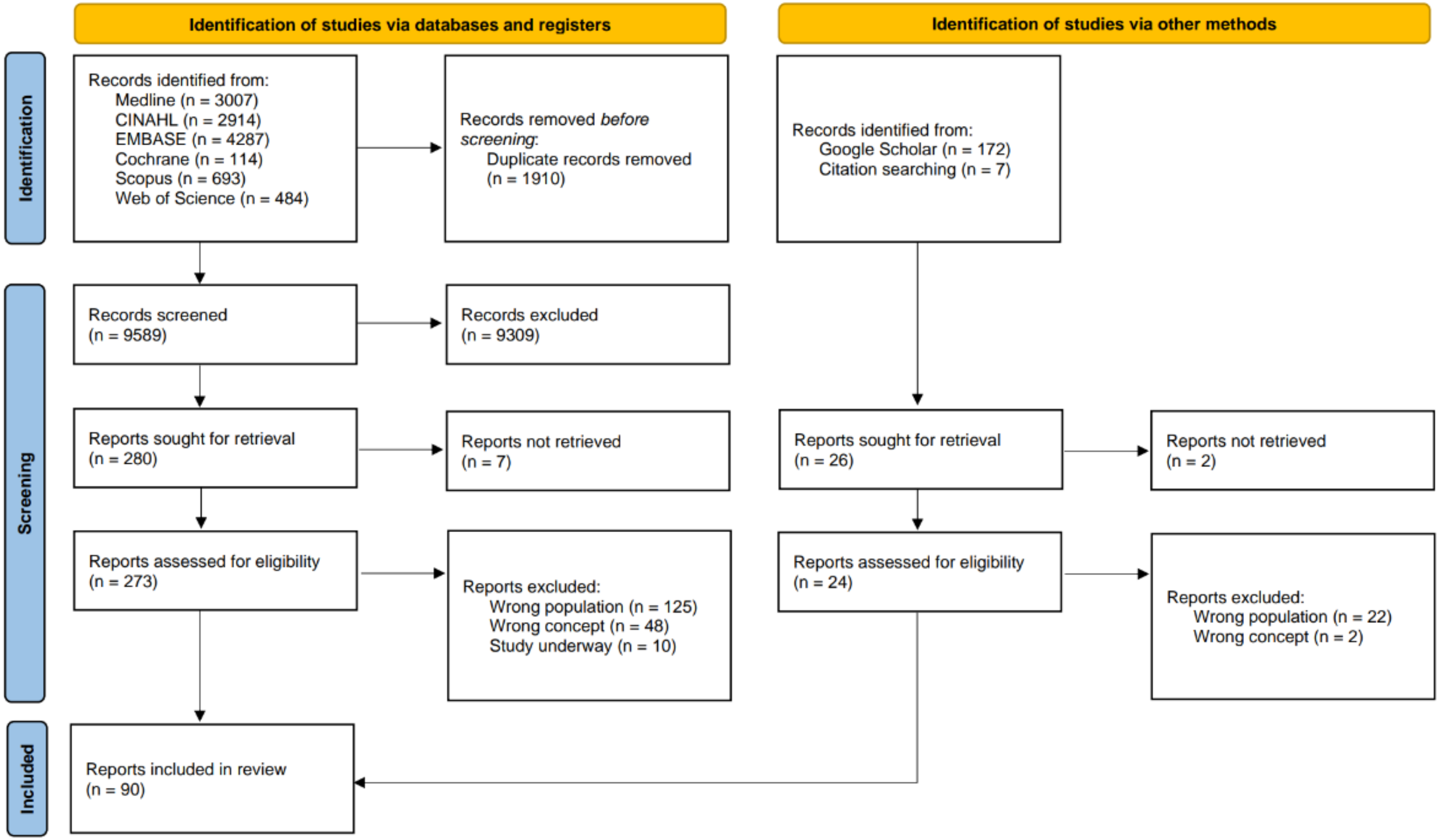


Figure 2.1 PRISMA flow diagram.

2.6 Results

2.6.1 Study Inclusion

Initial screening of databases retrieved 11,499 records, with an additional 172 records identified from Google Scholar and seven from citation searching. After the removal of duplicates, 9,768 records remained for title and abstract screening. Two hundred and ninety-seven records proceeded to full-text screening. Ninety reports met the inclusion criteria and were included in the review. The PRISMA flow diagram (Figure 2.1) illustrates the number of records and reports at each of these stages and the distribution of reasons for exclusion. The following sections (Sections 2.6.2-2.6.5) will address Review Sub-Question #1 (Page 27).

2.6.2 Characteristics of Included Studies

A summary of general characteristics of all included reports is reported in Appendix 2. This scoping review included 90 reports: 73 research studies, 6 narrative reviews, and 11 narrative, opinion and text. The reports were published between 1994 and 2022, with a sharp increase in publication rates from 2014, peaking in 2020 (14 reports) (Figure 2.2). Reports were published in 27 different countries but most originated from Italy (n=29, 32.6%) followed by China (n=7, 7.9%). Five reports were translated successfully by Google Translate (Paczkowski et al. 2012; Fot et al. 2019; Hui et al. 2019; Wang et al. 2020; He et al. 2021a).

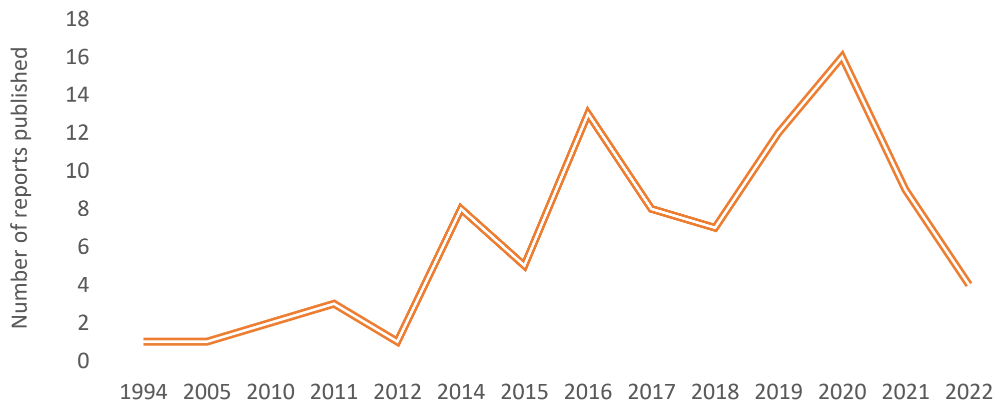


Figure 2.2 Number of reports by year of publication.

2.6.3 Research Characteristics

Most of the included literature in this scoping review comprises research (n=73, 81.1%). This included 64 observational studies (71.1%), six randomised controlled trials (6.7%), and three secondary analyses (3.3%). Of the observational studies, the most common sub-type was cohort study (n=43, 67.2%). Twenty of the study reports were in the form of conference abstracts (22.2%). The most common setting that studies were conducted in was intensive care (n=48, 88.9%). All studies included patients, with a large range in sample size (n=1 to 351). Age was well-balanced between paediatric (n=34, 51.5%) and adult patients (n=32, 48.5%). Of the 55 primary studies that reported patients' sex, 38 included mostly male patients (52%) while seven studies included only males (12.7%). Many primary studies included a mixed surgical population. Of the 55 primary studies which reported type of surgery, the most common were congenital cardiac surgery (n=31, 56.4%) followed by coronary artery bypass grafts (n=19, 34.5%) and valve repairs or replacements (n=19, 34.5%).

2.6.4 Narrative Review Characteristics

This review included six narrative reviews (6.7%). All narrative reviews aimed to summarise LUS applications in cardiac surgery, with half focusing on the paediatric population (3.3%). The specific focus of the reviews varied from improving awareness of LUS among other specialists (Efremov et al. 2020) to discussing the need for a new LUS protocol (Garduno-Lopez, Garcia-Cruz and Baranda-Tovar 2019) to highlighting the role of LUS in weaning and extubation in paediatric cardiac patients (Hamadah and Kabbani 2017). The earliest narrative review was published in 2016 (Cantinotti et al. 2016) and country of origin included Italy (Cantinotti et al. 2016, 2022; Bertolone et al. 2022) (n=3), Russia (Efremov et al. 2020) (n=1), Mexico (Garduno-Lopez, Garcia-Cruz and Baranda-Tovar 2019) (n=1), and Saudi Arabia (Hamadah and Kabbani 2017) (n=1).

2.6.5 Narrative, Text, and Opinion Characteristics

Other evidence types included in the scoping review (n=11, 12.2%) consisted of letters to the editor (n=6, 6.7%), editorials (n= 3, 3.3%), editorial commentary (n=1, 1.1%) and a scientific letter (n=1, 1.1%). Some reports underlined cases in which LUS played an important role in pathology identification and treatment (Saranteas 2011; Antonella et al. 2016; Cantinotti et al. 2020a). Other reports carried a discussion between researchers regarding studies conducted using LUS (Cantinotti, Giordano and Kutty 2020; Steppan, DiGiusto and Steppan 2020), including one letter to the editor (Sperandeo, Mirijello and De Cosmo 2020) in which use of LUS in another included study (Cantinotti et al. 2020b) was questioned.

2.6.6 Addressing Review Sub-Questions

The following sub-sections will address the Review Sub-Questions #2-5 (Section 2.3).

How and Why has LUS been used in the Cardiac Surgery Population?

Ten reasons for performing or discussing LUS were identified from included reports (Box 2.1). Primary studies most commonly aimed to compare or determine the diagnostic (n=27, 37%) or prognostic (n=30.1%) utility of LUS. In narrative reviews and within narrative, opinion and text, LUS was most commonly suggested to be a prognostic tool (n=8, 47.1%) or used as part of the standard protocol (n=8, 47.1%) for cardiac surgery patients. Other suggested reasons for use across all included reports were using LUS to monitor pathology progression (n=18, 20.2%), to assess a deteriorating patient (n=16, 18%), and either to confirm or 'rule out' a suspected pathology (n=16, 18%).

Within primary studies, LUS was most commonly performed on postoperative day (POD) zero (n=40, 55.6%) followed by preoperatively (n=20, 27.8%), POD1 (n=17, 23.6%) and POD2 (n=10, 13.9%). In the narrative reviews and narrative, opinion and text, most reports suggested that LUS should be used postoperatively, but did not specify a day or time (n=9, 64.3%). The frequency of scanning windows for up to POD7 and discharge can be seen in Figure 2.3 while a more extensive list can be seen in Box 2.1. These demonstrate the extensive range and combination of scanning windows used in the current literature.

Box 2.1 Scoping Review Findings. *Key: POD = postoperative day; LUS = lung ultrasound; NA = not applicable; NR = not reported; BLUE = bedside lung ultrasound in emergency; CCROSS = cardiac, cerebral, renal, optic nerve, and lung ultrasound; FAST = focused assessment with sonography for trauma; eFAST = extended focused assessment with sonography in trauma.*

Profession of LUS Operator (n=24)

Medical Consultant	16
Anaesthesiologist	10
Physiotherapist	5
Medical Resident	2
Nurse	2
Sonographer	2
Anaesthetist	2
Radiographer	1
NR	66

LUS Protocols (n=54)

Previously Reported Protocols (n=25)

Volpicelli et al. 2012	9
The BLUE-Protocol (Lichtenstein 2014)	7
Acosta et al. 2014	4
Lichtenstein and Mauriat 2012	2
Cantinotti et al. 2018	1
Monastesse et al. 2017	1
Bouhemad et al. 2015	1
Volpicelli et al. 2006	1
Lichtenstein et al. 2004	1
Coiro et al. 2015	1
Targhetta et al. 1994	1
The FALLS Protocol (Lichtenstein 2014)	1
Cattarossi 2013	1
Picano et al. 2006	1
CCROSS	1
eFAST	1
FAST	1

Author-modified Protocols (n=26)

12 regions	15
6 regions	7
8 regions	3
28 regions	2
4 regions	3
NR	36

Reason for using LUS (n=90)

Compare diagnostic ability	30
Feasibility of a new prognostic tool	22
Monitor pathology progression	18
Assess a deteriorating patient	16
Confirm or 'rule out' suspected pathology	16
Feasibility of new protocol	13
Standard protocol	12
Prognostic tool	10
Outcome measure	8
Question diagnostic ability	1
NA	1

Number of LUS Operators in Primary Studies (n=25)

1 operator	19
2 operators	2
3 operators	3
NR	51
NA	14

Time Windows in Relation to Cardiac Surgery (n=86)

Pre-operative	21
Peri-operative	4
Immediately after surgery	6
Post-operative not specified	28
On admission	4
POD 0	44
POD 1	18
POD 2	11
POD 3	7
POD 4	3
POD 5	5
POD 6	2
POD 7	4
Before/after intervention	6
Before discharge	7
Other	11
NR	4

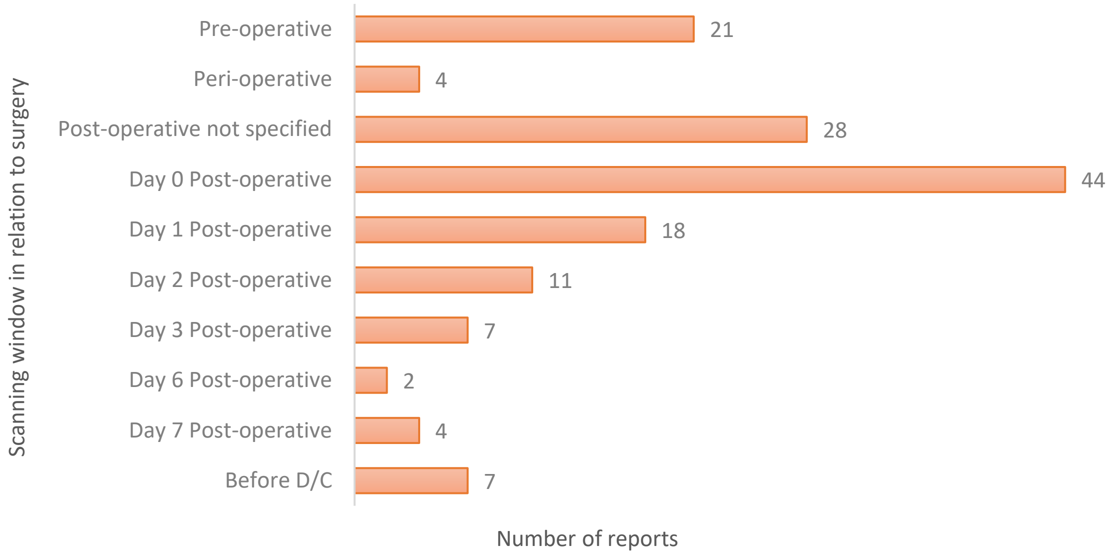


Figure 2.3 Scanning windows in relation to cardiac surgery.

What Anatomical Structures, Artefacts, and Pathologies have been Investigated?

The included reports found, sought, or discussed several anatomical structures, artefacts, and pathologies that can be investigated with LUS with many reporting more than one of each. Across all reports, B-lines were the most identified and sought artefact (n=45, 81.8%) followed by lung sliding (n=23, 41.8%) and A-lines (n=18, 32.7%) (Figure 2.4). Narrative reviews and narrative, opinion and text discussed using B-lines to assess for extravascular lung water (EVLW) (n=7, 63.6%). Eight primary studies used B-lines for this purpose (18.2%). Out of the 82 reports which reported pulmonary pathologies (91%), the most common pathologies of focus were pleural effusion (n=42, 51.2%), atelectasis (n=33, 40.2%), pneumothorax (n=28, 34.1%), pulmonary oedema (n=23, 28%) and consolidation (n=21, 25.6%) (Figure 2.5).

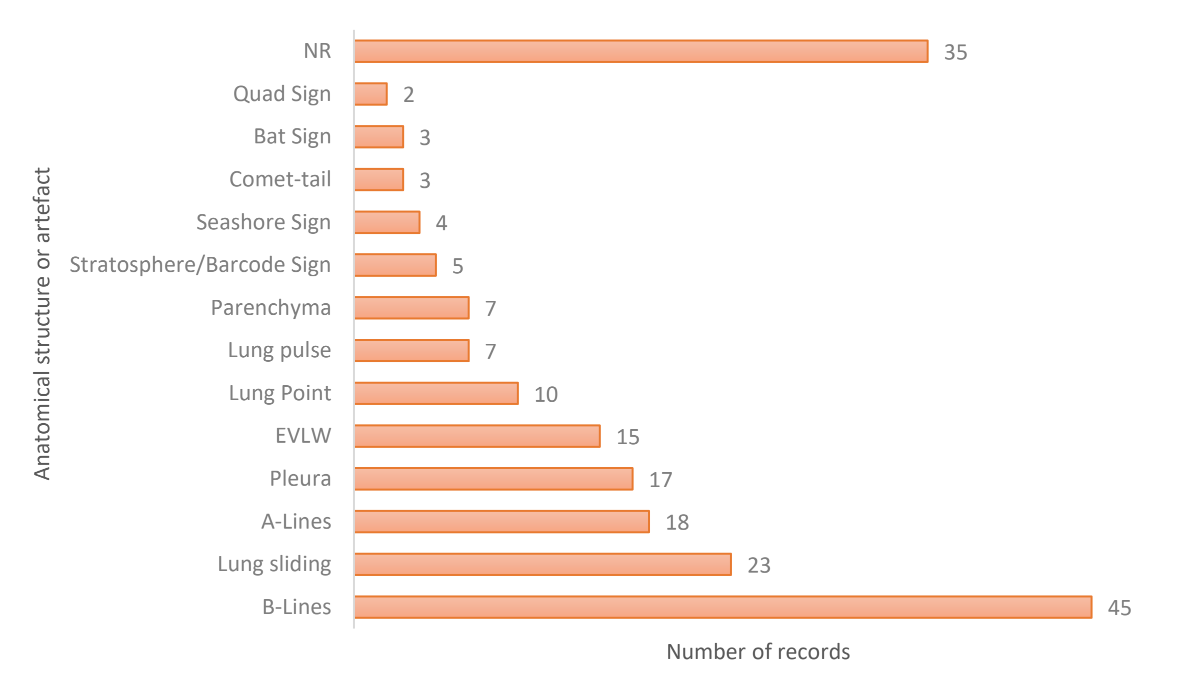


Figure 2.4 Anatomical structures and artefacts sought, found, or discussed. *Key: NR = not reported; EVLW = extravascular lung water.*

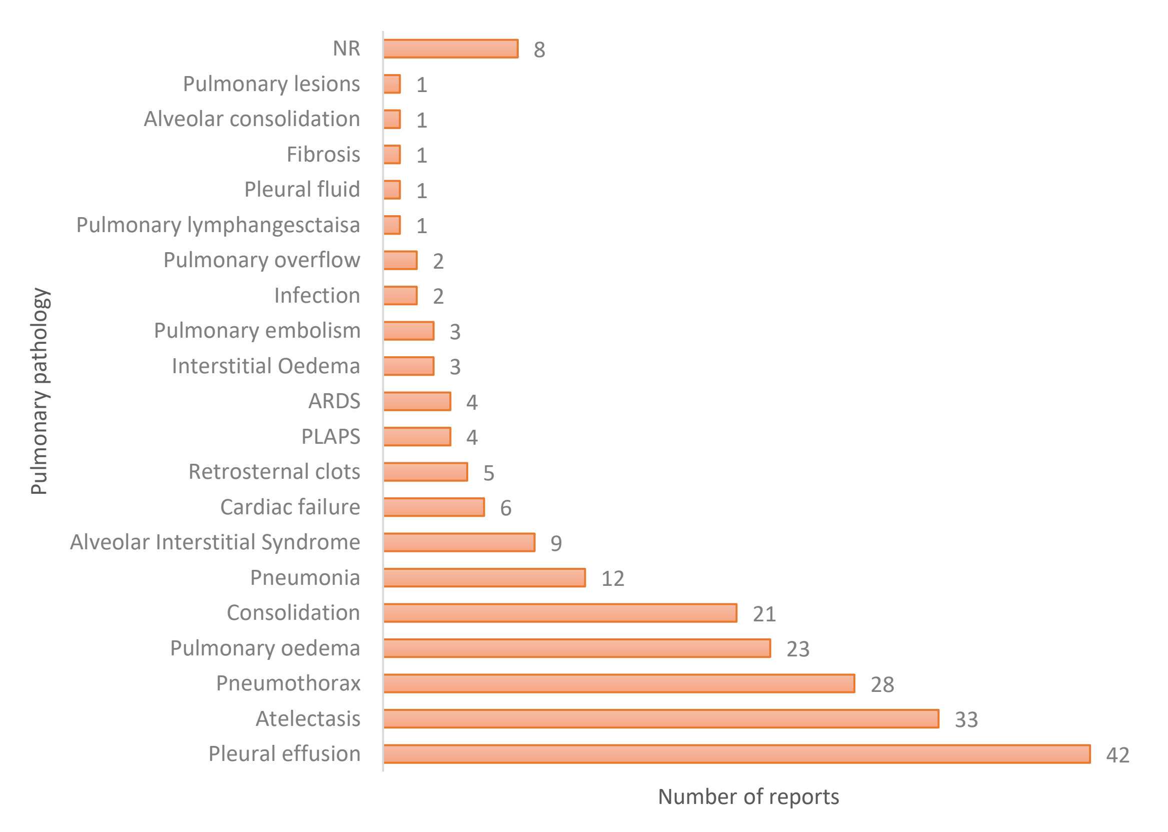


Figure 2.5 Pulmonary pathologies found or sought by lung ultrasound. *Key: NR = not reported; ARDS = acute respiratory distress syndrome; PLAPS = posterolateral alveolar and/or pleural syndrome.*

Who is Operating LUS?

The profession of the LUS operators in primary studies was underreported with only 23 studies reporting a profession (31.5%). Of those 23 studies, the most common professions were anaesthesiologists (n=9, 39.1%) and medical consultants (n=9, 39.1%). In the narrative reviews (n=4, 4.4%) and editorials (n=2, 2.2%) which discussed operator profession, physiotherapists (n=3, 50%) and nurses (n=2, 33.3%) were the most common non-medical professions. Non-medical LUS operators were first identified in an editorial in 2017 (Cantinotti, Giordano and Valverde 2017), with the first primary study involving a non-medical LUS operator published in 2019 featuring a physiotherapist in a single patient case study (Hayward and Hayward 2019b). An observational cross-sectional study included a physiotherapist as one of the two LUS operators along with a cardiologist in a study the following year (Azeredo Terra 2020). Of the 25 primary studies that reported the number of LUS operators, it was most common to have one LUS operator for the study (n=19, 76%). There were never more than three operators involved.

What LUS Methods and Protocols have been used?

There was a lack of reporting regarding LUS methods and protocols. Only 25 (43%) of all reports where applicable reported how many LUS operators were involved, only 24 reports (26.7%) mentioned the profession of the LUS operator, and only 25 (27.8%) reported a previously reported LUS protocol. Of the primary studies, only 20 reported using a previously reported LUS protocol (27.4%).

There was a large variety of protocols used or discussed across all reports; a total of 18 different previously reported protocols were mentioned. Twenty-five primary studies used an author-modified protocol – a protocol which involved scanning 4, 6, 8 12, or 28 regions of the chest, but did not cite a protocol previously reported (34.2%). The specific regions scanned varied across all author-modified protocols. The most commonly reported protocol was the international evidence-based recommendations for LUS by Volpicelli et al. 2012 (n=7, 35%) (Volpicelli et al. 2012) followed by Acosta et al. 2014 for the paediatric population (n=4, 20%) (Acosta et al. 2014). Protocols were infrequently discussed in narrative reviews or narrative, opinion and text (n=5). Nonetheless, the most commonly reported protocol in these 5 reports was the BLUE-protocol (n=3, 60%) (Lichtenstein 2014).

This review also found a wide variety in and combinations of scanning windows. While it was most common for patients to be scanned with the combination of preoperatively and POD-zero (n=6, 6.7%), there were a total of 69 unique combinations for when LUS was performed in relation to cardiac surgery. The most common scanning windows have been synthesised and reported individually by number of reports in Box 2.1 with several unique time windows grouped as "other," e.g., after one-week of birth, before or after imaging, or POD18.

2.7 Discussion

In this scoping review, literature concerning the use of LUS within the cardiac surgery population was identified and explored, providing a comprehensive map of the evidence base to date. Lung ultrasound has gained significant traction over the last decade, with a growing number of publications since 2014 exploring its use in this population. The reporting of LUS methods, however, was found to be inconsistent; this needs to be addressed in future research to better interpret and generalise findings to be applied in clinical practice.

2.7.1 Types of Sources

A total of 90 reports were included, none of which were systematic reviews. The reporting of LUS methods in primary studies, however, was variable and heterogenous, which would make formal synthesis of the current evidence base challenging. Evidence syntheses are valuable resources for clinicians and are used to inform clinical practice guidelines (Platz 2021). There is therefore a need for further high-quality research to be conducted and adequately reported in order to facilitate future synthesis of the evidence-base to provide robust practice recommendations. Moreover, no qualitative studies were identified by the search strategy, highlighting the need for further research to investigate the facilitators, barriers, and perspectives of patients and clinicians regarding the use of LUS in the cardiac surgery population. A systematic review on the barriers, enablers, and interventions for evidence-based practice in physiotherapy found there was a preference for gaining knowledge from 'human' sources as opposed to 'computer' sources, finding many physiotherapists' primary sources to be clients, personal experience, courses, and in-service training (Scurlock-Evans, Upton and Upton 2014). Therefore, qualitatively exploring patients' and clinicians' experiences may be of interest to clinicians as well.

2.7.2 The Paediatric Population

Just over half of the reports were centred on the paediatric population, with the most prevalent surgery type being congenital cardiac surgery. The finding was expected, as LUS has become popular in this population due to its non-invasive and radiation-free nature and is being used more often for the diagnosis and follow-up of paediatric pulmonary conditions (Musolino et al. 2022).

2.7.3 The Uses of LUS

The use of LUS as a diagnostic tool has been extensively studied in both the cardiac surgery population and beyond. LUS-use to identify PPCs has been reported in this review as monitoring pathology progression, assessing deteriorating patients, and confirming or 'ruling out' suspected pathologies. Further, LUS has also gained popularity as a prognostic tool. Pulmonary oedema became a pathology of interest within the included reports in 2012 (Paczkowski et al. 2012), and in 2014, B-lines began to be used to assess for extravascular lung water (EVLW) to predict and diagnose pulmonary oedema (Ricci Z. et al. 2014). Another way LUS is used as a prognostic tool is by using a LUS score to attempt to predict a variety of conditions. A LUS Score can be used to predict death, ICU admission, endotracheal intubation, and weaning failure with moderate accuracy (Le Neindre et al. 2021). Some authors have described the potential for LUS to go beyond its role as a diagnostic tool, specifically as a way of measuring the effectiveness of recruitment manoeuvres (Tusman, Acosta and Costantini 2016; Cylwik and Buda 2021). Only eight studies in this review (8.9%) explored using LUS as an outcome measure for intervention. This potential role of LUS therefore requires more exploration through further high-quality observational research or randomised controlled trials.

2.7.4 The Use of LUS by Non-Medical Professions

The evidence base regarding non-medical healthcare professionals performing LUS in the cardiac surgery population is limited. Studies with non-cardiac patients have explored this concept: Le Neindre et al. found thoracic ultrasound has a high impact on physiotherapists' clinical decision-making for critical care patients (Le Neindre et al. 2023). Further studies have assessed the ability of nurses to assess for cardiogenic dyspnoea using traditional LUS with good accuracy (Mumoli et al. 2016) and reliably measure and quantify pleural effusion after cardiac surgery using handheld LUS (Graven et al. 2015). Additionally, several narrative reviews have discussed the potential for non-medical professionals to use LUS within their scope of practice (Leech et al. 2015b; Karthika et al. 2019). There is evidently a growing interest in LUS from non-medical professionals. With the House of Commons Health and Social Care Committee reporting the NHS facing the greatest workforce crisis in its history (House of Commons Health and Social Care Committee 2022) and recent widening of scope of physiotherapist responsibilities, such as the introduction of First Contact Practitioners (Goodwin et al. 2021), widening the scope of LUS use to other healthcare professionals could relieve the pressure on the healthcare system. Further primary research involving these professional groups is required if this potential is to be realised, as well as scope of practice and governance framework devised to ensure any potential overlap in scope is accounted for.

2.7.5 LUS Techniques and Methods

This review found a lack of reporting regarding LUS techniques and methods. This is consistent with other LUS evidence syntheses: Heldeweg et al. (2022) raised the same concern for methodological inconsistencies in a systematic review evaluating the impact of LUS on clinical-decision making in the emergency department, intensive care, and in the general ward; Hayward and Janssen (2018) found it difficult to compare studies with the numerous different scanning techniques in their scoping review exploring the use of thoracic ultrasound by physiotherapists. A recent scoping review on the use of LUS to detect atelectasis, consolidation, and pneumonia in the adult cardiac surgery population (Churchill et al. 2023) also found there to be a lack of consistency in LUS methodologies, including variations of frequencies, probes, modes, and positioning on top of the methods described in this scoping review. New international recommendations by Demi et al. (2023) suggest extensive studies are required to define the optimal imaging settings for LUS.

At most, only nine reports cited the same previously reported protocol. This could be attributed to the lack of available protocols to replicate in research. The protocols most cited, Volpicelli et al. international recommendations (2012) and the BLUE-protocol (Lichtenstein 2014), were not introduced until 2012 and 2014, respectively. The first instance of a protocol cited in the included primary studies was in 2014 with the BLUE-protocol (Menzel et al. 2014). It is possible the sudden rise in the popularity of LUS has not allowed time for more standardised protocols to be developed and evaluated which may be contributing to the inconsistent reporting. It should be noted this may suggest LUS is currently used by medical professions without standardised protocols or with a wide variety in protocols used, making implications and generalisation to the influence of LUS on clinical practice equivocal. With the rise in research recognising the heterogeneity in LUS methods and protocols, it is likely more focus will be brought upon using a smaller number of protocols to allow for better evidence synthesis in the future.

The methodological inconsistency among studies could have an impact on the advancement of LUS research. For instance, the 27 primary studies assessing the diagnostic ability of LUS contained a variety of eight different protocols with a mix of previously reported protocols and protocols unique to the particular study. The diversity in scanning techniques and time windows may introduce confounding variables, making it difficult to generalise findings. Additionally, this can pose challenges to clinicians looking to incorporate evidence-based LUS practice.

Furthermore, the protocols which have been previously reported and replicated vary in purpose and technique. The recommendations by Volpicelli et al. (2012) include a variety of methods. While an eight-region LUS examination is recommended for general patients with interstitial syndrome, a two-region approach is recommended for the critically ill. Other recommendations suggest what region to begin scanning and which direction to travel in without specifying the number of zones, e.g., the technique for lung consolidation should begin at the area of interest and progress to the entire lung as needed. The BLUE-protocol (Lichtenstein 2014) is specifically for patients with acute respiratory failure and consists of six regions, or "points." Literature in other populations suggests scanning more regions: a prospective cohort study evaluating the impact of different LUS protocols in the assessment of lung lesions in COVID-19 patients found a 12-region method to improve diagnostic power compared with a ten- or eight-region method (Tung-Chen et al. 2021); a retrospective cohort study found similar results in their secondary analysis finding a 12-region method to be superior to an eight- or six-region method (Brenner et al. 2021). The protocol used by Acosta et al. (2014) does consist of a 12-region method for children with anaesthesia-induced atelectasis; this method was used solely by studies with a paediatric population in this review, however only two were assessing for atelectasis (He et al. 2021b, 2021a).

2.7.6 Challenges for Clinical Practice

With so many variations in protocols for varying populations and pathologies, conducting research with consistent LUS methods and selecting the most appropriate protocol to use clinically remains a challenge. Standardising protocols and methods will improve consistency in the research, facilitating more effective evidence synthesis. This in turn can improve generalisation of findings to the cardiac surgery population. Once the best practice for LUS is established, future research can more effectively investigate other queries, such as the indications for LUS, effective scanning windows, alternative LUS applications, and who else may be able to use LUS in other fields. Improving clinical practice and the ability to detect PPCs in timely and efficient manner begins with improving consistency of LUS methods in the research.

2.7.7 Criticism

Despite its growing popularity, there is some remaining doubt and scepticism regarding the use of LUS. One letter to the editor by Sperandeo (Sperandeo, Mirijello and De Cosmo 2020) questioned the diagnostic capability of LUS when using B-lines as a pathognomonic marker of lung disease. Owing to the growing interest in LUS over the past decade, there remains a significant amount of research to be conducted on both its established and novel applications, making it a challenging task to comprehensively investigate all aspects of the tool. As further research is needed to fully understand the potential of LUS, researchers and clinicians may continue to approach its use with caution and in conjunction with other tools.

2.7.8 Recommendations for Future Research

Standardising LUS protocols would be advantageous for future research, and qualitative studies could shed light on the facilitators, barriers, and perspectives of LUS operators in this population, as well as the experience of patients themselves. Once best practice for LUS is established, exploring alternative applications of LUS, such as its potential as a measure of treatment effectiveness, would be beneficial. Further investigation of the use of LUS by other healthcare professionals, including physiotherapists and nurses, is encouraged before any recommendations for practice can be made. Future research may also explore the use of thoracic ultrasound to assess the diaphragm following cardiac surgery due to the commonality of phrenic nerve injury.

2.7.9 Strengths and Limitation of this Scoping Review

This review involved a comprehensive search strategy and protocol which was developed by an experienced review team. Despite the rigorous approach, it is possible that some relevant articles may have been missed. This scoping review was limited to records which were either in English or could be translated by Google Translate. Nonetheless, the five included reports translated using Google may have a degree of inaccuracy. Illegible or untranslatable reports were excluded (n=4), therefore mapping the entire evidence base was not possible. While the methodological quality of the literature was not assessed, this was in keeping with methodological guidance for scoping reviews (Peters et al. 2021), which aim to map available literature rather than assess the quality.

2.8 Conclusion

This scoping review has comprehensively mapped the current literature exploring the use of LUS within the cardiac surgery population. While LUS has garnered significant attention in the field of cardiac surgery, this scoping review has identified areas requiring further investigation to fully harness its potential. Further research is needed to establish best practices for LUS, including standardising methods, exploring its use by non-medical professions, and conducting qualitative studies. Lung ultrasound has the potential to improve patient outcomes by enabling early identification of PPCs. With continued research, LUS may prove to be a valuable tool for clinicians and researchers in the cardiac surgery population.

The primary research following on from the scoping review which forms the main component of this thesis was a large and comprehensive mixed methods study. This doctoral study was designed to progress the knowledge base on the use of LUS in the cardiac surgery population. The study addressed several of the gaps identified within this scoping review. This doctoral work explored LUS use by physiotherapists and included a qualitative component to explore barriers, facilitators, and perspectives of those already using LUS in practice. The LUS methods included a named protocol (the BLUE-protocol) and ensured thorough reporting for future evidence synthesis. The pathologies of interest in the primary research are the three most common pathologies of interest in the cardiac surgery population: atelectasis, pleural effusion, and pneumothorax. The following chapters outline the methodology and methods explored to conduct this work.

Box 2.2 Key Scoping Review Takeaways.

Scoping Review Key Takeaways:

- Physiotherapist-operated LUS was only reported in two studies
- There are no qualitative studies on the use of LUS within the cardiac surgery population
- There is high heterogeneity in LUS protocols and methods
- There is variable reporting of LUS methods

How the Primary Research Addressed the Gaps in the Literature:

- Conducted empirical research on the use of LUS by physiotherapists within the cardiac surgery population
- Conducted qualitative research on the use of LUS within the cardiac surgery population
- Provided transparency in reporting LUS methods and protocol
- Conducted the research with a named and previously reported protocol

3. METHODOLOGY, METHODS, & MATERIALS

3.1 Introduction

The previous chapter discussed the literature on the use of LUS within the cardiac surgery population. This chapter will begin by presenting the primary doctoral research aims and objectives. It will then discuss the research philosophy, reviewing the worldview, methodology, and study design. The chapter will continue by describing and justifying the research participants selected, the materials and methods used, and the data processing and analysis conducted.

3.2 Study Aim & Objectives

Chapter 2 mapped the current literature and identified the gaps within the knowledge base of LUS-use in the cardiac surgery population. The findings were considered and informed the following aims and objectives for the primary doctoral research. Only two studies were identified in the scoping review involving physiotherapist-operated LUS within the cardiac surgery population and no studies with physiotherapists as participants. The current and potential use of LUS by physiotherapists treating cardiac surgery patients needs to be further explored. Therefore, this doctoral study was designed to explore the current use of LUS in a cardiothoracic physiotherapy department to measure if there is an influence on practice and to explore the physiotherapists' views on its use. The results of this study may aid the discussion on whether to further pursue LUS training and research in physiotherapy.

The overall aim of this doctoral study was to explore the use of LUS among physiotherapists working in cardiac care in one UK hospital. The objectives of this study were:

1. To explore the influence of LUS on respiratory physiotherapists’ identification and management of postoperative pulmonary complications (PPCs) after cardiac surgery.
2. To explore respiratory physiotherapists’ perceptions and experiences of LUS, with particular reference to:
    a. Their views on the role of LUS in identifying and managing PPCs after cardiac surgery.
    b. Their views on the indications for LUS in the cardiac surgery population.
    c. Their views on the impact LUS might have on patient outcomes.

3. To determine the current use of LUS within a cardiothoracic physiotherapy department in one UK hospital when managing patients after cardiac surgery by measuring:
    a. The average length of time of LUS assessment
    b. The average number of LUS orders for patients within this population in
        i. A day
        ii. A week
        iii. A month

4. To measure potential relationships between certain cardiac surgery patient demographic and/or surgery details and changes to pathology identification, management, and certainty through regression analysis.

3.3 Research Philosophy

This section will present my worldview as the researcher, define elements of research philosophy as it pertains to my worldview, and discuss other common worldviews.

3.3.1 My Worldview

A research paradigm is a constructed "basic set of beliefs that guides action"(Guba 1990 p.17). Each paradigm consists of a particular ontology, epistemology, methodology and axiology. These labels represent the "personal biography of the researcher," giving insight into the researcher's view of the world, and are therefore more often simply called the researcher's "worldview" (Denzin and Lincoln 2018). The way a researcher approaches the world has a framework (ontology) that will indicate a specific set of questions (epistemology) that are then investigated and explored in specific ways (methodology) (Denzin and Lincoln 2018). This section discusses the origins of my worldview.

My motivation to conduct research is to improve physiotherapy practice. The push for evidence-based practice within physiotherapy has increased the drive to produce research to inform clinical practice (Bithell 2000; Shaw, Connelly and Zecevic 2010). This drive initially began with a push for randomised controlled trials (RCTs) with a positivist/post-positivist approach, following the medical model. Although there is benefit to testing clinical methods and techniques using RCTs, the physiotherapy community has become resistant to this model, as this model does not capture the complexity and contextual elements of physiotherapy practice (Parry 1997; Bithell 2000; Shaw, Connelly and Zecevic 2010). More recently, the importance of understanding the perspectives of all stakeholders within physiotherapy (e.g., patients, carers, clinicians) through a constructivist approach has been highlighted, emphasising the value of meaning for all those involved to improve empowerment (Parry 1997). Physiotherapy research, therefore, does not fall neatly into any one paradigm, but requires drawing from multiple paradigms to thoroughly answer questions that arise from clinical practice (Parry 1997; Shaw, Connelly and Zecevic 2010). Pragmatism attempts to “gain knowledge in the pursuit of desired ends” (Morgan 2007, p.69); the desired end of clinical research is to improve clinical practice and make practice more evidence-based. Therefore, to best answer a clinical physiotherapy-focused research question, I took a pragmatic approach.

3.3.2 Pragmatism & the Paradigm Questions

Having established pragmatism as my worldview, this next section reviews the ontological, epistemological, methodological, and axiological questions that are relevant to me and my work. Pragmatism does not have a set ontology, epistemology, methodology, and axiology, but often drifts between worldview elements, resulting in varying combinations and differences in philosophical commitments, something which Johnson et al. (2007) believes should be embraced as an important part of pragmatism and mixed methods research. However, Morgan (2007) cautions pragmatists to still consider worldviews, as we cannot separate ourselves from our personal history, social background, and cultural assumptions, as well as our values and politics. In the following sections, I will define the common paradigm questions and explain my philosophical stance in line with my worldview.

Ontology

“What is the nature of ‘reality’?” (Guba 1990 p.18)

Philosophy considers ontology to be a branch of metaphysics, concerning the theory of being. Contemporary philosophy of science highlights the role metaphysical assumptions play in shaping the impact of inquiry (Denzin and Lincoln 2018). The most common ontological positions are variations of realism and relativism (Guba 1990; Denzin and Lincoln 2018). Realism is the belief one reality exists, driven by immutable natural laws; Relativism is the belief that multiple realities exist based on the mental constructions dependent on the individual (Guba 1990). Pragmatists do not claim to know if their current “picture” or “conception” accurately represents “reality,” but simply choose the approach that is better at producing the desired or anticipated outcomes (Cherryholmes 1992). As a pragmatist, my research questions arise from consideration of intended consequences, the impact of inquiry thus far, and where the research may lead irrespective of the "true" nature of reality.

Epistemology

"What is the nature of the relationship between the knower (the inquirer) and the known (or knowable)?" (Guba 1990 p.18)

Crotty (1998) describes three main epistemologies: objectivism, subjectivism, and constructionism. The objectivist epistemology believes meaning and meaningful reality exists apart from consciousness. The subjectivist epistemology holds that meaning does not come from the interaction between the subject and object but is imposed on the object by the subject. The object does not contribute the generation of meaning. Constructionism believes there is no objective truth to be discovered but comes into existence purely through interaction between the subject and object and the construction of meaning by the subject. Morgan (2007) describes pragmatism as having an intersubjective epistemological approach, asserting there is both a "real" world and all individuals have a unique interpretation of that world, and this is the view I hold in my own work.

Methodology

"How should the inquirer go about finding out knowledge?" (Guba 1990 p.18)

Methodology is often the main paradigm question with which researchers engage in their work. Methodology is finding the appropriate research strategy, process, design, and/or methods for the desired outcome (Crotty 1998).

Guba (1990) describes methodological approaches such as experimental, dialogic, and dialectic approaches. More recently, methodological approaches have been discussed under the umbrellas of quantitative, qualitative or mixed methods approaches (Creswell and Creswell 2018; Denzin and Lincoln 2018). Quantitative research tests objective theories and examines relationships among and between variables. The numbered variables are measured and are often analysed using statistical procedures (Creswell and Creswell 2018). Qualitative research is often described as naturalistic and interpretive, using the perspectives of the research participants as the main way to explore phenomena from the inside. Qualitative research often uses non-standardised and adaptable methods to generate data that are sensitive to social context and can be adapted to the individual participant or case (Ritchie et al. 2013).

Pragmatism uses any methods necessary to obtain a more comprehensive answer to suit the complexities of clinical practice. With consideration of my epistemological stance, I believe both objective and subjective investigation should be conducted to best understand the research problem by capturing both the “real” world and how individuals living in that world view it through their own lens. This often results in a mixed methods methodology, pulling from both quantitative and qualitative research to address the research problem (Creswell and Creswell 2018). Due to the paucity of research conducted on LUS-use by cardiothoracic physiotherapists (Chapter 2), the evidence base would benefit from both quantitative and qualitative methods. The objectives presented in Section 3.2 would best be answered by both quantitative and qualitative methods, with a quantitative component measuring the potential impact of LUS on practice and a qualitative component exploring the perceptions and experiences of physiotherapists already regularly performing and engaging with LUS. Therefore, I chose a mixed methods methodology. There are several mixed methods research designs, which are discussed in Section 3.4.1.

Axiology

> *“What is intrinsically worthwhile? What is it about the human condition that is valuable as an end in itself?” (Heron and Reason 1997 p.286)*

Heron and Reason (1997) argued axiology to be the fourth fundamental question and necessary complement to balance an inquiry paradigm, highlighting the importance of understanding what is intrinsically worthwhile, what is the value of knowledge and how it plays into the research inquiry. The stance was later adopted by Denzin and Lincoln (2018) and has become a standard part of research paradigms. As a pragmatist and physiotherapist, practical and transactional knowing is instrumentally valuable as a means to improve clinical practice, which is an end in itself, is intrinsically valuable.

3.3.3 Common Worldviews

There exist other worldviews commonly used within research. This next section discusses three common worldviews and justifies why I hold a pragmatic worldview. A summary of the worldviews can be found in Table 3.1.

Postpositivism

Postpositivism developed in the 19th century from writers who challenged the idea of absolute truth of knowledge (positivism), recognising human error impeding us from being absolutely certain about our claims of knowledge. Postpositivism is a deterministic paradigm that is reductionistic in nature. Postpositivists aim to identify and assess causes and effects and do so by reducing ideas into small and discrete sets to test hypotheses and research questions. This lens is based on observation and measurement of objective reality, testing and verifying the laws and theories which govern the world (Creswell and Creswell 2018). Due to their objective and theoretical nature, postpositivists often conduct quantitative research (Creswell and Creswell 2018). While I value investigating the objective reality, I believe it is important to consider the perceptions and understanding of those living within the reality, and therefore do not hold a postpositivist worldview.

Constructivism

The constructivist, or interpretivist, paradigm originated from the works of Berger and Luckmann (1967) and Lincoln and Guba's Naturalistic Inquiry (1985). Constructivists believe individuals seek to understand their world, developing subjective meanings of their experience. Constructivist research aims to rely on the participants views as much as possible. The research questions developed from constructivism tend to be broader and more general than that of postpositivism, allowing the participants to construct subjective meanings through discussions and interactions. Qualitative is the most common methodology used by constructivists (Creswell and Creswell 2018). Although I consider and value subjective meanings, I believe these meanings can help us to better understand the objective reality and should be applied accordingly rather than stand alone.

Participatory

Heron and Reason (1997) critiqued Guba and Lincoln's constructivism to include a self-reflexive element, creating the participatory worldview. The participatory worldview emphasises the individual and the integration of action with knowing. Creswell and Creswell (2018) describe those with this worldview as "transformativists," explaining those with this view feel postpositivism imposed laws and theories which does not consider marginalised communities and feels constructivism does not advocate enough for action to help these communities. The central focus of research in this paradigm is the lives and experiences of marginalised and diverse groups, linking political and social action to the research (Heron and Reason 1997; Creswell and Creswell 2018). Although my values and beliefs align more closely to the participatory worldview than the other two worldviews discussed and I find the research conducted with this worldview intrinsically worthwhile, my research and work does not pertain only to marginalised communities.

Table 3.1 Common Worldviews. *Descriptions taken from [1]Guba (1990) and [2]Heron and Reason (1997).*

Worldview	**Ontology**	**Epistemology**	**Axiology**	**Methodology**
Postpositivism[1]	**Critical Realist.** Reality exists and is driven by natural laws but can never be fully apprehended[1]	**Modified Objectivist.** Objectivity is essential but can only be approximated[1]	**Propositional knowing** about the world is intrinsically valuable[2]	**Modified Experimental, Manipulative.** Questions/hypotheses are stated in advance and subjected to empirical tests in carefully controlled conditions, but redress imbalances by investigating in more natural settings and expanding to qualitative methods[1]
Constructivism[1]	**Relativist.** Realities exist in the form of multiple mental constructions, the form and content dependent on the persons who hold them[1]	**Subjectivist.** Inquirer and inquired into are infused into a single entity; findings are created from interaction between the two[1]	**Propositional, transactional knowing** is instrumentally valuable to social emancipation and is intrinsically valuable[2]	**Naturalistic, Hermeneutic, Dialectic.** Individual constructions are elicited and refined hermeneutically and compared and contrasted dialectally, with the aim of generating one (or a few) constructions on which there is substantial consensus[1]
Participatory[2]	**Participatory Reality.** Subjective-objective reality, cocreated by mind and given cosmos[2]	**Critical Subjectivist.** Inquirer integrates experimental, propositional, and practical knowing into findings[2]	**Practical knowing** how to flourish with a balance of autonomy, cooperation, and hierarchy in a culture is intrinsically valuable[2]	**Political Participation, Collaborative Action Inquiry.** Primacy of the practical; use of language grounded in shared experiential context[2]
My Worldview: Pragmatism	**Unknown Reality.** Does not claim to know if conception accurately represents reality	**Objectivist & Subjectivist.** Both a real world and interpretations of it	**Practical, transactional knowing** is instrumentally valuable as a means to improve clinical practice, which is an end in itself, is intrinsically valuable	**Mixed Methods.** Uses any methods necessary to obtain a more comprehensive answer to suit the complexities of reality

3.4 Mixed Methods Research & Study Design

The following section discusses mixed methods research designs and justifies the primary research study design.

3.4.1 Mixed Methods Research

In line with pragmatism, I used a mixed methods approach to achieve a more comprehensive exploration of the topic. As a pragmatist, I felt both quantitative and qualitative methods were required to address the research objectives. Mixed methods research (MMR) uses both quantitative and qualitative data with the aim to integrate the data, achieving additional insight beyond what either quantitative or qualitative data could do alone (Creswell and Creswell 2018); MMR captures data that reflects individual lived experiences, ensuring the consideration of the participant's perspective (Regnault 2018), and providing a more holistic understanding with stronger inferences (Wasti et al. 2022). Within the context of physiotherapy, this methodological approach allows for the development of quantitative data to inform treatment and technical practice while considering clinical and life context that contribute to patient and physiotherapist empowerment through qualitative methods (Shaw, Connelly and Zecevic 2010). MMR, however, comes with challenges; it requires expertise in multiple methodologies and methods (Regnault 2018; Skamagki et al. 2022; Wasti et al. 2022). A strength of this doctoral supervisory team is the knowledge of the methods implemented in this thesis.

With MMR, integration of the quantitative and qualitative data is required. Integration can occur at several levels, such as at the levels of design, methods, or interpretation and reporting (Skamagki et al. 2022). A critique of MMR is the lack of integration of data, resulting in the findings reported separately for each of the methods (Bryman 2007; Skamagki et al. 2022; Wasti et al. 2022.)

In order to ensure design quality, different mixed methods study designs were considered to ensure suitability and appropriateness. Creswell and Plano Clark (2017) describe three main types of mixed methods designs: convergent, explanatory, and exploratory. The convergent design, previously referred to as the triangulation design (Creswell and Plano Clark 2007), aims to directly compare and contrast quantitative and qualitative data on the same subject in a single phase or overlapping design. The explanatory and exploratory designs are two-phase designs, with one data set used to build upon the other: The explanatory design uses qualitative data to explain or build on initial quantitative results; The exploratory design begins with qualitative to explore a subject area and uses the data to inform the quantitative phase (Creswell and Plano Clark 2017). The pool of potential participants was small due to the novelty of LUS-use among physiotherapist working in cardiac care; using qualitative research to follow up quantitative research can be useful when the participant group is too small for significant statistical analysis or when the participant group have a valuable perspective on an under-explored subject area (Ritchie et al. 2013). Therefore, I aimed to conduct either a sequential explanatory or convergent mixed methods study.

3.4.2 Study Design

Due to the restrictive timeline of the doctoral degree, a convergent mixed methods design was chosen over a sequential explanatory design as a sequential design requires full analysis of the quantitative results prior to the initiation of the qualitative phase. However, I chose to conduct a fully integrated convergent study, which is a variant of the convergent design that contains interactive elements during implementation (Creswell and Plano Clark 2017). Preliminary results from the quantitative phase would help to inform the qualitative phase to explore a deeper exploration of the quantitative results.

3.5 Research Participants

3.5.1 Participant Population

This research was designed and conducted in collaboration with a UK cardiothoracic department which had already implemented LUS as part of everyday practice. Due to the novelty of LUS-use by physiotherapists, it was not common at the time of the study to have an entire department engaging with LUS as a regular part of physiotherapy practice. To best explore what integrating LUS within physiotherapy practice may resemble, it was decided recruiting from this one department with all physiotherapists engaging with LUS to some extent would best address the research aim rather than recruiting other physiotherapists spread across multiple departments or hospitals.

3.5.2 Inclusion Criteria

The inclusion criteria for physiotherapist recruitment were a qualified physiotherapist working in the cardiothoracic department within one hospital in the UK who had given signed informed consent to participate in the study. The inclusion criteria were not limited to those accredited in LUS to consider perspectives of those with less experience with and exposure to LUS.

3.5.3 Exclusion Criteria

Exclusion criteria for physiotherapist recruitment were any unqualified physiotherapist staff (e.g., student physiotherapists, physiotherapy technical instructors). Part of this study aimed to explore the influence and impact of LUS on physiotherapists' identification and management of postoperative pulmonary complications (PPCs), therefore only physiotherapy staff qualified to identify and manage PPCs were included.

3.5.4 Participant Recruitment & Sampling

Prior to recruiting participants, the gatekeeper, a senior physiotherapist based in the cardiothoracic department, was approached, and approval was gained. The gatekeeper agreed to become the local principal investigator (PI). The local PI distributed the information sheet to the potential participants via email (Figure 3.1) (Appendix 3-4). A research site visit was conducted in person to allow for any questions or concerns regarding the study to be addressed. Interested participants were then invited to directly contact me by email if they wished to participate to ensure participation was voluntary. The participants had two months to deliberate and discuss participation prior to consenting. It was made clear through the information sheet, email, and discussions in person that participants did not have to participate and may withdraw at any point with no negative consequences on themselves or their position. If the physiotherapist wished to participate, the consent form (Appendix 5) was sent to me via email, which I co-signed. Once informed consent was gained, the participating physiotherapists were given their unique identifier and received a link to an online questionnaire for demographic information via email.

Within the National Health Service (NHS) in the UK, there are standard pay bands for qualified physiotherapists that, for predominantly clinical roles, range from Band 5 to Band 7. Newly qualified physiotherapists tend to begin as a Band 5, the roles tend to become more specialised at Band 6, and line managers in specified departments tend to be Band 7. It is common for Band 5 physiotherapists to rotate through different departments throughout the year, ranging typically from four to six months for each rotation. Band 6 job posts may also be rotational with a tendency to be within a specific area of physiotherapy, e.g., respiratory, and each rotation lasts slightly longer for about 6 months to a year. During the set data collection period from January to March 2023, a rotation of Band 5 and Band 6 staff occurred, resulting in a total of ten physiotherapists that could be recruited from the cardiothoracic department. A power calculation was not conducted to determine sample size as this project was exploratory and the sample size was limited to those working in the cardiothoracic department of one UK hospital. Therefore, convenience sampling was adopted, and the aim was to recruit up to all ten physiotherapists who were all successfully recruited.

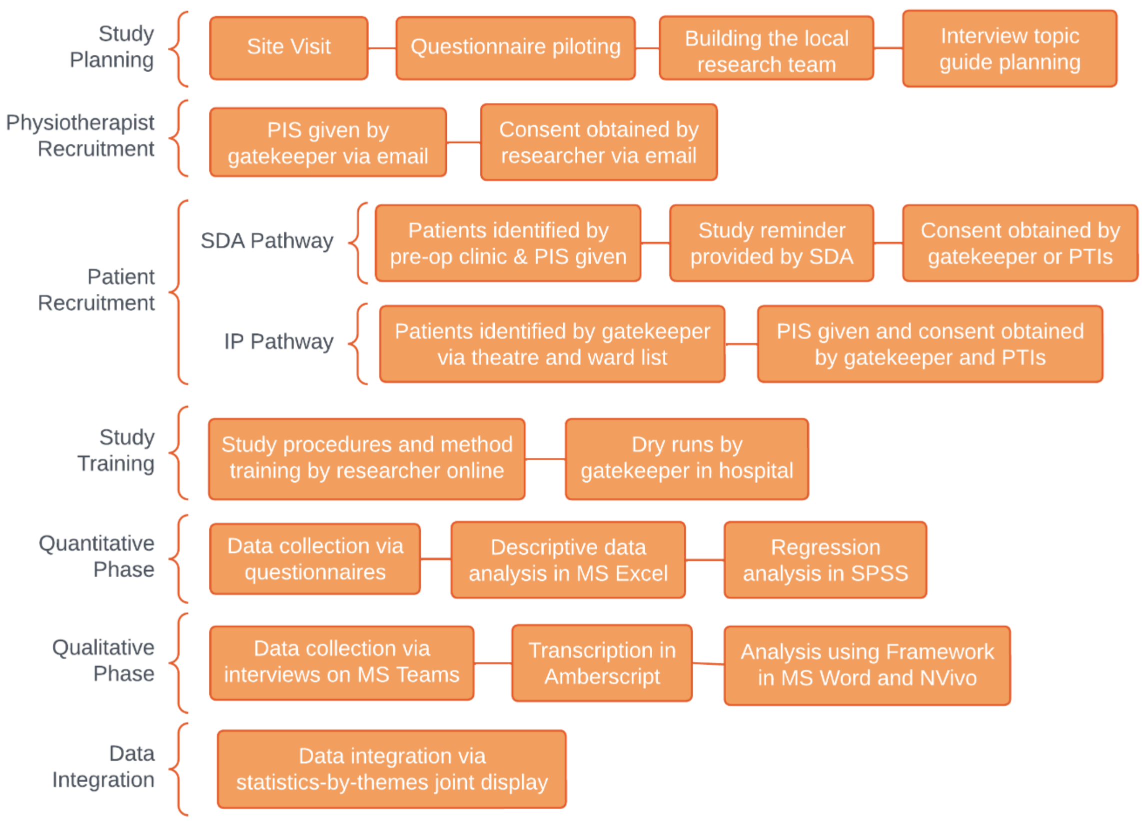


Figure 3.1 Summary of Primary Research. *Key: PIS = physiotherapist/patient information sheet; SDA = Same Day Admissions; IP = inpatient; PTIs = physiotherapy technical instructors; MS = Microsoft.*

3.6 Patient Volunteers

Although patients were not the focus of the study, patient volunteers were recruited for the physiotherapists to assess, and their anonymous data was collected to address Objective #4. Due to the limited research on the use of LUS by physiotherapists, there are many unknown variables in this study, such as when to perform LUS, who to perform LUS on, and indications for LUS; the literature at the time of designing this study did not indicate what patient population or time window should be studied. The senior physiotherapists within the collaborating cardiothoracic department had previously discussed conducting LUS on every day one cardiac surgery patient as standard practice as they felt this may allow PPCs to be caught earlier in this population. Since the literature did not indicate when LUS should be conducted post-surgery, it was decided through discussions with the department that we would study day one cardiac surgery patients. Inclusion and exclusion criteria were set for recruiting patients to limit unknown variables, too many of which could lead to difficulties in interpreting and understanding relationships between the data.

3.6.1 Patient Volunteers Inclusion and Exclusion Criteria

Lung ultrasound procedures differ from adults to paediatrics due to chest size and anatomical features. To mitigate confounding variables and improve interpretive distinctiveness, this study focused on the use of LUS in the adult cardiac surgery population. The study was limited to the bypasses and valve surgeries listed below as a suggestion by the local PI, as more complex surgeries comprise a minority of the patient population and could alter how the physiotherapist assess and manages the patient in a way that could skew the quantitative results. The need for cardiac surgery can become urgent quickly. Even patients who have been scheduled for an elective surgery may become an urgent case and taken to theatre early. Due to this, gaining informed consent was an ethical and logistical challenge. Therefore, the study excluded emergency cardiac surgery patients.

Inclusion criteria for patient volunteers:

- The patient is an adult of any gender 18 years or over.
- The patient is undergoing one or a combination of the following surgeries:
    - Coronary artery bypass graft
    - Aortic valve repair/replacement

  - Mitral valve repair/replacement
  - Tricuspid valve repair/replacement
- The patient is undergoing non-emergency cardiac surgery.
- The patient provides written informed consent.

Exclusion criteria for patient volunteers:

- The patient is under the age of 18.
- The patient is an adult without capacity to consent.
- The patient is undergoing emergency cardiac surgery.
- The patient refuses physiotherapy assessment of day one after their surgery.

3.6.2 Patient Volunteers Sampling and Consent

Local Research Team

A local research team (Figure 3.2) was put together for the quantitative phase, mainly for patient volunteer recruitment due to the complexity of gaining informed consent. Within the cardiothoracic physiotherapy department, the physiotherapy technical instructors assisted with volunteer patient recruitment. Physiotherapy technical instructors (PTIs) are members of the physiotherapy team that are not qualified physiotherapists but may assist and support physiotherapists with executing treatment plans and patient education. Three additional teams outside of physiotherapy assisted with the study: the Cardiothoracic Surgery Pre-Operative Assessment Clinic (pre-operative clinic), Cardiac Same Day Admissions (SDA), and the Cardiac Surgical Co-ordinators (surgical co-ordinators). The local PI gained access to the pre-operative clinic calendar, the SDA calendar, the surgical co-ordinators' spreadsheet, and theatre list to assist with volunteer patient recruitment.

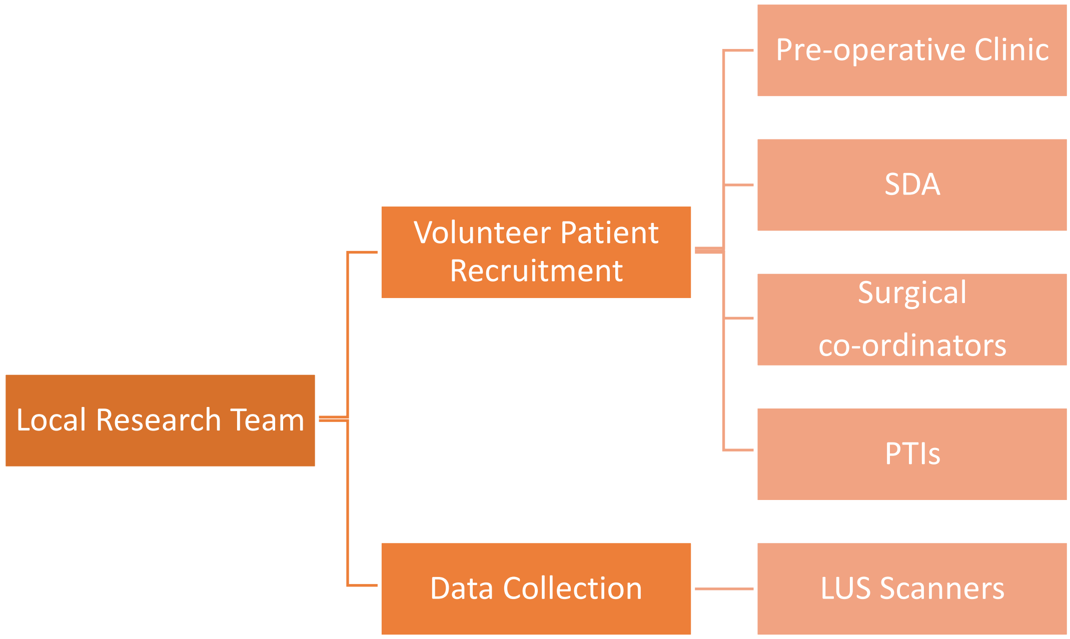


Figure 3.2 Local Research Team. *SDA = Cardiac Same Day Admissions, PTI = Physiotherapy technical instructors.*

Volunteer Patient Recruitment Procedures

The local PI was provided with the patient volunteer criteria via email and paper copy. The local PI then distributed the patient volunteer criteria as well as volunteer patient recruitment packs to the nursing staff at the pre-operative clinic. This allowed for the pre-operative clinic to identify potential patient volunteers and provide them with a recruitment pack (Appendix 6-8). The patients were asked to bring back the consent form (Appendix 8) if they decided to participate and one of the PTIs or the local PI answered any further questions or information prior to countersigning the consent form when they arrived either in SDA or on the wards as an inpatient. Within the physiotherapy department, the local PI and PTIs used the criteria, as well as a patient management spreadsheet used by the surgical co-ordinators, to identify potential inpatient volunteers on the wards. They provided the patients with the information sheet (Appendix 7) and allowed a minimum of 24 hours and aiming for at least 48 hours for the patients to deliberate participation prior to gaining written informed consent. A minimum of 24 hours was implemented only if the patient's surgery was scheduled or rescheduled too soon to allow for 48 hours or more. The patient volunteers were made aware they could withdraw from the study at any time with no impact on the treatment and care they received. The process of identifying and sampling patient volunteers is shown in Figure 3.1.

The local PI provided a patient identification number (PIN), a unique identifier, to patients who had given informed consent and tracked patient volunteers in a spreadsheet on a protected drive within the hospital that only the PTIs, LUS Scanners (discussed in Section 3.8.2) and local PI had access to. The research team outside of the hospital did not have access to identifiable information for the patients.

3.7 Quantitative Materials

This section will discuss the materials used for data collection during the quantitative phase.

3.7.1 Questionnaires

One online demographic questionnaire and three paper-based data collection questionnaires were created specifically for the study by me. The online demographic questionnaire (Appendix 9) was hosted on Jisc online surveys© (GDPR compliant).

The three paper-based data collection questionnaires were initially designed by using my research objectives and current literature on the demographic and surgical risks of developing PPCs (e.g., relevant past medical history, eventful surgery). The strength of creating questionnaires specifically for this doctoral research is the ability to ensure the research aim and objectives were addressed. However, a limitation is the lack of validation of the questionnaires and the difficultly this may bring to evidence synthesis. The lack of validation was addressed through a rigorous process to ensure quality questionnaires. During study planning in June 2022, I visited the research site, had discussions with the physiotherapy staff, and observed daily clinical practice, particularly initial assessments of day one cardiac surgery patients. As a novice physiotherapist, I valued the involvement and input from the clinicians to ensure the research would be applied and clinically relevant. I drafted the questionnaires based on observations and discussions, and then collaborated with the local PI to ensure the study would naturally and accurately capture the sought after data and could be integrated into normal daily practice. Discussions were had with the current physiotherapy staff and initial assessments were observed. On a second research visit, the quantitative data collection questionnaires were initially piloted with a cardiothoracic physiotherapist who met inclusion criteria, but who would rotate out of the department before the data collection period. Feedback was considered from the physiotherapist and the revised questionnaires went through three more pilots with three respiratory physiotherapists independently using a case study. Adaptions were made to enhance the clarity of questions, add or remove questions, alter options for multiple-choice responses, and expand questions to capture more detail. The final version of the questionnaires was reviewed by all three physiotherapists and members of the supervisory team to satisfaction, ensuring design fidelity and quality. The data collected from the questionnaires were analysed using standard statistical analyses used in other studies to mitigate the challenges of evidence synthesis due to not using a previously validated questionnaire.

To allow for more in-depth analysis of the influence of LUS on pathology identification, the questionnaires included probability scales for the participant to create a probability distribution for three pathologies: atelectasis, pleural fluid, and pneumothorax. These pathologies were decided based on discussions with the cardiothoracic department and the local PI on which pathologies were the most seen with LUS. These three pathologies are also the three most common pathologies in the literature on LUS-use within the cardiac surgery population. Despite pleural effusions being one of the most common pathologies post-cardiac surgery, the term 'pleural fluid' was chosen over 'pleural effusion' as it is difficult to differentiate excess water (pleural effusion) from blood (haemothorax) or other fluids on LUS during the early days after surgery. Lung ultrasound is comparable to the gold standard of CT and therefore LUS is assumed to provide accurate diagnosis for the sake of this study and LUS findings were not confirmed using a gold standard reference. However, the sensitivity and specificity of LUS has not been tested when operated by physiotherapists. Therefore, when discussing probability in this study, it will be referred to as the participant's perceived probability of the pathology, or their best guess as to the probability.

The probability scales were completed using the bisection method. The bisection method (or quartile method) is a method of prior elicitation (Morris, Oakley and Crowe 2014). Prior elicitation is a method of Bayesian inference that involves eliciting subjective knowledge (presence of pathology) of domain experts (physiotherapists) in a structured manner to be able to form prior knowledge probability distributions (before LUS) (Mikkola et al. 2021). A benefit of eliciting a probability distribution rather than asking for a single point estimate (such as with more traditional 0-100% confidence or likelihood scales) is the ability to account for uncertainty (Morris, Oakley and Crowe 2014). The participants marked the median, lower quartile, and upper quartile on a continuous scale from zero to one using prompting questions for each pathology before and after LUS. A core concept to Bayesian statistics is the idea that prior beliefs should be updated in light of new data (Bittl and He 2017); completing the bisection method before and after LUS captures how the prior probability distribution for the pathology was updated based on purely the LUS findings.

3.7.2 Lung Ultrasound

The LUS machine used to perform the scans for the study was the Venue Go™ (GE Healthcare). A picture of this machine is seen in Figure 3.3. The settings were adapted for each patient. The common probes used during LUS examination are the curvilinear or phased array 5-9 MHz probes (Marini et al. 2021).

Figure 3.3 The Venue Go ultrasound machine used for the quantitative data collection.

3.8 Quantitative Methods

3.8.1 Demographic Data

After written informed consent was obtained, each participant's age, sex, qualification, current job post, relevant experience, and a definition of a "standard" physiotherapy assessment was collected via the demographic questionnaire (Appendix 9) to aid data analysis. The questionnaire was provided via email with a link through which the participants independently completed it.

3.8.2 LUS Operators & Protocol

This study involved physiotherapist engaging with LUS. Although some of the participating physiotherapists were accredited, not all were, which served as a barrier to having the participants perform LUS themselves. Lung ultrasound is also operator dependent; variations in scanning techniques and competency for those who were accredited could have influenced results. Therefore, three LUS-accredited physiotherapists within the cardiothoracic department were part of the local research team as 'LUS Scanners.' The local PI was the main LUS Scanner and attempted to perform the majority of scans for the study to improve design fidelity by mitigating any confounding variables from having multiple scanners involved. However, to allow for flexibility in the physiotherapists' busy clinical schedules and to maximise the data collected by the participants, two additional LUS Scanners were available to scan as needed when the main LUS Scanner was not available. The main LUS Scanner conducted about 80% of LUS scans during the study. All three LUS Scanners were accredited through the lung module by Focused Ultrasound in Intensive Care (FUSIC), the Intensive Care Society's point-of-care ultrasound training and accreditation package. All three are registered FUSIC Lung mentors. The two additional LUS Scanners received a refresher training from the main LUS Scanner to ensure as much consistency across the LUS Scanners as possible. The combined experience with LUS between the three LUS Scanners was 11.5 years. The main LUS Scanner had held LUS accreditation for seven years.

Established LUS protocols are often targeted towards certain populations or conditions. Since all patients were scanned regardless of indication or condition, there was not one protocol that would perfectly fit every patient. The FUSIC Lung module teaches using the BLUE-protocol lung points, therefore all of the LUS Scanners were most familiar with this protocol. The scoping review conducted as part of this thesis found the BLUE-protocol to be the second most common protocol used in the literature on LUS-use in the cardiac surgery population (Farrell et al. 2023). The BLUE-protocol, first published in 2008 by Daniel Lichtenstein, is a protocol developed for patients in acute respiratory failure (Lichtenstein and Mezière 2008). Although not every volunteer patient was in acute respiratory failure, the BLUE lung points are still considered excellent starting points for assessment and is preferred when time is a crucial commodity having only a six-region protocol (Murali et al. 2022) rather than other protocols which can consist of up to 28-regions (Farrell et al. 2023);further investigation of other lung points can be considered based on the individual patient's presentation. The BLUE-points can be seen in Figure 3.4. There are two upper BLUE-points, two lower BLUE-points, and two posterolateral (PLAPS) points for a total of six lung points at minimum for every patient volunteer. Lung ultrasound was performed in this study with a curvilinear sector probe with a frequency of 1.4 – 5.7 MHz with the depth set between 12-18cm. Most images were captured within brightness or 2-D mode (B-mode) which shows two-dimensional images, but occasionally used M-mode which is used to capture motion as required if a pneumothorax is suspected.

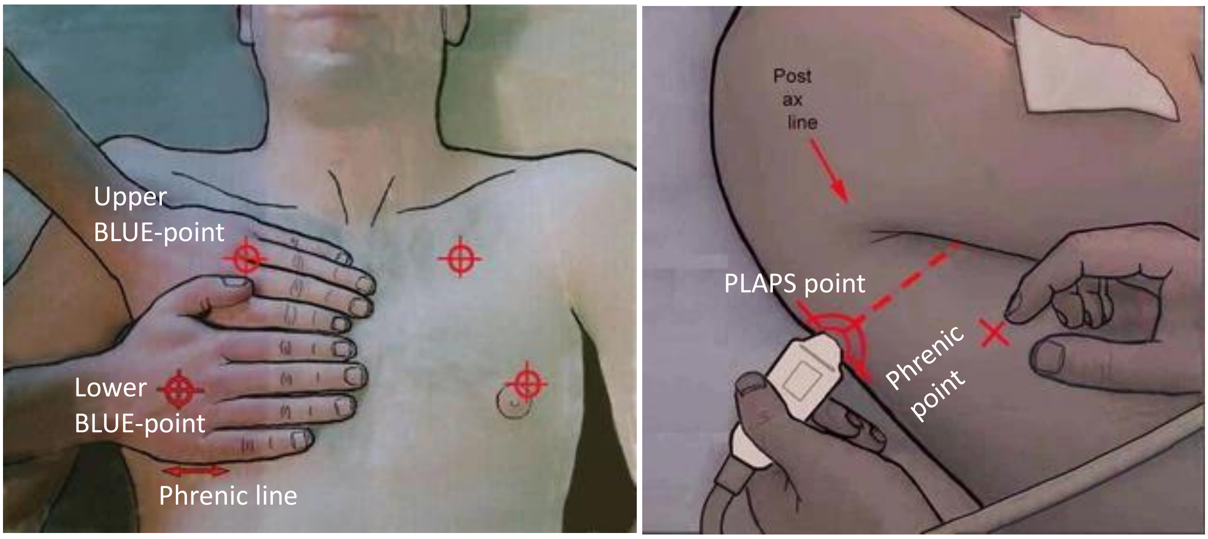


Figure 3.4 The BLUE-points from the BLUE-protocol. *Adapted from Lichtenstein and Mezière 2011. BLUE-hands, or the hand size of the patient, are used for rough measurements of the BLUE-points. Key: BLUE: Bedside Lung Ultrasound in Emergency; PLAPS: posterolateral alveolar and/or pleural syndrome.*

3.8.3 Participant Study Training

Study procedure training was conducted prior to the initiation of data collection to improve design fidelity and quality. Prior to the start of data collection, the participants attended an online training session I conducted which included a formal introduction to the study as well as specific training on how to complete the questionnaires and the data collection procedures. The training included instruction on how to use the bisection method as it involved eliciting a probability distribution, which can be difficult for those without experience in making probability judgements (Morris, Oakley and Crowe 2014). The local PI then took the participants through a dry run of the procedures and allowed for questions prior to beginning the study.

3.8.4 Data Collection Procedure

A flow chart of the quantitative data collection procedure can be seen in Figure 3.5. At the beginning of the clinical day, the participating physiotherapists were allocated a patient volunteer by the local PI. The physiotherapists assessed the volunteer patient as they normally would. The physiotherapist then completed the first data collection questionnaire (Questionnaire #1), noting the patient's demographic and surgical details, their pathology identification, uncertainty in pathology identification, overall impression of the patient, and management plan (Appendix 10). One of the LUS Scanners would then perform LUS on the volunteer patient, blinded to the participant's initial assessment. The LUS Scanner verbally reported their impression of the patient and documented the same impression in the second data collection questionnaire (Questionnaire #2) as well as their uncertainty in their impression using the bisection method (Appendix 11). With the new knowledge of the LUS scan results, the participant then reassessed their pathology identification and management plan, documenting any changes in the third data collection questionnaire (Questionnaire #3) (Appendix 12). After completion of Questionnaire #3, the participant continued with the patient's treatment and care as normal.

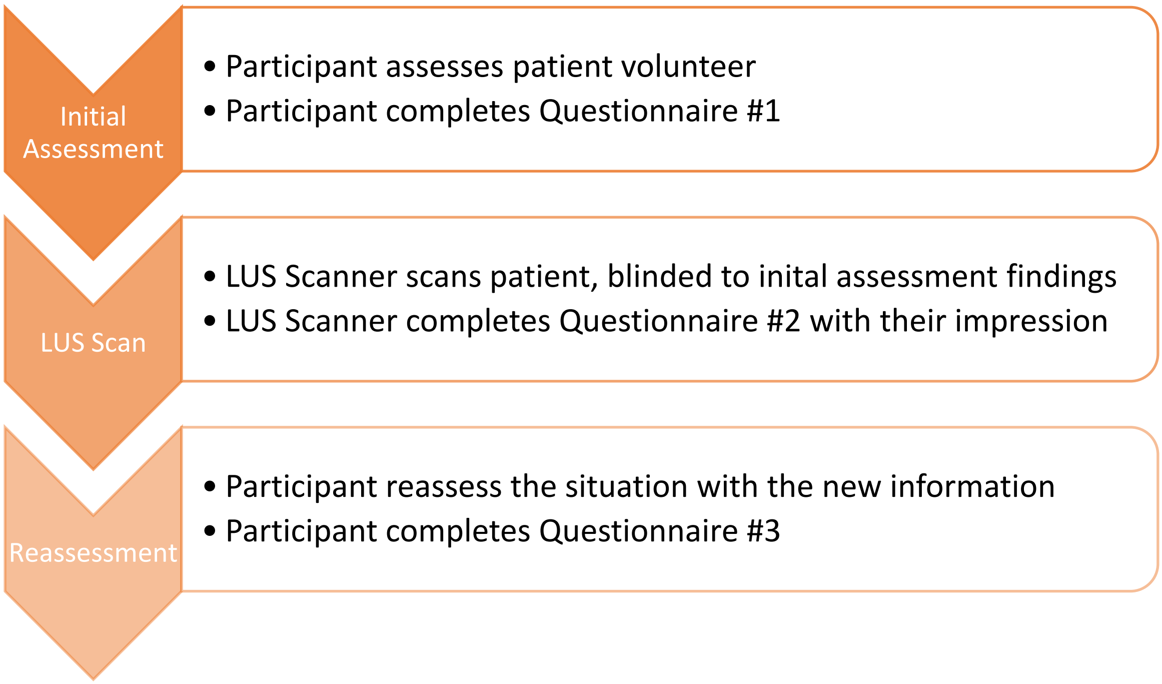


Figure 3.5 Quantitative phase study procedures.

3.8.5 Data Processing

Demographic Questionnaire

The demographic questionnaire results were exported from JISC surveys to Microsoft Excel® (Excel) and were cleaned for analysis.

Data Collection Questionnaires

The questionnaires were scanned within the hospital by the local PI and sent to me over email. I collated the data from the questionnaires for most questions by manual entry directly into an Excel workbook, except for the probability scales. The probability scales were digitised, converting the lines into numerical data and the distance of each line measured from the zero mark. I then input these numbers into the MATCH Elicitation Tool (Morris, Oakley and Crowe 2014) using the quartile input mode and a Log Normal distribution. The expected value/mean (μ) and standard deviation (σ) was recorded. The numerical data from the scales, the mean and standard deviation were then manually entered into the same Excel data workbook for analysis. When data were missing, contradictory, or illegible, I contacted the participants for clarification. Copies of the questionnaires were held by the local PI within a locked cabinet in a locked office, and I held a copy of the scanned questionnaires in a password-protected folder in a secure university network for reference if data needed to be checked for accuracy.

Volunteer Patient Workbook

The local PI documented which surgical pathway the volunteer patients were recruited from. A local surgeon took interest in the study shortly after data collection began and suggested the type of surgical incision, sternotomy or minimally invasive, may be of interest. The minimally invasive approach was an anterior right thoracotomy which involves a small intercostal incision to the right of the sternum as opposed to a division of the sternum. An anterior right thoracotomy reduces postoperative bleeding, enhanced patient recovery, reduced postoperative complications, and reduced costs (Vohra et al. 2023). The local PI added the type of incision to the volunteer patient workbook. Once the study completed, the local PI removed the names of the volunteer patients and sent the workbook containing the PINs, surgical pathway, and type of incision to me via email. I then added these details to the Excel data workbook manually.

3.8.6 Data Analysis

The following section discusses the quantitative data analysis plan and procedures. The quantitative data analyses chosen helped to answer research objectives #1, #3, and #4. The results are summarised in the Chapter 4.

Descriptive Data Analysis

Analysis began with descriptive statistics. Frequencies and percentages were calculated for nominal and ordinal data from both the participant demographics and patient volunteer demographic/surgical data; the mean and standard deviation were calculated for continuous and discrete data.

Understanding the influence LUS has on pathology identification and management planning helps to understand how LUS may influence clinical reasoning of physiotherapists. The influence of LUS on pathology identification was measured in many ways to address research objective #1. The rate of concordance between the participant's clinical impression and that of the LUS scanner was calculated using Question #2 on Questionnaire #3 which asked the participant if they felt the LUS findings matched their own impression of the patient's presentation. The median, lower and upper quartile documented by the participants pre- and post-LUS using the bisection method were displayed in an error bar chart. The difference from pre- to post-LUS was calculated using the perceived median probability of each pathology, recorded by the participant using the bisection method, and then mean was calculated for either an increase or decrease in probability following LUS. The data was presented as box plots, one for increases and one for decreases in perceived probability for all pathologies.

While there were a few specific questions to address with the quantitative findings, i.e., how often LUS would have been performed, the main objective for collecting quantitative data was to explore the potential influence LUS has on physiotherapy practice within the cardiac surgery population. Due to not having a specific question to address, the data analysis process involved rearranging the data to search for common trends that may help advise future more-specified research questions. Through the exploration of the data, thresholds were created and subsequent qualitative labels (e.g., confidence or high confidence) were applied to enhance interpretation and discussion of results; this process helps to highlight values and changes that may inform how LUS may be influencing practice. Applying qualitative labels and thresholds to assist in interpretation and discussion is common practice within quantitative research (Swinton et al. 2022), with well-known thresholds and cut-offs such as Cohen's d acknowledged to be arbitrary (Tagliaferri et al. 2024).

Thresholds were created to dichotomise a portion of the continuous data in order to make the data easier to interpret and maintain consistency. Continuous data is better suited for addressing specific research questions and is able to explore more complex relationships including non-linear relationships when there is a basic understanding of the functional form. In contrast, this study aimed to explore a novel concept making it difficult to anticipate functional forms of any relationship. With the assistance of a statistician and research team, thresholds were determined based on the distribution of the data and best judgement. A difference between the pre- and post-LUS median probabilities larger than 25% was chosen to demonstrate an influence of LUS on perceived probability, with the frequency and percent of occurrence calculated for each pathology. A shift of 25% was determined from looking across the distribution of median values for every patient and each pathology and choosing a point at which a shift larger than this point was considered substantial. The identification of the presence or absence of a pathology was placed into binary categories with a median probability less than 50% signifying the pathology is not likely present, and over 50% signifying the pathology is likely present. If the median probability crossed the 50% threshold from before to after LUS, this was seen as a change in binary categorisation, or re-categorisation, and a change in the perceive presence of the pathology. The frequency and percent of re-categorisation was calculated for each pathology, and a confusion matrix was constructed to present the data.

The study also aimed to measure the influence of LUS on uncertainty in pathology identification. Uncertainty was measured in two ways: the strength of the participant's perceived probability of the pathology following LUS and the change in uncertainty of their perceived probability from before to after LUS. Two sets of thresholds and qualitative labels were created to aid in the discussion of confidence in pathology identification. I determined the thresholds by exploring the distribution of the median probability values for each patient and pathology before and after LUS and considering the extreme ends of probability to denote confidence of the physiotherapist. A post-LUS median probability value of over 90% or below 10% was recorded as high confidence in the perceived presence of the pathology. A post-LUS median probability of over 80% or below 20% was recorded as confidence in the perceived presence of the pathology. The frequency and percent of the median probability shifting into these ranges following LUS were calculated to represent the change in confidence in identifying the probability of the pathologies due to LUS. The difference between the lower and upper quartile marked by the participants using the bisection method was the interquartile range (IQR). An IQR uncertainty ratio was calculated from before to after LUS (pre/post) for each pathology to show change in uncertainty due to LUS. Cases where there was no overlap in the IQRs from before to after LUS demonstrated a high influence of LUS on perceived probability and/or uncertainty.

The influence of LUS on management planning was also measured in several ways to address Research Objective #1. The frequency and percent of change in management was calculated from Question #5 of Questionnaire #3 asking the participants if their current management or treatment plan will change in any way. Details of why and how management changed were documented and the frequencies and percentages calculated. Participants documented if they felt they needed to deliberate with medical staff or if an invasive procedure may be needed both before and after LUS, and the frequency and percent of change were calculated for these.

Research Objective #3 looked to explore the current use of LUS in this department to improve understanding of how much time and resources LUS may require, which could assist decisions on future implementation. To address Research Objective #3, the mean length of time for a LUS scan and standard deviation were calculated. Since this study required every volunteer patient to be scanned, Question #20 on Questionnaire #1 asked the participants if they would have normally ordered LUS for the patient. Frequencies and percentages were calculated for the number of LUS scans that would have normally been ordered for these patients by day, week, and month.

Inferential Data Analysis

The data were cleaned and imported into SPSS (IBM SPSS Statistics 28) for further analysis. To address Research Objective #4, a series of univariate logistic regressions were conducted using the participant and volunteer patient demographics as well as volunteer patient surgery details to explore potential relationships to change in management, concordance of clinical impressions, and changes in probability, uncertainty, and re-categorisation for each pathology. Understanding the relationships between demographic and surgical details may help to inform clinical protocols by suggesting potential indications for LUS within the cardiac surgery population. Univariate logistic regression was used with binary outcomes with inferences based on odds ratios (OR), 95% confidence intervals and the associated p values. When using categorical predictors, a reference level is set, and the OR identifies whether the other levels of the predictor are more likely (OR > 1) or less likely (OR < 1) to be associated with the binary event. The odds ratio directly represents the odds, e.g., if the odds ratio measuring the odds of females earning a doctorate of physiotherapy compared to males (the reference category) was three ($OR_{male:female} = 3$), it would mean women have three times the odds of earning a doctorate of physiotherapy compared to men.

3.9 Qualitative Materials

This section will discuss the materials used for data collection during the qualitative phase.

3.9.1 Interview Topic Guide

I created the interview topic guide specifically for the study, with questions created to specifically address the research objectives discussed in Section 3.2 (Appendix 13). The topic guide was modified based on the preliminary results of the quantitative phase to further explore and expand upon quantitative findings as well as to improve within-design consistency; preliminary data from the quantitative phase that I felt required more explanation were gathered for each interview participant and presented during Section #3 of the interview topic guide for comment. The topic guide was piloted to improve design fidelity during mock interviews I conducted with two respiratory physiotherapists independently and the topic guide was adapted to ensure the guide was comprehensive, with additional questions added based on common topics discussed in both interviews originally not within the guide.

3.10 Qualitative Methods

The second phase consisted of semi-structured interviews with the participants from the first phase to explore the perceptions and experiences of those using LUS in their practice, as well as expand upon the quantitative findings.

3.10.1 Participants

Following the quantitative phase, all participants were invited to take part in an interview. The inclusion criteria remained the same as in the first phase. This thesis was the first, to the researcher's knowledge, to explore the use of LUS by physiotherapists in the cardiac surgery population. Therefore, it was deemed useful to captures as many perspectives and experiences as possible. Convenience sampling was conducted with the aim of including as many participating physiotherapists from the quantitative phase as were willing. This was estimated to be between five and ten participants. A total of seven participants were recruited.

3.10.2 Data Collection

Location

The interviews were held on Microsoft Teams®. Conducting interviews online can be beneficial for participants with busy schedules, such as these participants who were conducting interviews during their clinical time. Online interviews are also beneficial when the researcher has a budget or timetable that does not allow for extensive travel (Ritchie et al. 2013); this was the case for this project which was unfunded and had a distant research site. A disadvantage of online or telephone interviews is the chance to miss physical cues of body language or facial expressions which could indicate further probing. However, some researchers argue face-to-face is not necessarily superior to online interviews for building rapport (Ritchie et al. 2013). Being able to see the faces of those involved in the interview is thought to improve the rapport required for good conversation and interaction; for this reason, the interviews were conducted through a video call on Microsoft Teams® when possible, leaving telephone interviews as a last resort. The interviews were captured on an Olympus DS-9000 Digital Recorder, which is an encrypted and password-protected device.

Semi-structured Interviews

This phase consisted of conducting semi-structured interviews. Ritchie et al. (2013) argue key features of in-depth interviews include combining structure with flexibility, interaction, getting below the surface, generation, and maintaining the importance of language. Using semi-structured interviews as opposed to purely structured interviews allows for the flexibility to probe to get below the surface.

Interviews were planned to be between 30 and 60 minutes in length and were conducted by me in May 2023. At the start of each interview, it was discussed what was to be expected from the interview and the participant was ensured of confidentiality and anonymity. Any questions the participants had were answered prior to starting. The participant was also reminded the interview would be audio-recorded using an external device. The participants provided informed written consent to take part in the interview and have their audio recorded prior to quantitative phase, but another verbal consent to continue was obtained. The topic guide was followed, but probing was conducted, and further questioning was done as necessary to fully explore the topics.

3.10.3 Data Processing

Following each interview, the audio recording was uploaded into the Olympus Dictation Management System where the file was converted and exported to a secure server at the university. Amberscript (GDPR-compliant) was used for machine-made transcription, after which I reviewed the transcripts for accuracy and anonymisation.

Full verbatim (or denaturalised transcription) maintains every utterance, repetition, mistake, and grammatical error. Intelligent verbatim (or naturalised transcription) writes over oral discourse features, using “literacization” to tailor the spoken word to written (Bucholtz 2000; McMullin 2023). There are no set rules for applying transcription techniques and the decision should be based on the research question and approach (McMullin 2023). Therefore, intelligent verbatim was used as it improved readability by omitting when the participant misspoke or corrected themselves, allowing the transcript to be closer to what the participant intended (McMullin 2023).

3.10.4 Data Analysis

There are a number of qualitative analysis approaches described in the literature. Some forms of analysis have a focus on how language is used in social interaction (e.g., discourse analysis and ethnomethodology), others focus on the experience, meaning, and language (e.g., phenomenology and narrative methods), and others aim to develop theory from the data (e.g., grounded theory); many of these analysis methods have philosophical underpinnings which shape the analysis process (Gale et al. 2013). The use of language and theory development were not the aim of this doctoral work. Research Objective #2 aimed to explore the experiences of those engaging with LUS, therefore methods such as interpretive phenomenological analysis or narrative analysis were considered. However, this study did not aim to understand experience to the depth of the individual or to culminate the essence of the experiences, therefore these analysis methods were not used.

Thematic analysis has become a widely used form of qualitative analysis, with the approach described by Braun and Clark in 2006 for reflexive thematic analysis to be a popular method (Ritchie et al. 2013). Thematic analysis is a systematic and flexible method for identifying, organising, and gaining insight into patterns of meaning (Braun and Clark 2012). One of the reasons for thematic analysis being a popular method is because it is not tied any particular discipline or set of theoretical constructs. Due to the flexible nature and limited available literature compared to other qualitative methods (e.g., grounded theory, ethnography, and phenomenology), it is important to ensure trustworthiness is achieved (Nowell et al. 2017), such as with the criteria introduced by Lincoln and Guba (1985).

The Framework approach shares a similar analytic path to the one proposed by Braun and Clark. The approach was developed by NatCen Social Research in 1994, drawing on aspects of the scientific method and adapted to the nature of qualitative research with the aim of conducting research that is well-designed, well-conducted, and generates well-founded and trustworthy evidence (Ritchie et al. 2013). Framework is widely used and popular amongst healthcare fields. Ritchie et al. (2013) explain the Framework approach is not a type of analysis in the known sense, but a data management instrument which does not align with any one recognised 'school' of research, drawing on many traditions within qualitative research, which fits well into the pragmatism paradigm. Broadly, the Framework approach appeals to realism, interpretivism, pragmatism, reflexivity, and rigour. Ritchie et al. (2013) describe rigorous cross-sectional qualitative analysis using the stages presented in Figure 3.6. The Framework approach builds on the thematic analysis approach described by Braun and Clarke with an additional step; the stage of data summary and display is a key feature unique to Framework which stands this method apart from thematic analysis (Gale et al. 2013; Ritchie et al. 2013). This additional step would aid the researcher in remaining close to the original data and improving trustworthiness; therefore, the Framework approach described by Ritchie et al. (2013) was adopted for qualitative data analysis.

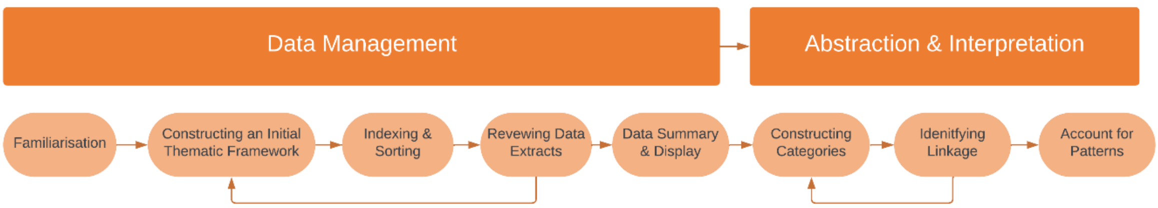


Figure 3.6 Cross-sectional Qualitative Analysis. *Adapted from Ritchie et al. (2014).*

Microsoft Word® (Word) was used for familiarisation and building the initial framework. The interview transcripts were then uploaded into NVivo 13 (QSR International Pty Ltd 2020), a computer-assisted qualitative data analysis software (CAQDAS), to assist with indexing, sorting, data summary and display. Using CAQDAS allows for quickly handling large amounts of data and has been said to improve rigour and consistency in approach. CAQDAS does not perform analysis; the software is simply a tool for data management (Ritchie et al. 2013). Framework matrices were exported from NVivo into Excel where the final stages of framework occurred.

Data Management

Framework begins with data management. Familiarisation consisted of immersing with the data beginning with conducting the interviews and reading the transcripts multiple times during the transcription stage. The aim of familiarisation is to become thoroughly familiar with the data (Ritchie et al. 2013). Immersing with the data is a key feature of familiarisation and ensures interpretive consistency to improve rigour. During familiarisation, two transcripts were chosen to develop an initial thematic framework: one from a participant who was accredited in LUS and one who was not. Two members of the research team (CF, CW) read through the transcripts on Word, making analytical notes. I collated the notes and used these to create an initial coding index (Appendix 14). The coding index was grouped and sorted to different levels of generality; these levels should ideally remain descriptive to stay grounded in the data which allows the researcher to 'hold' the overall structure of themes in their head as they continue analysis (Ritchie et al. 2013). The initial coding index was reviewed and revised between two members of the research team (CF, KC). The same two researchers then independently applied the initial coding index to one transcript to compare and found similar indexing density.

The next stage was indexing and sorting, where I applied the initial coding index to all transcripts in NVivo independently. Indexing and sorting allows for the researcher to intensely review the content of each theme in turn so details and distinctions may be investigated (Ritchie et al. 2013). I reviewed data extracts to allow for further refinement of the coding index, with amended and added topics and sub-topics to ensure the interviews were captured within the index thoroughly. The last step in data management, and the hallmark of Framework, was data summary and display. I created framework matrices for each main topic with a column for every sub-topic, an example of which can be seen in Appendix 15. Data summaries were then created, sub-topic by sub-topic, from the sorted data extracts for each participant across the whole dataset. Another member of the research team (KC) reviewed the matrices at this stage to improve credibility and interpretive agreement.

Framework matrices reduces the amount of data to a manageable level; creating data summaries immerses the researcher in the data more than cutting and pasting chunks of data extracts into the matrix would allow for (Ritchie et al. 2013). The framework matrices were exported from NVivo into Excel for abstraction and interpretation.

Abstraction & Interpretation

Following data management, Framework continues to abstraction and interpretation. The next stage in framework and the first stage in abstraction and interpretation is using description to construct categories. There are two key features of qualitative data that are critical for description: using the actual words used by those interviewed and using the substantive content of people' experiences to form the centre of evidence in analysis (Ritchie et al. 2013). Constructing categories begins with detecting elements and dimensions. I began by reading through all cases by sub-topic, noting the range of perceptions and experiences, and listing preliminary elements found in the responses, staying fairly descriptive to remain close to the data. These elements were collated into dimensions to differentiate between the variety of elements, grouping responses considered to be 'about the same thing.' I then compiled dimensions into categories, highlighting different types of responses. These categories were then organised into higher order classes which began to introduce more theoretical concepts, as is expected at this level (Ritchie et al. 2013). Finally, the classes were organised into overarching themes.

3.11 Data Integration

Bryman (2006) provided 16 motivations for integrating data; within the context of this study, my motivation for integrating data was to use one data set to explain the other, to improve credibility, and to use qualitative data to provide context for quantitative data. Data integration can occur at the level of design, methods, and/or the interpretation and reporting (Fetters, Curry and Creswell 2013; Skamagki et al. 2022). In this study, data integration occurred at all three levels.

At the design level, as previously discussed in Section 3.4.2, a fully integrated convergent design involves an interactive approach (Fetters, Curry and Creswell 2013) where iteratively the quantitative data collection process and preliminary data analysis drove change in the qualitative data collection procedures.

At the methods level, Fetters and colleagues (2013) describe four ways of integrating data: connecting by linking one database to the other through sampling; building by using one database to inform the data collection of the other; merging by bringing together the two databases for analysis; and embedding by linking data collection and analysis at multiple points. The databases in this study were connected by recruiting those involved in the quantitative phase. This study also used the qualitative data collection to build upon the preliminary findings from the quantitative phase, as well as merged the two databases at analysis. This study would have benefited from embedding. Embedding would have involved collecting qualitative data to gain a better understanding of contextual factors or biases which may have altered the quantitative methods. However, as this was an unfunded doctoral thesis, embedding was out of scope for this study.

Fetters and colleagues (2013) described three approaches to integrating data at interpretation and reporting level: integrating through narrative, integrating through data transformation, and integrating through joint displays. Integrating through narrative can involve writing both qualitative and quantitative findings together on a theme-by-theme or concept-by-concept bases narratively (the weaving approach), reporting the different data sets separately (the contiguous approach), or reporting results by stages or steps (the staged approach). Integration through data transformation requires one data set to be converted into the other type of data and then integrated. The third approach, integrating through joint displays, involves bringing data together visually using a figure, table, matrix, and/or graph to present the different datasets side by side (Fetters, Curry and Creswell 2013). I integrated the data through a joint display using a statistics-by-themes model. The statistics-by-themes model is the most common joint display used within mixed methods health science research (Guetterman, Fetters and Creswell 2015).

Once I had the quantitative and qualitative results side-by-side, inferences were made from both datasets separately. Inferences are conclusions and interpretations made from the collected data (Teddlie and Tashakkori 2009). Once I compared the quantitative inferences to the qualitative inferences, conclusions were drawn from the integration of the inferences forming meta-inferences (Teddlie and Tashakkori 2009). The meta-inferences were compared with the quantitative and qualitative inferences it comprised, determining if the qualitative inference confirmed, expanded, or was discordant with the quantitative inference to ensure the meta-inferences reflected this relationship and the inferences were integrated effectively. The meta-inferences were then considered in line with the research aim and objectives to ensure there was correspondence and the study fulfilled its original purpose. The meta-inferences were reviewed and agreed upon by a member of the supervisory team (KC) to improve interpretive agreement. The meta-inferences were compared to the current literature base to determine if the study findings confirmed, expanded, or were discordant with the literature, considering theoretical consistency within the wider literature. The inferences and meta-inferences were added to the statistics-by-theme joint display.

3.12 Quality & Rigour

Several steps were taken to ensure the study was high quality and rigorous. Traditionally, high quality and rigour in quantitative research is accomplished by ensuring reliability and validity. Reliability is the reproducibility and consistency of the research, while validity is assessing whether the research accomplished what it aimed to accomplish (Bowling 2014). The concepts of reliability and validity have been modified to assess quality and rigour in qualitative research. However, Dellinger and Leech (2007) identified as many as 17 terms for validity described within qualitative research. The most widely used concept for qualitative rigour is trustworthiness (Eckhardt and DeVon 2017); Lincoln and Guba (1985) introduced trustworthiness to enhance the quality and rigour of qualitative research, describing trustworthiness to be determined based on the credibility, transferability, dependability, and confirmability of the research.

The challenge for mixed methods researchers is the ability to appeal to the many facets of quality and rigour across both methodologies; it involves addressing the quantitative standards of reliability and validity, the qualitative standards of trustworthiness, and the credibility of inferences made using both data sets (Teddlie and Tashakkori 2009). Lincoln and Guba (1985) stated that their four elements of the naturalist's (Constructivist's) trustworthiness were equivalent to the conventionalist's (Positivist's) concepts of internal validity, external validity, reliability, and objectivity suggesting that researchers assessing the quality and rigour of research conducted within either paradigm could be attempting to assess the same concept. However, since the two paradigms make different knowledge claims, they require different terminology and criteria (Lincoln and Guba 1985). Several researchers, therefore, have created frameworks for assessing the quality and rigour of mixed methods research with terminology and criteria specific to mixed methods, considering the standards of both methodologies while also suggesting standards for interpreting inferences drawn from both data sets (Onwuegbuzie and Johnson 2006; Dellinger and Leech 2007; Teddlie and Tashakkori 2009; Eckhardt and DeVon 2017).

An integrative framework for inference quality developed by Teddlie and Tashakkori (2009) was used which encompasses two broad families of design quality and interpretative rigour, addressing the standards of both quantitative and qualitative research while also addressing the quality of the inferences made from both datasets (Table 3.2).

Design quality is concerned with how the design of the research addressed the overall research questions and is made up of four components: design suitability, design fidelity, within-design consistency, and analytic adequacy (Teddlie and Tashakkori 2009). To enhance design quality, it was ensured the design was suitable to address the research question by closely considering the research philosophy and worldview. The research materials were piloted thoroughly and all those involved in the research received appropriate training for their involvement, improving design fidelity. The quantitative preliminary results influenced the qualitative data collection through an amendment of the interview topic guide and the usage of the preliminary data as a reflection point within the interviews; this is in line with the fully integrated convergent mixed methods study design and demonstrates within-design consistency and reliability. Analytic adequacy, reliability, and validity were also demonstrated by the follow through of the qualitative analytic strategies chosen prior to the initiation of the study as well as consistent consulting with a chartered statistician for the quantitative analysis. Transparency in the study's design process, procedures, analysis and interpretation provide an audit trail, or a record of how the research was conducted and conclusion arrived at by the researchers (Carcary 2020), to improve confirmability.

Several steps were taken to achieve a high interpretive rigour, which concerns the degree to which the interpretation of the research is credible based on the results and consists of six components: interpretive consistency, theoretical consistency, interpretive agreement, interpretive distinctiveness, integrative efficacy, and interpretive correspondence (Teddlie and Tashakkori 2009). The use of the Framework approach enhanced interpretive consistency by the nature of the immersion process to keep the researcher close to the raw data. The study findings were compared to the current literature to interpret theoretical consistency, which also improved transferability and validity. The interpretation of both data sets was agreed upon by the supervisory team and peer debriefing was conducted for the qualitative, demonstrating the interpretive agreement and dependability of the research. Interpretative distinctiveness was sought through the mitigation of confounding variables in the quantitative phase and ensuring a clear audit trail with peer debriefing for the qualitative phase. Table 5.1 in Chapter 5 displaying the study's meta-inferences show clear relationships between datasets and integrative efficacy. Interpretive correspondence and validity are demonstrated within Sections 5.2-5.4 presenting how the meta-inferences address all research aims and objectives. Table 3.2 shows the full framework with comments on how these elements were addressed in the design of the study and analysis of the data.

Table 3.2 Integrative Framework for Inference Quality. *Based on the framework from Teddlie and Tashakkori (2009) with comments on how these elements were addressed.*

Aspects of Quality	**Research Criterion**	**Comments**
Design Quality	1. Design suitability (appropriateness)	• A fully integrated convergent mixed methods design was chosen in line with the pragmatic worldview.
	2. Design fidelity (adequacy)	• All research materials went through multiple rounds of piloting prior to implementation. • All research participants received pre-study training. • We attempted to use one LUS Scanner for consistency, with the other two Scanners having the same training as the main Scanner.
	3. Within-design consistency	• The interview topic guide was amended following initial analysis of quantitative data. • The preliminary results of the quantitative data were used for comment in the interviews to link both phases.
	4. Analytic adequacy	• Qualitative analytic strategies were chosen prior to the study being conducted and followed through. • Quantitative analysis was advised by a chartered statistician.
Interpretive Rigour	5. Interpretive consistency	• A key feature of the Framework approach is the immersion of the researcher in the data with the participant's perceptions and own words as the core of the qualitative results.
	6. Theoretical consistency	• There is slight variation in the findings from the quantitative phase compared to other similar studies; the populations, however, differ and may explain the slight variation. The overall trends were relatively consistent in that LUS does appear to influence pathology identification and management planning. • The result from the qualitative phase is consistent with other empirical findings in the literature.
	7. Interpretive agreement	• For both phases of this mixed methods study, interpretation was reviewed and agreed upon by the supervisory team. • Peer debriefing was conducted for the qualitative phase with a member of the supervisory team.
	8. Interpretive distinctiveness	• In the design of the quantitative phase, variables were limited to mitigate confounding variables. • In the qualitative phase, a clear audit trail was created, and peer debriefing was conducted.
	9. Integrative efficacy	• Meta-inferences were drawn from the comparison of the quantitative and qualitative phases, showing clear agreement between datasets in the joint display in Chapter 5.
	10. Interpretive correspondence	• Within the discussion, there is a presentation of how the meta-inferences addresses all research aims and objectives.

3.13 Ethical Considerations

3.13.1 Patient Volunteers

Although the physiotherapists were the focus and the main participants of the study, patient volunteers were involved and were therefore also ethically considered. No harm was anticipated for the patient volunteers as LUS is a non-invasive, radiation-free, and safe diagnostic tool. Patient information was required for analysing the impact of LUS in relation to certain patient demographic and surgery details, but no identifying information was required or requested. Patients can face emotional or information overwhelm after surgery that can impact their ability to make decisions or follow explanations to allow for informed consent (Bester, Cole and Kodish 2016), therefore consent from volunteer patients was required prior to surgery.

3.13.2 Informed Consent and Potential Harm

Potential participants and volunteer patients of the study received an information sheet which described the research, what participation entailed, and any potential risks or benefits. Lung ultrasound is a low-risk diagnostic tool. Nonetheless, the patient volunteer's incision site from surgery may be sensitive to movement and therefore may result in some discomfort if the patient needed to be repositioned for the LUS scan. The research focused on the assessment of the patient and I had no influence over treatment. There was no negative impact to the patient volunteer's treatment and care if they wished not to participate. There was no direct benefit for either the physiotherapist participants or patient volunteers; this was made clear on the information sheet provided to both groups. The LUS results may change the treatment for the patient if something unexpected was revealed through the images, however, as LUS is a highly reliable diagnostic tool, it should only improve accuracy of diagnosis and therefore positively impact the management plan. Anything found via LUS would be escalated appropriately and treated by the MDT. This added diagnostic ability had the potential to be an indirect benefit to the patient volunteer's care.

3.13.3 Confidentiality and Data Protection

Confidentiality and anonymity were applied to both the participants and patient volunteers. Each participant was given a unique identifier and each volunteer patient was given a patient identification number (PIN). These identifiers were used for all data collection and analysis. Any personal or identifiable information in the study was stored in password-protected files on a secure network folder at the university. Any paper data will be stored in a locked cabinet on university premises.

3.14 Ethical Approval

All previously discussed ethical considerations and measures taken were outlined in an application for ethical approval. Ethical approval was first sought from the RGU School of Health Sciences Ethics Committee, with approval provided on 9th August 2022 (Reference number SHS/22/05). The study was then reviewed by the South East Scotland Research Ethics Committee and approved on 10th November 2022 (REC reference: 22/SS/0089; IRAS 316369). Permission to conduct the study locally was granted by Blackpool Teaching Hospitals Research and Development (R&D) on 21st October 2022. Ethical approval letters can be found in Appendix 16-17.

3.15 Summary of Methods

This chapter has discussed the research philosophy, methodology, and study design of this primary research. A pragmatic approach was adopted, taking both a subjective and objective epistemological view with the aim of acquiring practical, transactional knowledge as a means to improve clinical practice. A mixed methods methodology was used to conduct the primary research with a fully integrated convergent design. The mixed methods study began with a quantitative phase which aimed to empirically assess the influence of LUS on pathology identification, confidence, and management planning of cardiothoracic physiotherapists in one UK hospital assessing day one non-emergency cardiac surgery patients. Recruitment of the research participants occurred online with me directly, while recruitment of the volunteer patients required a local research team. The research involved LUS Scanners as part of the research team to assist in data collection.

Data was collected by paper-based questionnaires. The preliminary quantitative data was used to inform the qualitative phase, with individual data from the quantitative phase used during semi-structured interviews of a sub-set of the participants from the quantitative phase for comment. The aim of the interview was to explore the experiences and perceptions of those engaging with LUS. The quantitative data were analysed using descriptive and inferential statistics within Excel and SPSS. The qualitative data were analysed using the Framework approach within Word and NVivo. The data from both phases were analysed separately with integration occurring at the interpretation and reporting level using a statistics-by-themes joint display and the creation of meta-inferences. The chapter following will present the study findings from first the quantitative phase, followed by the qualitative phase, with both phases initially reported separately as they were analysed.

4. RESULTS

4.1 Introduction

The previous chapter discussed the methodology, materials, and methods of the fully integrated convergent mixed methods study. This chapter will present the results from both the quantitative and qualitative phases. The chapter begins by reviewing the demographics of the physiotherapists and volunteer patients from the quantitative phase, followed by descriptive statistics, and regression analyses of patient and physiotherapist demographics, surgery details, and the physiotherapists' experience against several outcomes. The chapter continues by presenting how the quantitative phase interacted with and influenced the qualitative phase. The chapter continues by presenting the results from the qualitative phase. The following chapter presented the integration of the results from both phases with meta-inferences and continues into the discussion.

4.2 Demographics – Quantitative Phase

4.2.1 Physiotherapist demographics

A total of ten cardiothoracic physiotherapists took part in the study. There was a range of experience among the physiotherapists. Four physiotherapists (40%) were Band 5's with no experience with LUS, but were interested in learning, while six physiotherapists were Band 6's either in the process of becoming accredited (n=3; 30%) or already accredited in LUS (n=3; 30%). Six of the physiotherapists were female (60%) and most physiotherapists were between 25 and 34 years old (Table 4.1). Due to some of the physiotherapists rotating in and out of the department, there was some variation in the number of assessments completed with a mean number of assessments of 7.7 (±5.2).

Table 4.1 Physiotherapist demographics and characteristics. *(n=10)*

Participant Demographics	n(%)/mean±SD
Age Range	
18-24	2 (20%)
25-34	7 (70%)
34-44	1 (10%)
Sex	
Male	4 (40%)
Female	6 (60%)
Qualification	
BSc Physiotherapy	1 (10%)
BSc (honours) Physiotherapy	8 (80%)
MSc Physiotherapy (pre-registration)	1 (10%)
Years Qualified	4.07±3.04
Job Post	
Rotational Band 5	4 (40%)
Rotational Band 6	1 (10%)
Respiratory Rotational Band 6	2 (20%)
Static Band 6	3 (30%)
Contract	
Part-time	3 (30%)
Full-time	7 (70%)
Experience with Cardiac Patients (years)	1.3±1.5
Experience with LUS	
None, but interested	4 (40%)
In the process of accreditation	3 (30%)
Accredited	3 (30%)
If Accredited, Years of Experience with LUS (n=3)	1.5±1.4

4.2.2 Volunteer patient demographics

A total of 77 patients volunteered to take part in the study (Table 4.2). The mean age of the volunteer patients was 68 (±8.9 years) and the majority were male (n=57; 74%). The most common surgery performed was a triple coronary artery bypass graft (CABG) (n=23; 29.9%) and the majority were non-eventful (n=68; 88.3%). The number of volunteer patients that came from the elective and in-patient pathways were similar.

Table 4.2 Volunteer patient demographics & surgery details. *(n=77)*

Volunteer Patient Demographics	**n(%)/mean±SD**
Age (years)	68.2±8.9
Sex	
Male	57 (74%)
Female	20 (26%)
BMI (kg/m2)	28.2±4.6
Relevant Past Medical History	
None	29 (37.7%)
History of Smoking	24 (31.2%)
Asthma	3 (3.9%)
COPD	1 (1.3%)
History of Smoking, Asthma	3 (3.9%)
History of Smoking, CHF	1 (1.3%)
History of Smoking, COPD	4 (5.2%)
History of Smoking, Pulmonary Hypertension	5 (6.5%)
History of Smoking, COPD, Asthma	1 (1.3%)

Volunteer Patient Surgery Details	
Surgery	
CABG x1	12 (15.6%)
CABG x2	18 (23.4%)
CABG x3	23 (29.9%)
CABG x4	6 (7.8%)
AVR	8 (10.4%)
MVR	3 (3.9%)
CABG x1 + AVR	2 (2.6%)
CABG x2 + AVR	2 (2.6%)
CABG x3 + AVR	2 (2.6%)
TVR + MVR	1 (1.3%)
Incision Type *(n=76)*	
Sternotomy	70 (92.1%)
ART/MIS	6 (7.9%)
Surgical Pathway	
Elective Pathway	37 (48.1%)
Inpatient Pathway	40 (51.9%)
Eventful Surgery	
Non-eventful	68 (88.3%)
Eventful	9 (11.7%)
Prolonged anaesthesia	2 (22.2%)
Deterioration during surgery	1 (11.1%)
Significant blood loss	2 (22.2%)
Cardiopulmonary pathology prior to surgery	2 (22.2%)
Increased clotting	1 (11.1%)
VF in theatre, shock	1 (11.1%)
Dissected innominate vein, PPM wires cut	1 (11.1%)

4.3 Standard Physiotherapy Assessment

The physiotherapists recorded what comprises their standard initial assessment (standard physiotherapy assessment) of day one cardiac surgery patients in the demographic questionnaire completed prior to the start of the study. The following list is the combination of responses from the physiotherapists.

Subjective Assessment

- Previous medical/nursing notes
- Type of surgery
- History of present condition
- Present condition
- Past medical history
- Social history
- Coughing quality
- Secretion load and ability to self-manage
- Mobility

Objective Assessment

- Patient position
- Breathing/ventilation
- CXR
- Physiological Indicators:
    - Arterial blood gases
    - Oxygen saturation
    - Respiratory rate
    - Blood pressure
    - Heart rate
    - Heart rhythm

    - Fluid balance
    - Infusions
    - Mean arterial pressure
    - Temperature
    - Glasgow Coma Scale
    - Richmond Agitation-Sedation Scale
- Attachments
    - Drain output
- Auscultation
- Palpation

4.4 Physiotherapy Management

The physiotherapists recorded their management plan for the patient prior to engaging with LUS. The following list includes all treatments considered across all cases:

- Positioning
- Supported cough
- Spirometry
- Mobilisation
    - Sit to stand
    - March on the spot
    - Transfer to chair
    - Walk
- Intermittent positive pressure breathing
- Deep breathing exercises
- Active cycle of breathing
- Closed suction

Following LUS, the only treatment either removed or added to the management plan was intermittent positive pressure breathing.

4.5 Descriptive Statistics

4.5.1 Lung Ultrasound Use

The mean length of a LUS scan was five minutes and fifty-four seconds (5:54±1:27). The mean median probability value of the LUS Scanners was 81.9% with an IQR of 0.17, showing confidence among the LUS Scanners in their clinical impressions. Lung ultrasound would normally have been ordered for 14% (n=11) of the 77 volunteer patients. On average, two volunteer patients were assessed a day, seven patients in a week, and 25 patients a month. On average, a LUS would have normally been done on 12% of patients a day, 16% of patients in a week, and 12% of patients in a month. See Figure 4.1.

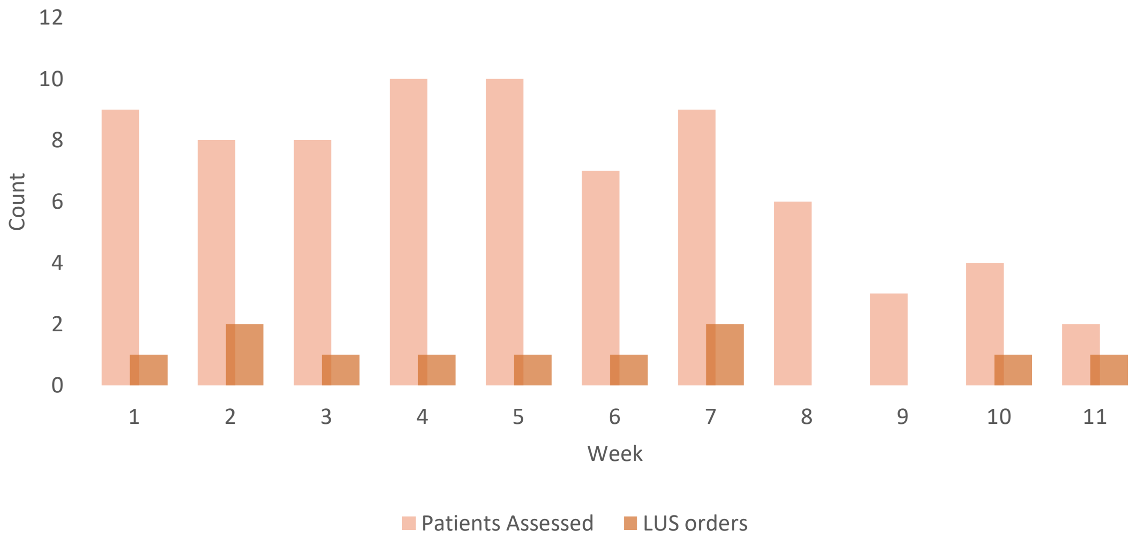


Figure 4.1 Number of lung ultrasound orders across study duration. *LUS: lung ultrasound.*

4.5.2 Pathology Identification

Concordance in Clinical Impressions

Following their initial assessment of the patient, the physiotherapists recorded their clinical impression. A clinical impression is a working informed opinion of the patient's condition based on the physiotherapist's assessment. The LUS Scanner also provided a clinical impression after performing LUS on the same patient. The physiotherapist then indicated on Questionnaire #3 whether they felt their clinical impression matched that of the LUS Scanner. In 43% of cases, the physiotherapist's patient impressions were discordant with that of the LUS Scanner (n=33).

Change in Pathology Probability

The difference of the perceived median probabilities from before to after LUS was calculated for each pathology (post-pre). A positive difference was interpreted as a perceived increase in probability, and a negative difference as a perceived decrease in probability. The mean was calculated for both increases and decreases in perceived probability for each pathology. When the perceived probability increased following LUS, it increased by a mean of 13.9% for atelectasis, 30.2% for pleural fluid, and 10.2% for pneumothorax; when the perceived probability decreased following LUS, it decreased by a mean of 22.8% for atelectasis, 19.4% for pleural fluid, and 12% for pneumothorax (Figure 4.2).

For 51 patients (66.2%), the median probability of one or more pathologies shifted by more than 25%: Sixteen cases for atelectasis (20.8%), predominantly towards increasing probability (n=10; 62.5%); thirty cases for pleural fluid (39%), nearly equally towards increasing (n=16; 53.3%) or decreasing probability (n=14; 46.7%); thirteen cases for pneumothorax (16.9%), predominantly towards decreasing probability (n=8; 61.5%).

The median probability value recorded by the physiotherapist before and after LUS was used to identify whether they believed the pathology was likely present (median > 50%) or not (median ≤ 50%), placing the results into binary categories. A confusion matrix of the pre- and post-LUS categorisations across all physios and patients can be seen in Table 4.3.

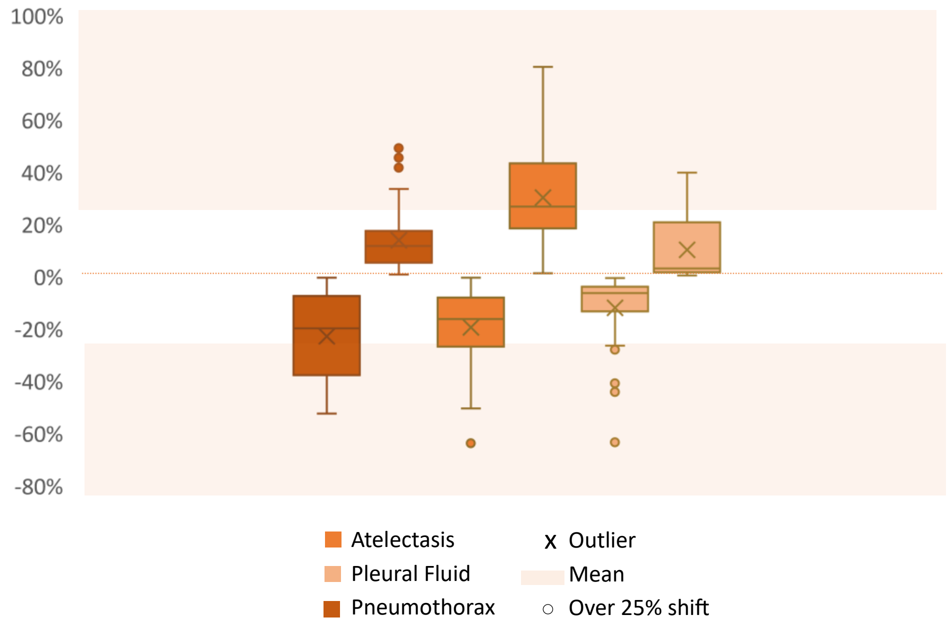


Figure 4.2 Box plots of the shift in the median probability value from pre- to post-LUS for atelectasis, pleural fluid, and pneumothorax separated into increases and decreases of probability.

Table 4.3 Confusion matrix for pre- and post-LUS by pathology.

Atelectasis		Pre-LUS	
		Not Likely	*Likely*
Post-LUS	*Not Likely*	4	5
	Likely	11	57

Pleural Fluid		Pre-LUS	
		Not Likely	*Likely*
Post-LUS	*Not Likely*	43	9
	Likely	16	9

Pneumothorax		Pre-LUS	
		Not Likely	*Likely*
Post-LUS	*Not Likely*	69	5
	Likely	3	0

Following LUS, if the median value changed binary categorisation, this was recorded as a change in the perceived presence of the pathology. For 42 patients (54.5%), the physiotherapist's perceived presence of one or more pathology changed categorisation following LUS. The perceived presence of atelectasis changed binary categorisation for 16 patients following LUS (20.8%) changing to be likely for 11 patients (14.3%) and not likely for five patients (6.5%). The perceived presence of pleural fluid changed binary categorisation for 25 patients following LUS (33.8%) changing to be likely for 16 patients (20.8%) and not likely for nine patients (11.7%). The perceived presence of pneumothorax changed binary categorisation for eight patients following LUS (10.4%) changing to be likely for three patients (3.9%) and not likely for five patients (6.5%). The physiotherapists were most accurate in their original pathology identification for pneumothorax (90%), followed by atelectasis (79%) and finally, pleural fluid (68%).

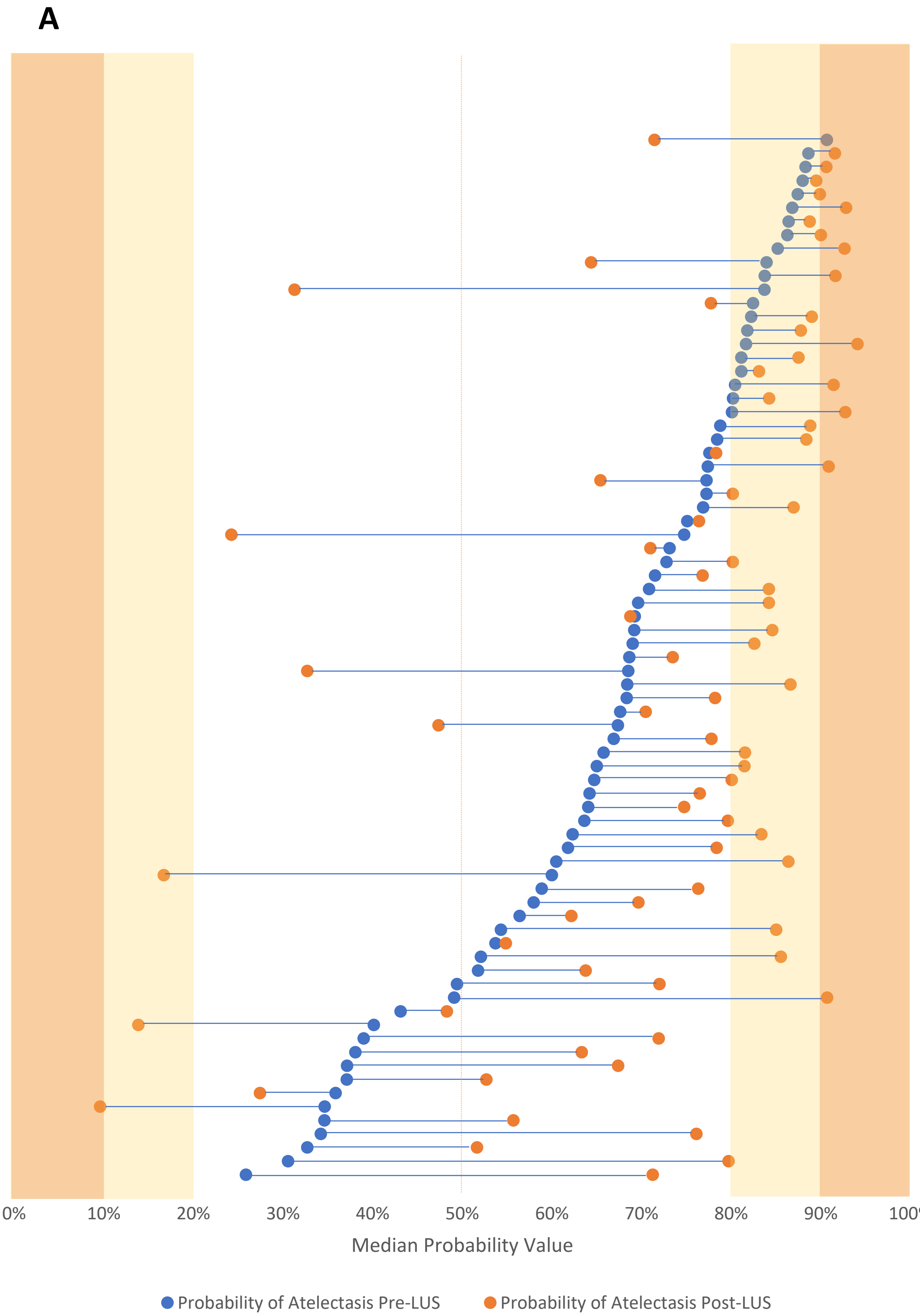
A median probability value over 90% or below 10% was recorded as high confidence of pathology presence post-LUS. A median probability value over 80% or below 20% was recorded as confidence in pathology presence post-LUS.

Prior to LUS, physiotherapists were confident in the presence of atelectasis in 21 cases (27%) and highly confident in one of those cases (1%). Following LUS, physiotherapists were confident in the presence of atelectasis in 39 cases (51%) and highly confident in 12 of those cases (16%). Overall, LUS resulted in the physiotherapists demonstrating confidence in the presence of atelectasis in 18 more cases and high confidence in 11 of those cases (Figure 4.3A).

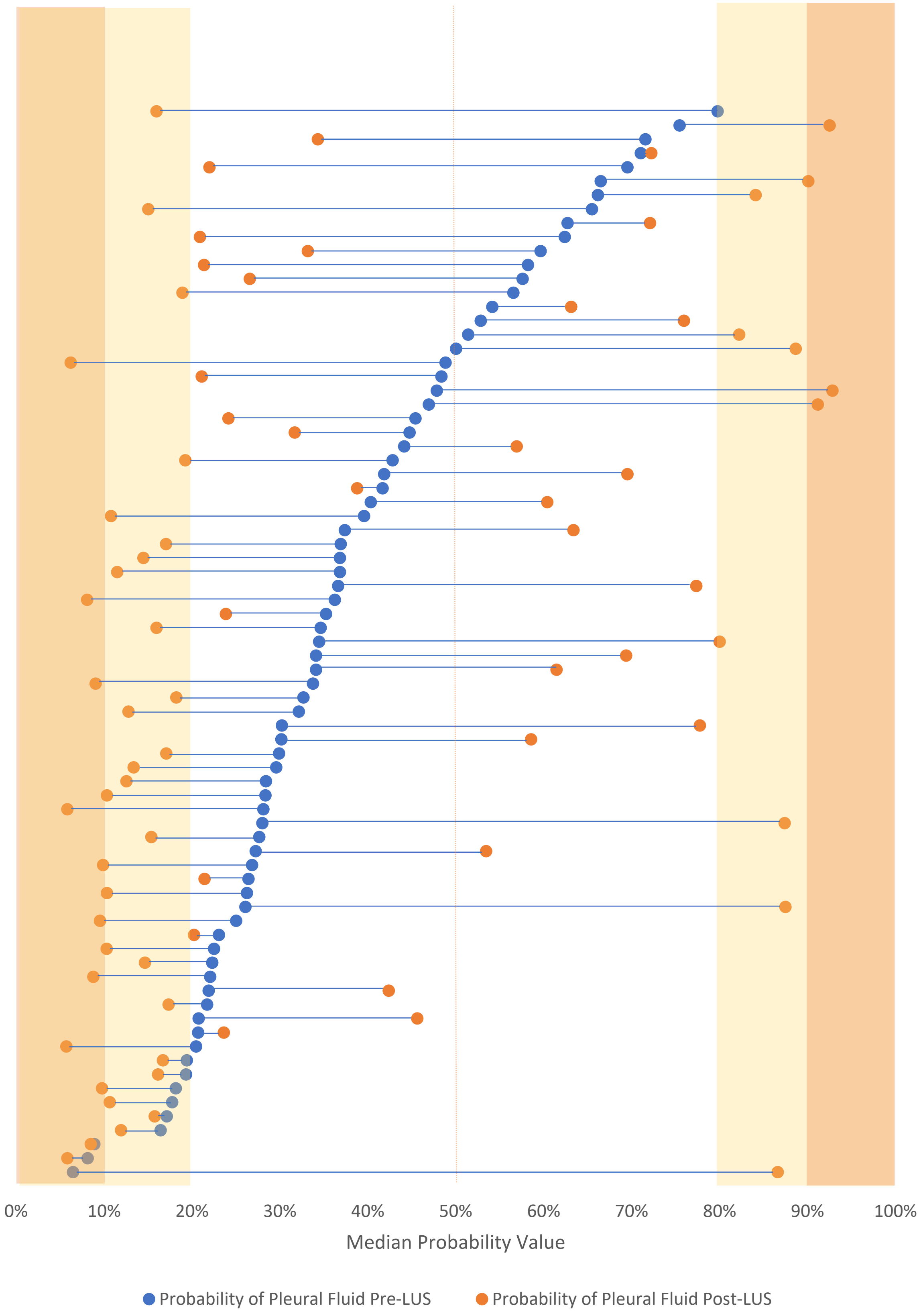
Prior to LUS, physiotherapists were confident in the presence of pleural fluid in nine cases (12%) and highly confident in three of those cases (14%). Following LUS, physiotherapists were confident in the presence of pleural fluid in 47 cases (61%) and highly confident in 15 of those cases (19%). Overall, LUS resulted in the physiotherapists demonstrating confidence in the presence of pleural fluid in 38 more cases and high confidence in 12 of those cases (Figure 4.3B).

Prior to LUS, physiotherapists were confident in the presence of pneumothorax in 42 cases (55%) and highly confident in three of those cases (4%). Following LUS, physiotherapists were confident in the presence of pneumothorax in 59 cases (77%) and highly confident in 29 of those cases (38%). Overall, LUS resulted in the physiotherapists demonstrating confidence in the presence of pneumothorax in 17 more cases and high confidence in 26 of those cases (Figure 4.3C).

Figure 4.3: Confidence of Physiotherapists Pre- and Post-LUS by Median Probability Value. *(A) Atelectasis. (B) Pleural Fluid. (C) Pneumothorax. Yellow range = confidence; Orange range: high confidence.*



B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80%
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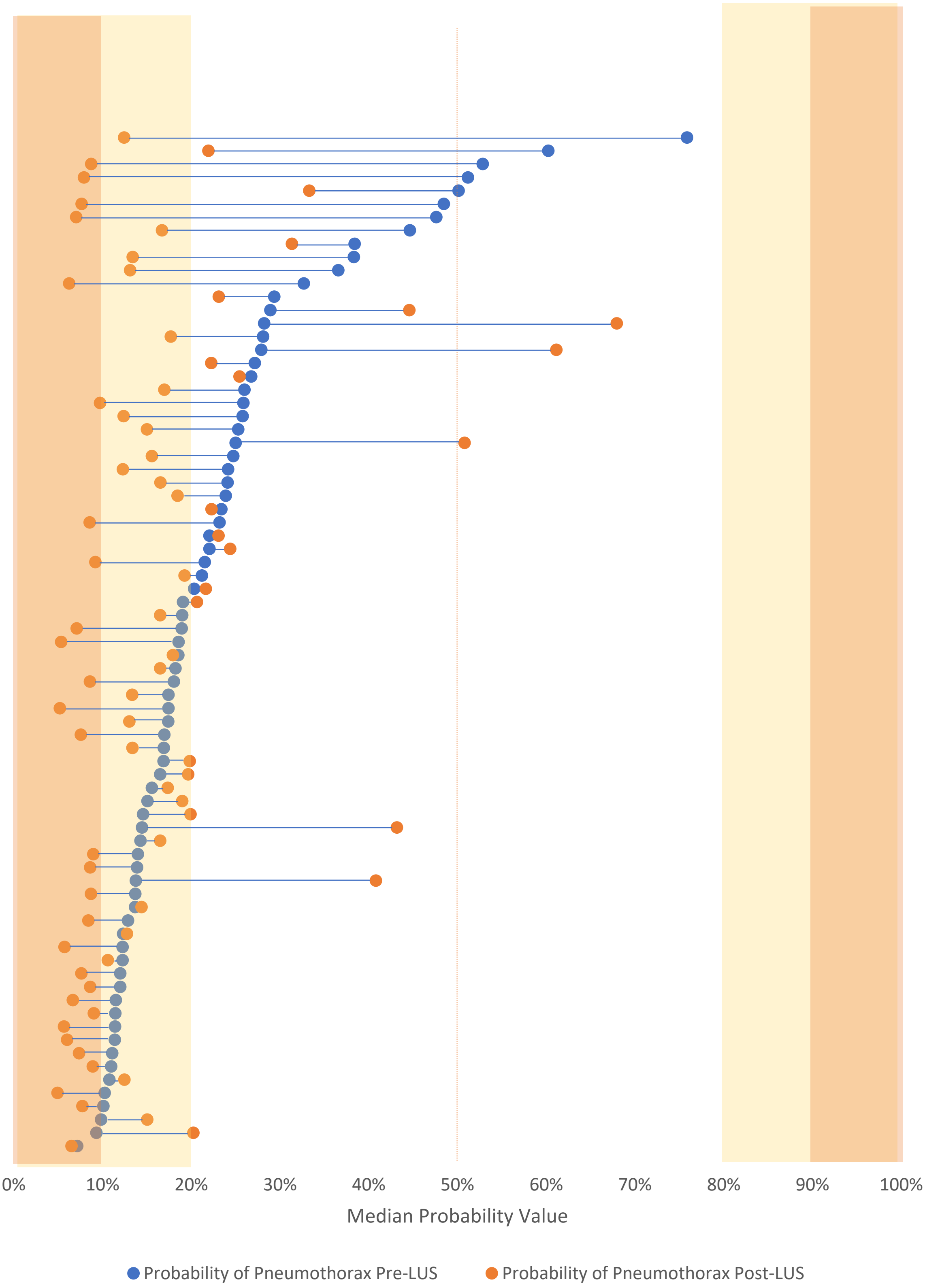
Median Probability Value
Probability of Pleural Fluid Pre-LUS
Probability of Pleural Fluid Post-LUS

C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Median Probability Value
Probability of Pneumothorax Pre-LUS
Probability of Pneumothorax Post-LUS

Change in Uncertainty

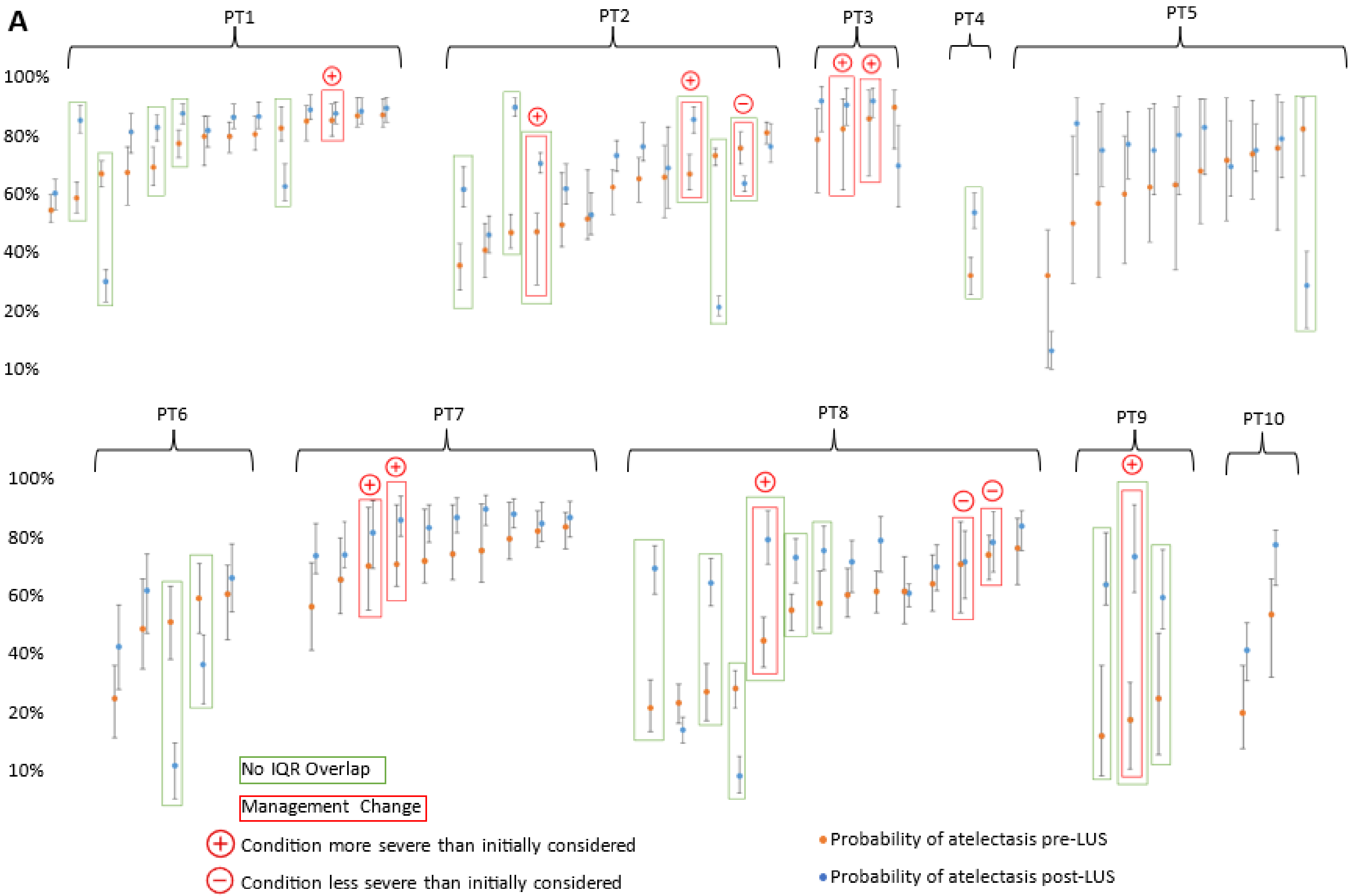
The ratio of uncertainty intervals, or IQR ratio (pre/post), were calculated for atelectasis (1.5), pleural fluid (1.8) and pneumothorax (1.5), showing a clear reduction in uncertainty in pathology identification. This can be seen as the decreased error bar length post-LUS shown for a majority of cases for each physiotherapist (Figure 4.4).

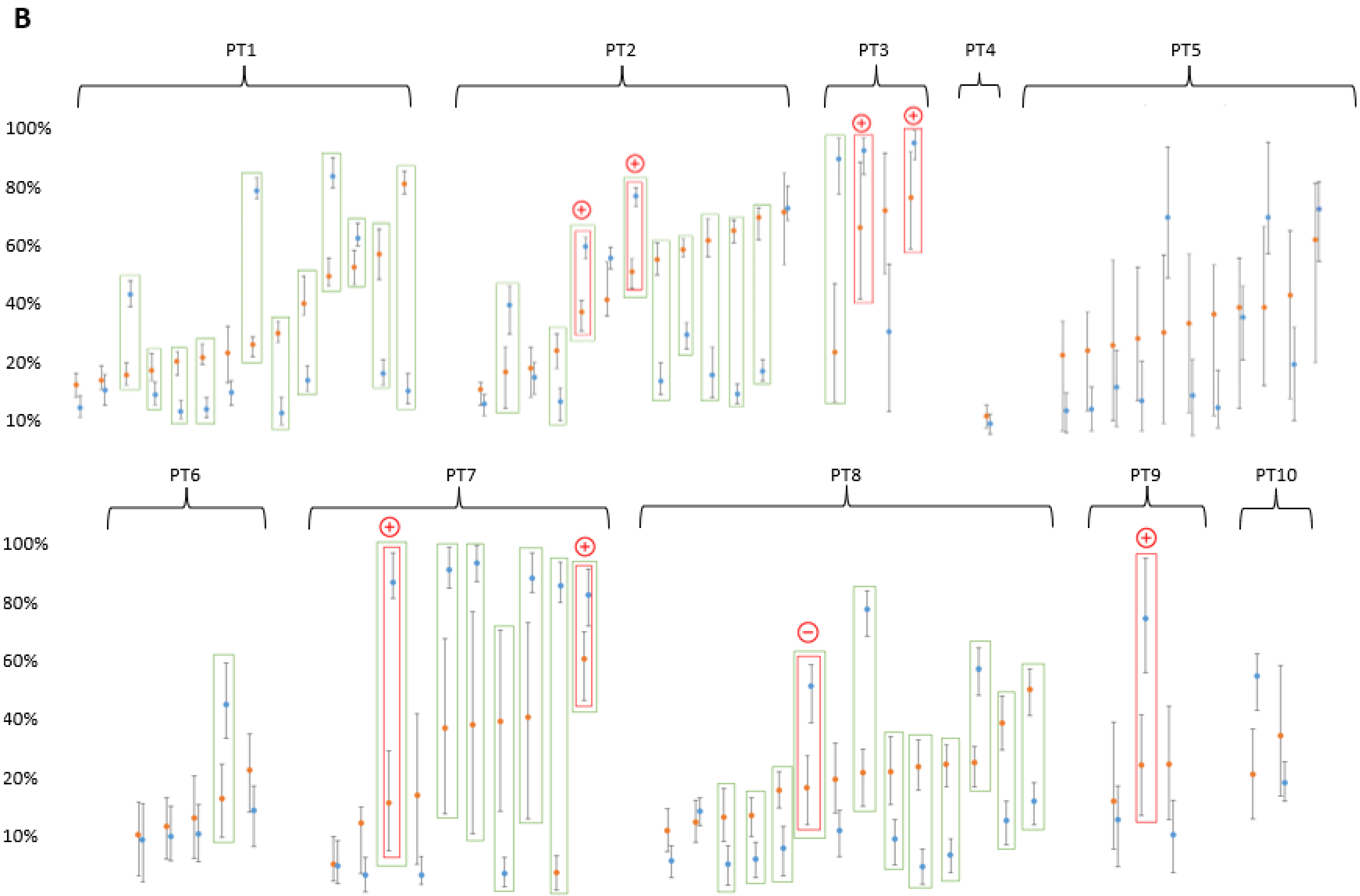
For 27 patients (35.1%), the physiotherapist's uncertainty reduced by more than half (IQR ratio > 2.0) for one or more pathologies following LUS: Twelve cases for atelectasis (15.6%), twenty-one cases for pleural fluid (27.3%) and thirteen cases for pneumothorax (16.9%).

There were several cases in which the median probability value and uncertainty shifted to where there was no overlap of the IQRs following LUS, showing a high influence of LUS on both pathology identification and uncertainty: twenty-three cases for atelectasis (29.9%), forty-four cases for pleural fluid (57.1%), and twenty-one cases for pneumothorax (27.3%). This can be seen boxed in green in Figure 4.4.

Figure 4.4 showcases that there was variation between physiotherapists in the number of patients assessed, shifts in median probability values and IQRs, and number of times management changed. Uncertainty differed between physiotherapists, with some showing more uncertainty than others (Figure 4.4). For example, PT1 had smaller IQRs both before and after LUS for all three pathologies while PT9 had larger IQRs overall. This may be due to the individual experience and perceptions of each physiotherapist. This study was designed to observe and capture the current influence of LUS on practice with minimal changes to current practice for the study; the nature of clinical practice involves individual physiotherapists with differing experiences treating individual patients with differing demographics and history. It was important to separate the data for each case and each pathology due to the unique combinations of physiotherapists and patients which could influence overall findings, and therefore, the error bars for the individual cases are displayed in Figure 4.4 arranged by increasing pre-LUS median probability value separated by each physiotherapist and pathology. Despite every case being unique, there was still a clear trend overall of (1) a reduction in uncertainty following the performance of LUS, (2) a higher influence of LUS on identifying pleural fluid, and (3) a high influence of LUS on pathology identification not always resulting in a change of management.

Figure 4.4 Error bars of the perceived probability arranged by physiotherapist. *(A) Atelectasis. (B) Pleural Fluid. (C) Pneumothorax.*

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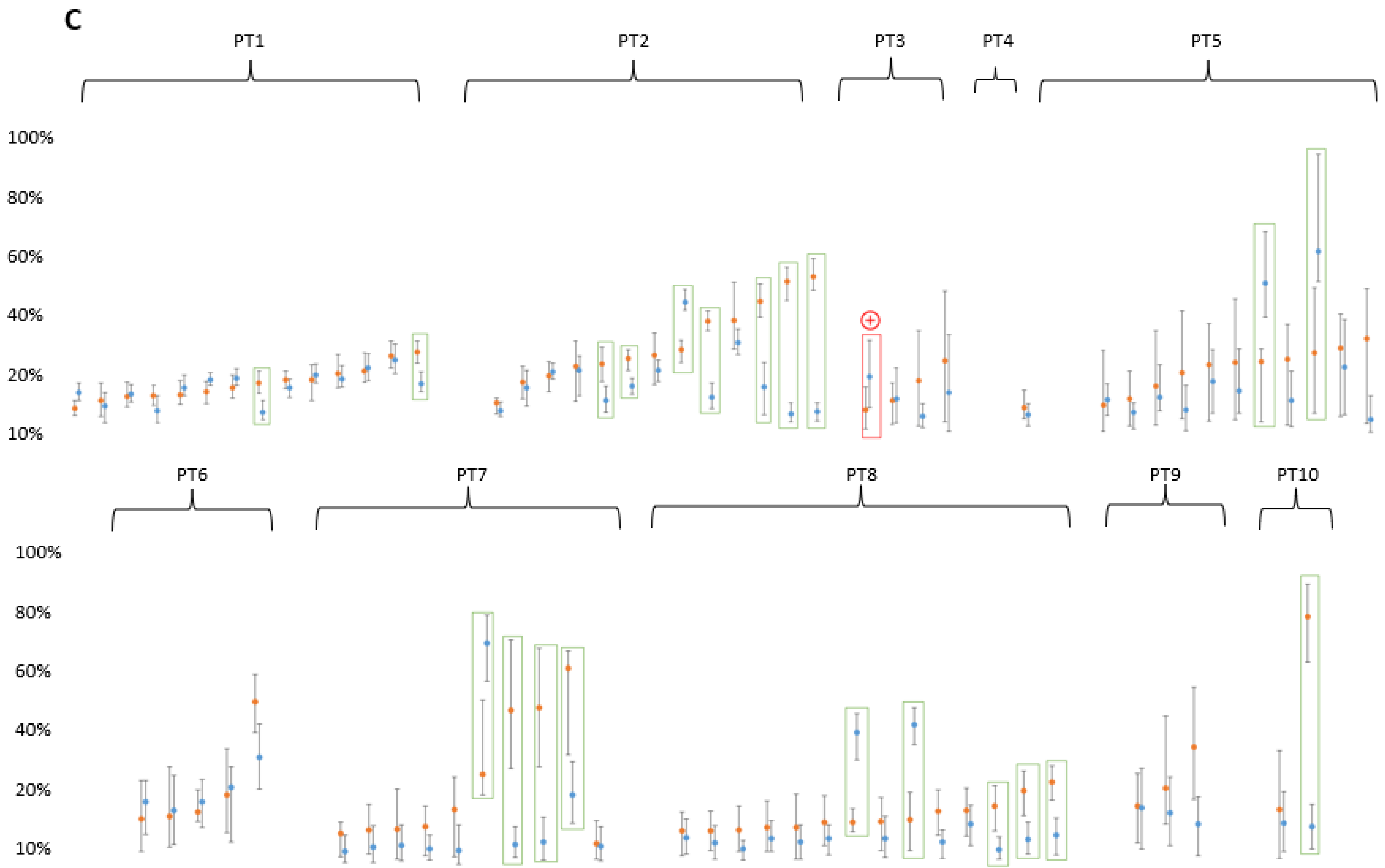
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4.5.3 Management Planning

Change in MDT Involvement

Out of all 77 cases, the physiotherapists considered deliberating with the medical staff five times pre-LUS (6%) and four times post-LUS (5%). For three cases, the reason for deliberating with medical staff remained the same: one case for delirium management, one to increase noradrenaline, and one for anti-emetics. In two cases, the physiotherapist planned to deliberate with medical staff, but recorded they no longer would after LUS for unclear reasons: one case to encourage mobilisation, and one case for possible salbutamol due to hearing a wheeze on auscultation. In one case, the physiotherapist indicated no deliberation was required prior to LUS, but after LUS planned to deliberate with the medical staff to advocate for a chest x-ray to establish whether there was a pneumothorax or not following the LUS Scanner indicating a possible pneumothorax.

Out of all 77 cases, the physiotherapists thought an invasive procedure may be required twice pre-LUS (2.6%), but this changed afterwards to not required in both cases for unclear reasons. In one case, the physiotherapist believed a chest drain or bronchoscopy may be required, with in the other, the physiotherapist felt suctioning was required.

Change in Physiotherapy Management

Management changed for 12 patients (16%). The physiotherapists changed management due to LUS revealing the patient's condition to be more severe (n=9; 75%) or less severe (n=3; 25%) than initially perceived; these cases are boxed in red in Figure 4.4. The physiotherapists changed management through a combination of adding treatment (n=8; 66.7%), removing treatment (n=2; 16.7%), increasing treatment frequency (n=4; 33.3%), decreasing treatment frequency (n=1; 8.3%), or increasing treatment intensity (n=4; 33.3%). The only treatment added or removed from the management plan was intermittent positive pressure breathing (IPPB). Frequency of treatment increased to twice a day while a decrease in the frequency of treatment was to once a day. When intensity was increased, it was by encouraging more spirometry, IPPB, and marching on the spot between sessions with nursing staff or independently.

On Questionnaire #2, the physiotherapists indicated whether they thought their initial impression recorded on Questionnaire #1 matched that of the LUS Scanner. The physiotherapists then indicated whether they would change their management or not based on the LUS findings on the same questionnaire. Despite the physiotherapists indicating their impression of the patient did not match that of the LUS Scanner for 33 patients, the physiotherapists indicated that their management would not change for these patients 87.9% of the time (n=29). Fifty percent of cases where the physiotherapists indicated a management change (n=6) involved the probability of one or more pathologies changing binary categorisation. A change in management was accompanied by a reduction in uncertainty by half for one or more pathologies: five cases regarding the perceived presence of atelectasis (41.7%), three cases regarding the perceived presence of pleural fluid (25%), and two cases regarding the perceived presence of pneumothorax (16.7%). Eleven of the 12 cases (91.7%) where the physiotherapist changed management were associated with the median probability value and uncertainty shifting to where there was no overlap of the IQRs following LUS: four cases due to a change in the perceived presence of atelectasis (33.3%) and seven cases due to a change in the perceived presence of pleural fluid (58.3%) (Figure 4.4).

4.6 Regression Analysis

A series of univariate logistic regressions were performed with the variables presented in Table 4.4 to test if any patient demographics or surgery details predicted a change in pathology identification, confidence or management following LUS. Due to only one patient having an underweight body mass index (BMI) and one physiotherapist who was the only participant between 35 and 44 years of age and the only rotational Band 6 physiotherapist, these categories were removed from the analysis. Full details from all regression analyses are presented in Appendix 18. A summary of point estimates of odds ratios is presented in Figure 4.5. The following section begins by reporting estimates that were significant ($p < 0.05$). The IQR of the odds ratios was calculated and reported for each dependent variable and the larger odds ratios are discussed.

Table 4.4 Regression Variables. *†reference category.*

Independent Variables

Patient Age
- Under 65 years†
- 65-75 years
- Over 75 years

Patient Sex
- Male†
- Female

Patient Body Mass Index
- Healthy (18.5-24.9)†
- Overweight (25-29.9)
- Obese (over 30)

Relevant Past Medical History
- Not present†
- Present

Surgery
- Coronary artery bypass graft (CABG)†
- Valve repair/replacement (VR)
- Both CABG and VR

Surgical Pathway
- Elective†
- Inpatient

Type of Incision
- Sternotomy†
- Minimally invasive

Eventful Surgery
- No†
- Yes

Physiotherapist Age
- 18-24 years
- 25-34 years†

Physiotherapist Sex
- Male†
- Female

Job Post
- Static Band 6†
- Rotational Respiratory Band 6
- Rotational Band 5

Contract
- Full-time†
- Part-time

Years Qualified
- More than 3 years†
- Less than 3 years

Years Experience with Cardiac Surgery Patients
- More than 1 year†
- Less than 1 year

LUS Experience
- Accredited†
- In process of accreditation
- None, but interested

Years Accredited in LUS
- More than 1 year†
- Less than 1 year, or not accredited

Dependent Variables

Change in Management
- No†
- Yes

Matching Patient Impression
- Yes†
- No

Change in Median Probability more than 25% for:
- *Atelectasis/Pleural Fluid/Pneumothorax*
  - No†
  - Yes

Change in Uncertainty more than 25% for:
- *Atelectasis/Pleural Fluid/Pneumothorax*
  - No†
  - Yes

Change in Binary Categorisation for:
- *Atelectasis/Pleural Fluid/Pneumothorax*
  - No†
  - Yes

Decreased odds — Increased odds

Category		Variable	Change in Management	Concordant Impressions	Shift in median probability Atelectasis	Shift in median probability Pleural Fluid	Shift in median probability Pneumothorax	Shift in Uncertainty: Atelectasis	Shift in Uncertainty: Pleural Fluid	Shift in Uncertainty: Pneumothorax	Re-categorisation: Atelectasis	Re-categorisation: Pleural Fluid	Re-categorisation: Pneumothorax
Patient Demographics & Surgery Details	Age	Under 65:65-75	0.39	0.33*	0.86	0.49	0.70	-	0.91	0.73	1.90	0.45	1.11
		Under 65:Over 75	1.23	0.69	1.23	0.17*	2.19	-	0.70	-	3.06	0.84	2.46
	Sex	Male:Female	0.94	1.94	1.67	1.06	1.33	-	2.38	-	0.94	1.57	0.55
	BMI	Healthy:Overweight	0.54	1.17	2.83	1.68	0.19	0.58	0.69	-	2.09	1.47	0.17
		Healthy:Obese	0.75	1.71	2.83	2.37	0.93	-	0.34	-	1.07	1.40	1.07
	Relevant PMH	None:Relevant PMH	0.24*	0.56	0.53	1.36	0.45	-	3.55	0.60	0.73	1.11	0.32
	Surgery	CABG:VR	0.40	0.91	1.18	0.78	0.87	-	0.98	-	2.18	1.63	-
		CABG:Both	-	0.64	-	1.57	-	11.6	-	-	0.87	1.14	-
	Surgical Pathway	Elective:Inpatient	1.36	1.49	0.66	1.71	3.78	0.92	0.91	-	0.48	1.62	7.64
	Incision	Sternotomy:MIS	6.78*	2.83	2.00	0.28	0.97	-	1.07	-	9.67*	0.38	-
	Eventful Surgery	Non-eventful:Eventful	1.66	3.04	2.12	2.15	0.58	-	0.65	-	2.12	3.00	1.09
Physiotherapist Demographics & Experience	Age	25-34:18-24	1	2.19	1.49	1.16	0.49	3.11	1.63	-	1.68	0.92	0.40
	Sex	Male:Female	0.71	2.52	1.87	1.21	1.86	-	1.61	0.74	1.32	0.73	1.28
	Band	Static B6:Resp Rot B6	2.4	0.39	0.69	0.80	-	-	1.10	1.47	0.32	1.04	-
		Static B6:Rot B5	3.36	1.75	2.50	1.24	0.63	-	1.02	-	2.50	1.86	0.43
	Contract	FT:PT	0.34	0.97	0.59	0.97	2.76	-	0.98	2.00	0.59	0.68	3.81
	Yrs Qualified	> 3 yrs: < 3 yrs	1.61	2.00	0.69	1.92	2.94	0.74	1.06	0.74	1.32	1.97	2.45
	Yrs in Cardiac	> 1 yr: < 1 yr	3.09	3.32*	2.27	1.25	0.71	-	0.86	-	5.11*	1.92	0.87
	LUS Experience	Accredited:In Process	1.24	2.04	0.32	1.73	2.89	-	1.44	1.87	4.50	1.43	3.12
		Accredited:None	2.43	3.38*	2.18	1.73	2.00	-	1.16	-	6.14*	2.15	1.40
	Years Accredited	> 1 yr: < 1 yr	6.44	4.67**	1.07	2.04	1.75	-	0.96	0.47	4.24	2.50	1.50

Figure 4.5 Odds Ratios Heat Map. *For each category, the reference variable is placed before the tested variable, e.g., Male:Female is showing the odds ratio for females compared to males. *p < 0.05, **p < 0.01. Key: BMI=body mass index; PMH=past medical history; CABG=coronary artery bypass graft; VR=valve replacement/repair; MIS=minimally invasive surgery.*

4.6.1 Regression Results for Patient Demographics & Surgery Details

This next section will discuss the results of the regressions run against the patient demographic and surgery details. Due to insufficient variability of data, only 97 out of the 121 possible regressions were conducted. Out of the 97 univariate regressions, five variables (5.2%) were found to be significant: the presence of relevant past medical history ($OR_{none:PMH}$=0.24, p=0.032) and a minimally invasive approach to surgery ($OR_{sternotomy:MIS}$=6.78, p=0.032) were significantly associated with a change in management; a patient between 65 and 75 years of age was significantly associated with discordance in patient impressions ($OR_{under65:65-75}$=0.33, p=0.043); a patient over 75 years of age was significantly associated with a shift in the perceived probability of pleural fluid by more than 25% ($OR_{under65:over75}$=0.17, p=0.018); and a minimally invasive approach to surgery was significantly associated with a change in binary categorisation for atelectasis ($OR_{sternotomy:MIS}$=9.67, p=0.014).

Change in Management

The majority of the odds ratios ranged from 1.33 to 0.43. Patients between 65 and 75 years of age (0.39), patients who only had a valve replacement/repair (0.40), and patients with relevant past medical history (0.24) had lower odds of having their management changed by the physiotherapist following LUS. The physiotherapists were 6.78 times more likely to change their management following LUS for patients who had minimally invasive surgery (Figure 4.6).

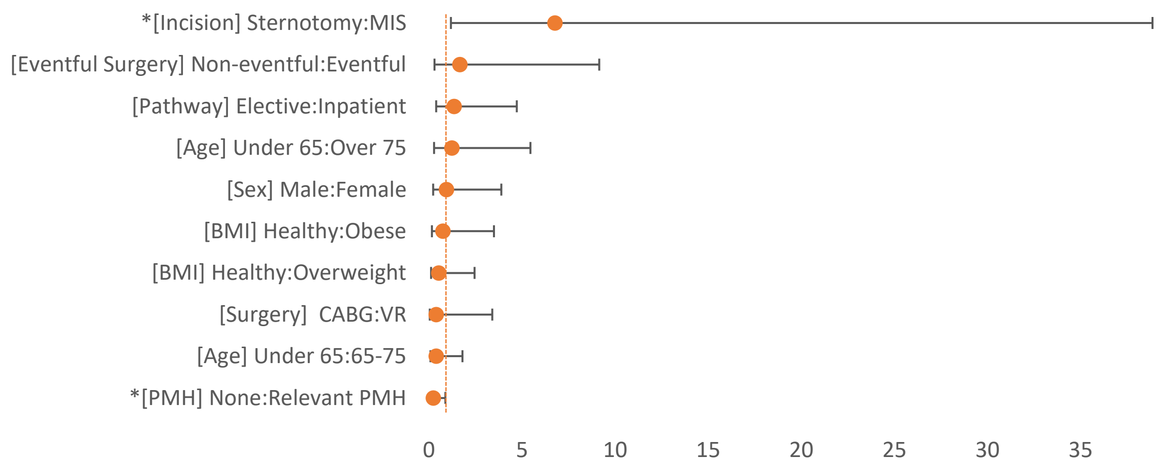


Figure 4.6 Patient Demographics & Surgery Details Odds Ratios – Change in Management.

Concordance in Patient Impressions

The majority of the odds ratios ranged from 0.66 to 1.83. Patients between 65 and 75 years of age (0.33) and patients with relevant past medical history (0.56) had a lower chance of the physiotherapist's impression being discordant with that of the LUS Scanner; those with a minimally invasive surgery (2.83) or eventful surgery (3.04) had a higher chance (Figure 4.7).

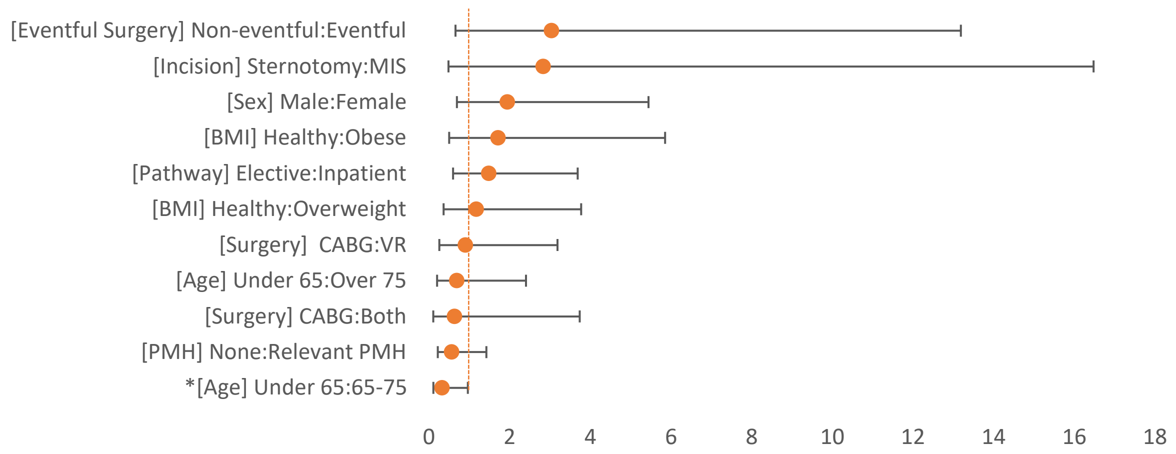


Figure 4.7 Patient Demographics & Surgery Details Odds Ratios – Concordant Patient Impressions.

Shift in Median Probability

The majority of the odds ratios ranged from 0.94 to 2.09 for atelectasis, 0.63 to 1.69 for pleural fluid, and 1.24 to 0.61 for pneumothorax.

Inpatients (0.66) and patients with relevant past medical history (0.56) had a lower chance of the physiotherapist's perceived probability of atelectasis shifting by more than 25% following LUS; patients with eventful surgery (2.12) or had either an overweight (2.83) or obese BMI (2.83) had a higher chance (Figure 4.8).

Patients between 65 and 75 years of age (0.49), over 75 years of age (0.17) or had a minimally invasive surgery (0.28) had a lower chance of the physiotherapist's perceived probability of pleural fluid shifting by more than 25% following LUS; those with eventful surgery (2.15) and patients with an obese BMI (2.37) had a higher chance (Figure 4.9).

Patients with an overweight BMI (0.19) or with relevant past medical history (0.45) had a lower chance of the physiotherapist's perceived probability of pneumothorax shifting by more than 25%

following LUS; patients over 75 years of age (2.19) or inpatients (3.78) had a higher chance (Figure 4.10).

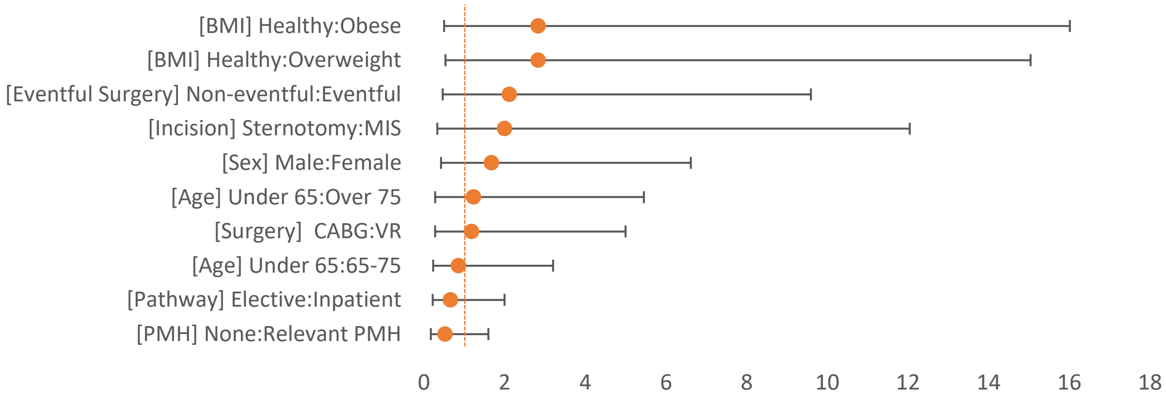


Figure 4.8 Patient Demographics & Surgery Details Odds Ratios – Shift in Probability of Atelectasis.

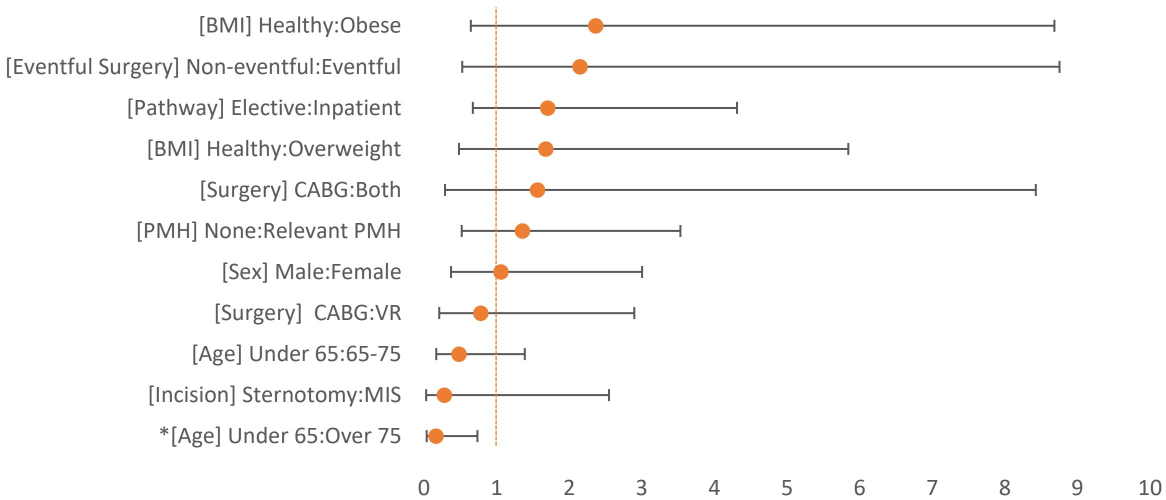


Figure 4.9 Patient Demographics & Surgery Details Odds Ratios – Shift in Probability of Pleural Fluid.

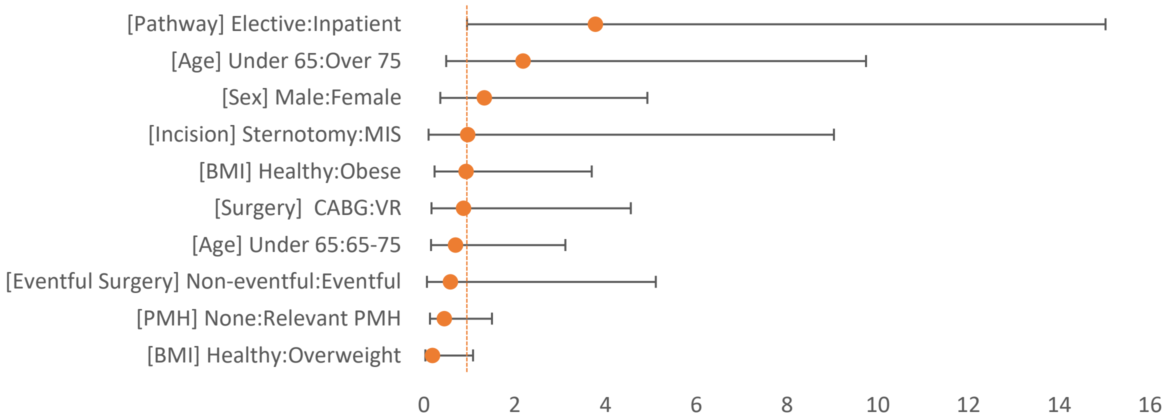


Figure 4.10 Patient Demographics & Surgery Details Odds Ratios – Shift in Probability of Pneumothorax.

Reduction in Uncertainty

Most categories did not have enough variability to run regressions for atelectasis and pneumothorax. The majority of the odds ratios for pleural fluid ranged from 1.05 to 0.70 (Figure 4.11). Physiotherapists were 11.6 times more likely to experience a reduction in uncertainty by over 25% for atelectasis for patients who had both a CABG and VR. There was a lower chance of the physiotherapist's uncertainty in pleural fluid to reduce by more than 25% for patients with an obese BMI (0.34); there was a higher chance for female patients (2.38) or those with a relevant past medical history (3.55).

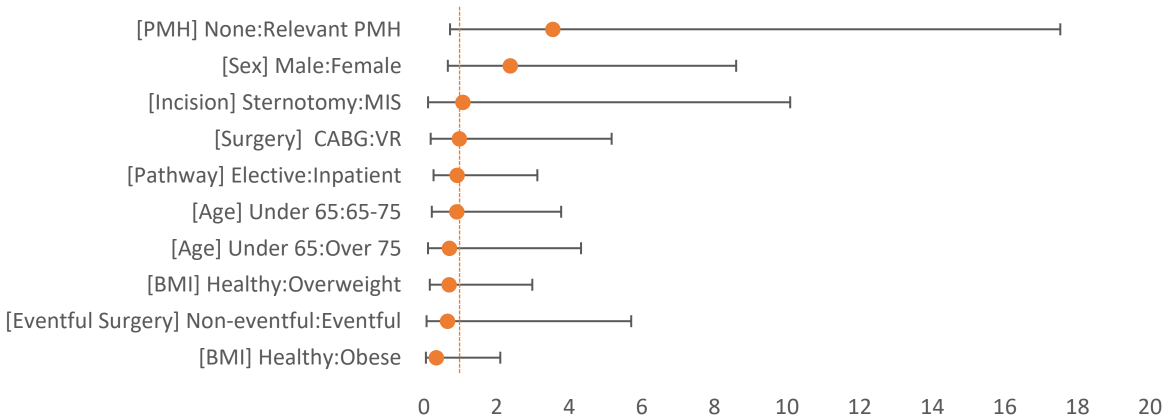


Figure 4.11 Patient Demographics & Surgery Details Odds Ratios – Reduction in Uncertainty of Pleural Fluid.

Re-categorisation of Pathology

The majority of the odds ratios ranged from 0.91 to 2.15 for atelectasis, 0.98 to 1.59 for pleural fluid, and 1.45 to 0.49 for pneumothorax.

There was a higher chance of the physiotherapist re-categorising the presence of atelectasis following LUS for patients with an overweight BMI (2.09), eventful surgery (2.12), patients who had only a VR (2.18), patients over 75 years of age (3.06), and minimally invasive surgery (9.67) (Figure 4.12).

There was a lower chance of the physiotherapist re-categorising the presence of pleural fluid following LUS for patients between 65 and 75 years of age (0.45) and those who had minimally invasive surgery (0.38); there was a higher chance for those with eventful surgery (3.00) (Figure 4.13).

There was a lower chance of the physiotherapist re-categorising the presence of pneumothorax following LUS for patients with a relevant past medical history (0.32) or an overweight BMI (0.17). The physiotherapists were 2.46 times more likely to change binary categorisation for pneumothorax following LUS for patients over 75 years of age and 7.64 times more likely for an inpatient (Figure 4.14).

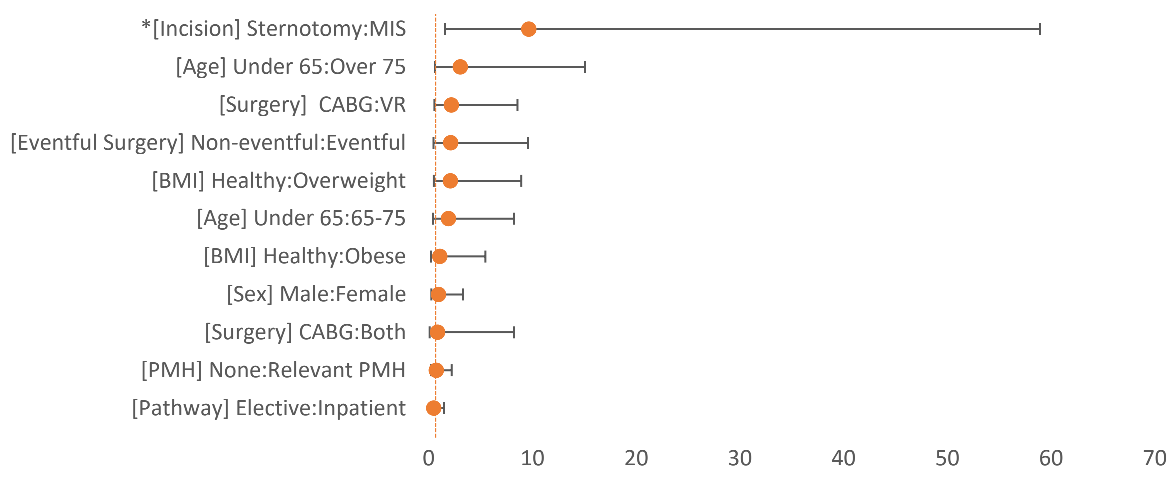


Figure 4.12 Patient Demographics & Surgery Details Odds Ratios – Change of Binary Categorisation of Atelectasis.

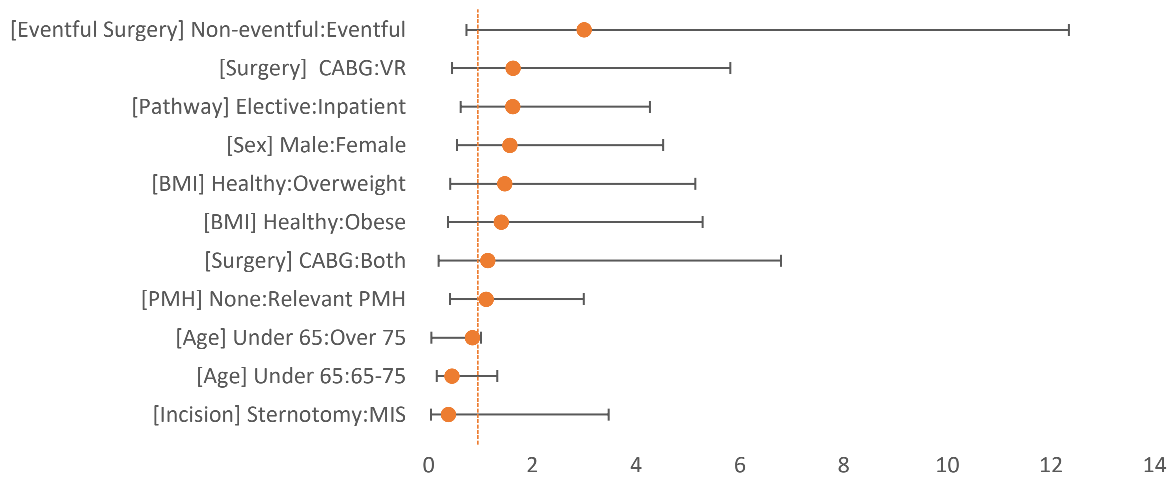


Figure 4.13 Patient Demographics & Surgery Details Odds Ratios – Change of Binary Categorisation of Pleural Fluid.

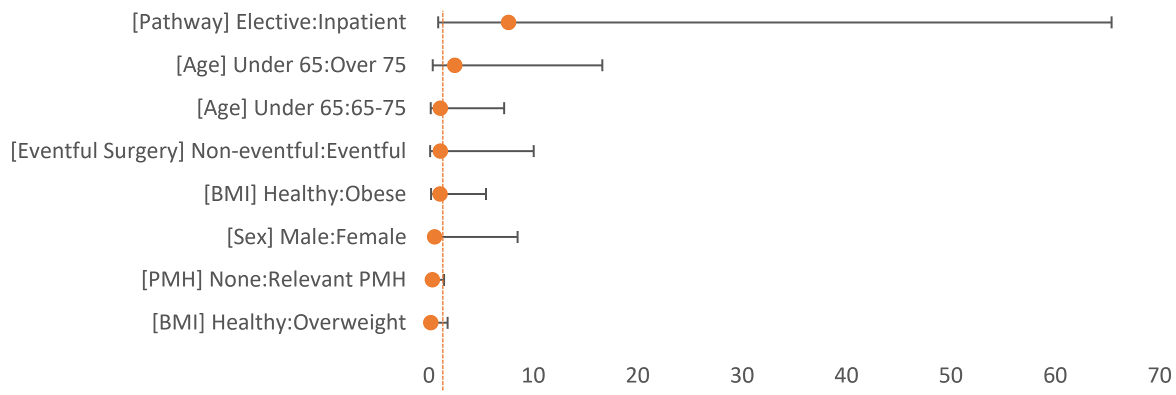


Figure 4.14 Patient Demographics & Surgery Details Odds Ratios – Change of Binary Categorisation of Pneumothorax.

4.6.2 Regression Results for Physiotherapist Demographics & Experience

This next section will discuss the results of the regressions run against the physiotherapist demographics and experience. Out of the 110 possible regressions, only 96 were conducted due to insufficient variety in the remaining 14. Out of the 96 regressions, five variables (5.2%) were found to be significant: Less than a year of experience with cardiac surgery patients ($OR_{>1:<1}$=3.32, p=0.014), no lung ultrasound experience ($OR_{accredited:none}$=3.38, p=0.026), and less than a year accredited or absence of accreditation ($OR_{>1:<1}$=4.67, p=0.007) was significantly associated with discordant patient impressions; Less than a year of experience with cardiac surgery patients ($OR_{>1:<1}$=5.11, p=0.018) and no lung ultrasound experience ($OR_{accredited:none}$=6.14, p=0.028) was significantly associated with the re-categorisation of atelectasis following LUS.

Change in Management

The majority of the odds ratios ranged from 1.06 to 2.93. There was a lower chance of part-time physiotherapists changing their management following LUS (0.34); there was a higher chance of respiratory rotational Band 6s (2.40), rotational Band 5s (3.36), those with no LUS experience (2.43), less than a year of experience with cardiac surgery patients (3.09) changing their management (Figure 4.15).

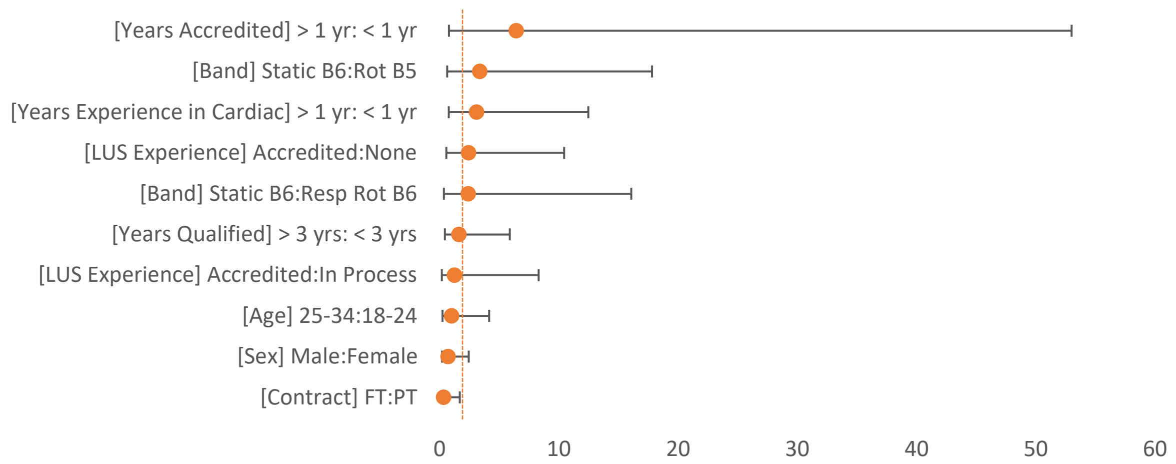


Figure 4.15 Physiotherapist Demographics & Experience Odds Ratios – Change in Management.

Concordance in Patient Impressions

The majority of the odds ratios ranged from 1.81 to 3.12. There was a lower chance of the patient impression from respiratory rotational Band 6s being in discordance with that of the LUS Scanner (0.39); those qualified for less than three years (2.00), those in process of becoming accredited (2.04), physiotherapists between 18 and 24 years of age (2.19), female physiotherapists (2.52), those with less than a year of experience with cardiac surgery patients (3.32), those with no experience with LUS (3.38), and those with less than a year of LUS accreditation (4.67) had a higher chance of discordance (Figure 4.16).

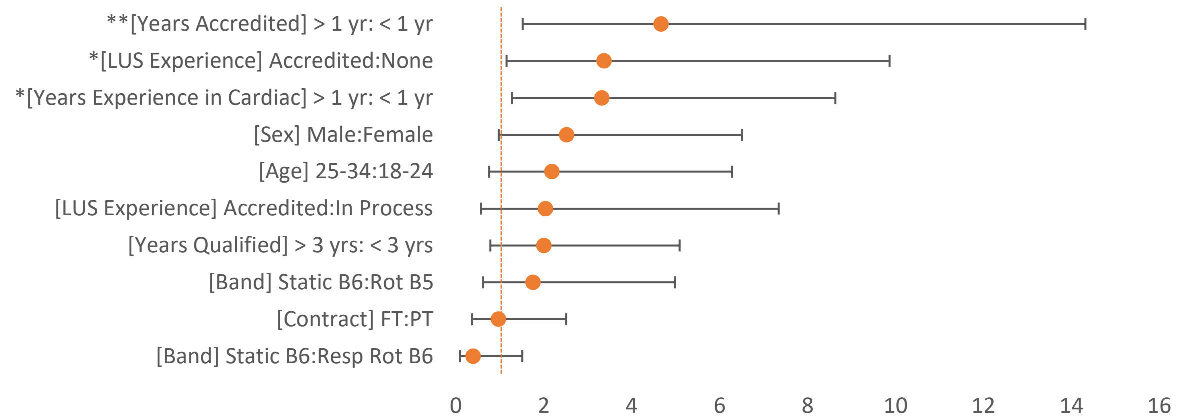


Figure 4.16 Physiotherapist Demographics & Experience Odds Ratios – Concordant Impressions.

Shift in Median Probability

The majority of the odds ratios ranged from 0.69 to 2.10 for atelectasis, 1.17 to 1.73 for pleural fluid, and 0.71 to 2.76 for pneumothorax.

Those in process of accreditation had a lower chance of their perceived probability of atelectasis shifting by more than 25% following LUS (0.32); those with no LUS experience (2.18), those with less than a year of experience with cardiac surgery patients (2.27), and rotational Band 5s (2.50) had a higher chance of their perceived probability of atelectasis shifting by more than 25% following LUS (Figure 4.17).

Those with less than a year of LUS accreditation were 2.04 times more likely to have their perceived probability of atelectasis shift by more than 25% following LUS (2.04) (Figure 4.18).

Physiotherapists between the ages of 18 and 24 years of age had a lower chance of their perceived probability of pneumothorax shifting by more than 25% following LUS; those with no LUS experience (2.00), part-time physiotherapists (2.76), those in process of accreditation (2.89), and those qualified for less than three years (2.94) had a higher chance of their perceived probability of pneumothorax shifting by more than 25% following LUS (Figure 4.19).

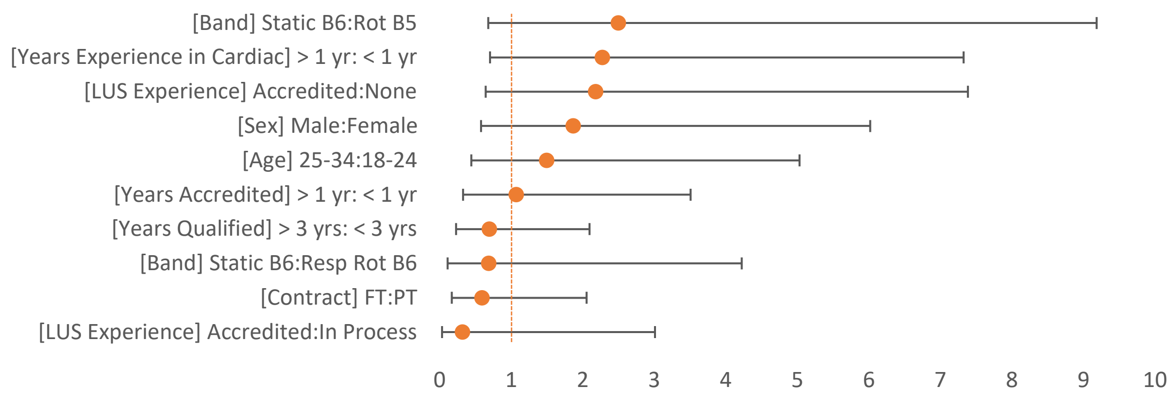


Figure 4.17 Physiotherapist Demographics & Experience Odds Ratios – Shift in Probability of Atelectasis.

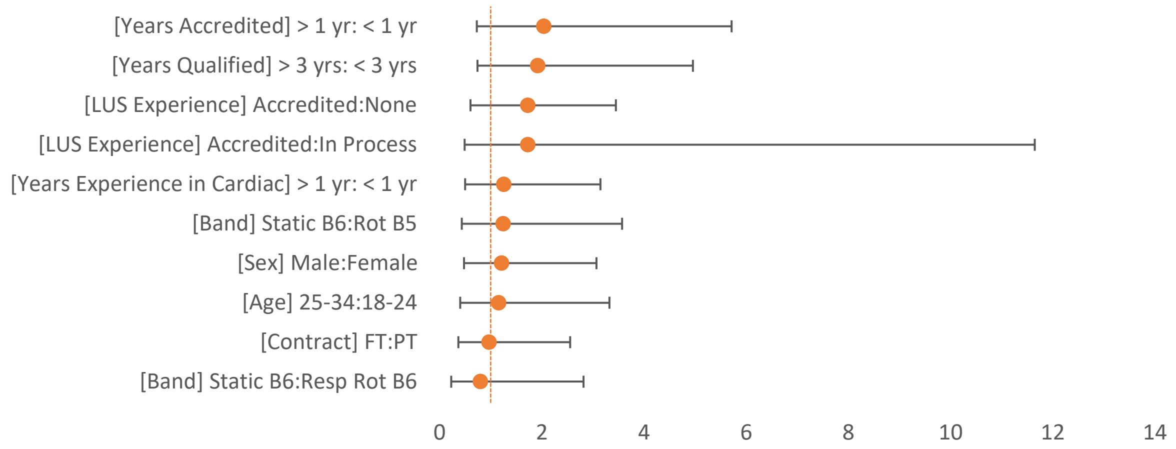


Figure 4.18 Physiotherapist Demographics & Experience Odds Ratios – Shift in Probability of Pleural Fluid.

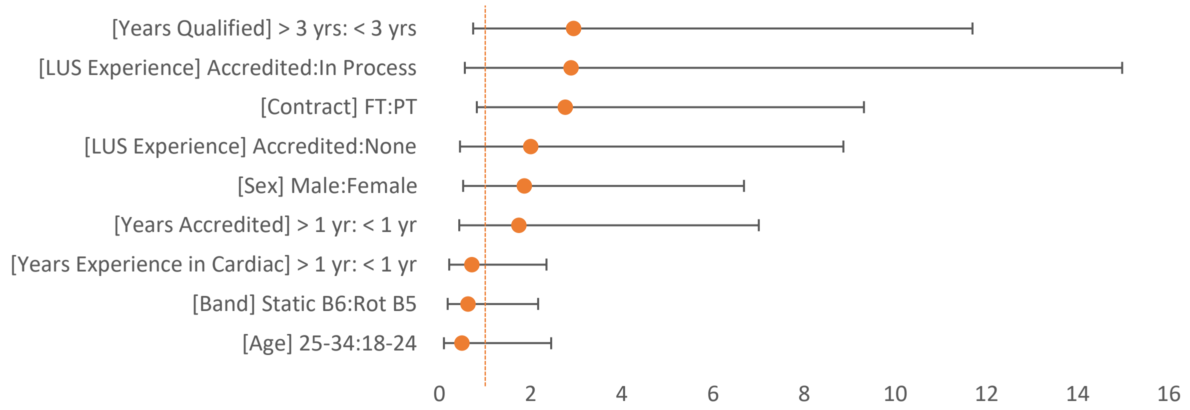


Figure 4.19 Physiotherapist Demographics & Experience Odds Ratios – Shift in Probability of Pneumothorax.

Reduction in Uncertainty

Most categories did not have enough variability to run regressions for atelectasis. The majority of odds ratios ranged from 0.98 to 1.37 for pleural fluid (Figure 4.20) and 0.74 to 1.77 for pneumothorax. Those between the ages of 18 and 24 were 3.11 times more likely to experience a reduction in uncertainty by over 25% for atelectasis. There was a lower chance of those with less than a year of LUS accreditation to experience a reduction in uncertainty by over 25% for pneumothorax (0.47) and a higher chance for those part-time (2.00) (Figure 4.21).

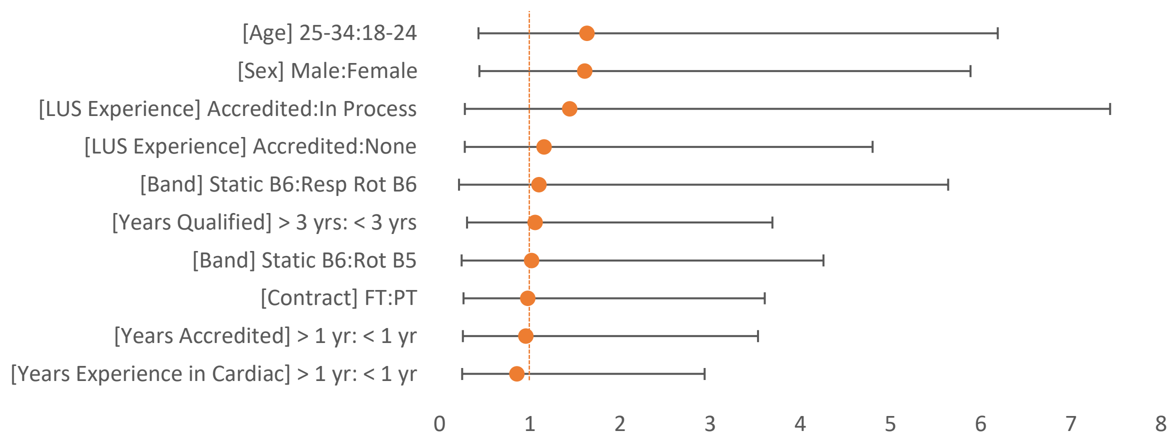


Figure 4.20 Physiotherapist Demographics & Experience Odds Ratios – Reduction in Uncertainty of Pleural Fluid.

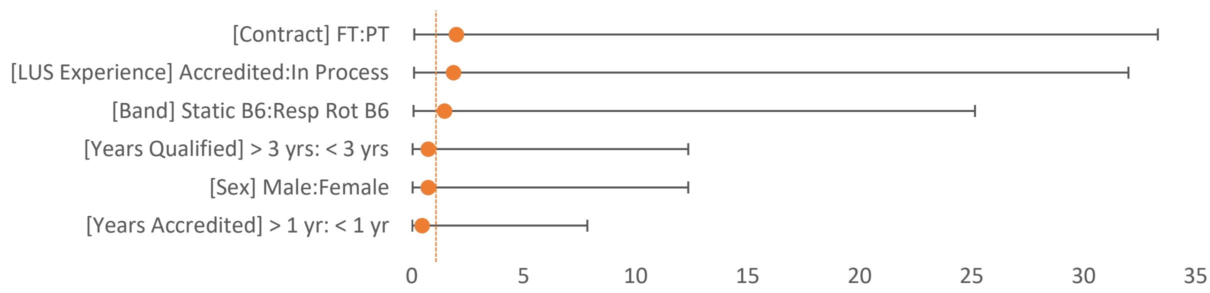


Figure 4.21 Physiotherapist Demographics & Experience Odds Ratios – Reduction in Uncertainty of Pneumothorax.

Re-categorisation of Pathology

The majority of the odds ratios ranged from 1.32 to 4.43 for atelectasis, 0.95 to 1.96. for pleural fluid, and 0.87 to 2.45 for pneumothorax.

There was a lower chance of respiratory rotational Band 6s re-categorising atelectasis following LUS (0.32); there was a higher chance of rotational Band 5s (2.50), those with less than a year of LUS accreditation (4.24), those in process of accreditation (4.50), those with less than a year of experience with cardiac surgery patients (5.11), and those with no LUS experience (6.14) re-categorising atelectasis (Figure 4.22).

There was a higher chance of those with no LUS experience (2.15) or those with less than a year of LUS accreditation (2.50) re-categorising pleural fluid following LUS (Figure 4.23).

There was a lower chance of those between 18 and 24 years of age (0.40) and rotational Band 5s (0.43) re-categorising pneumothorax following LUS; there was a higher chance of those qualified less than three years (2.45), those in process of accreditation (3.12) and part-time physiotherapists re-categorising pneumothorax following LUS (Figure 4.24).

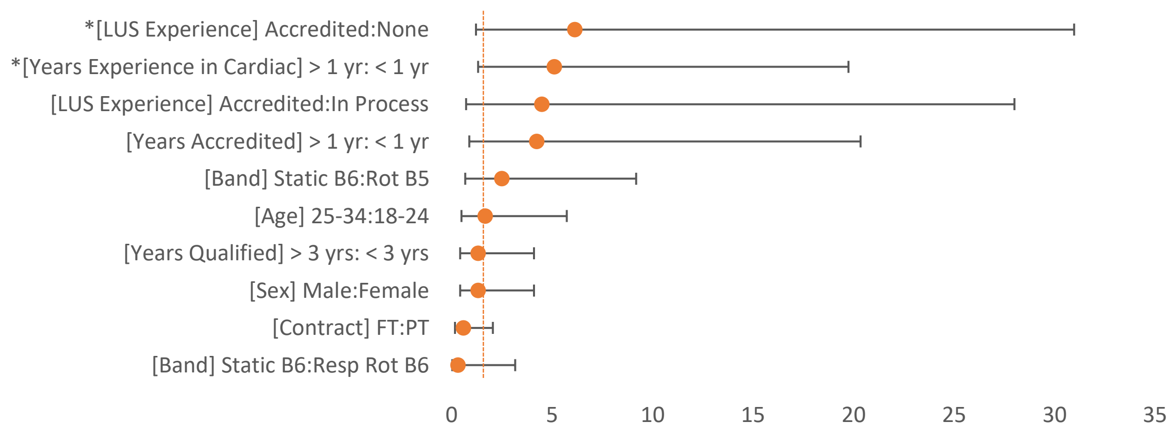


Figure 4.22 Physiotherapist Demographics & Experience Odds Ratios – Change in Binary Categorisation of Atelectasis.

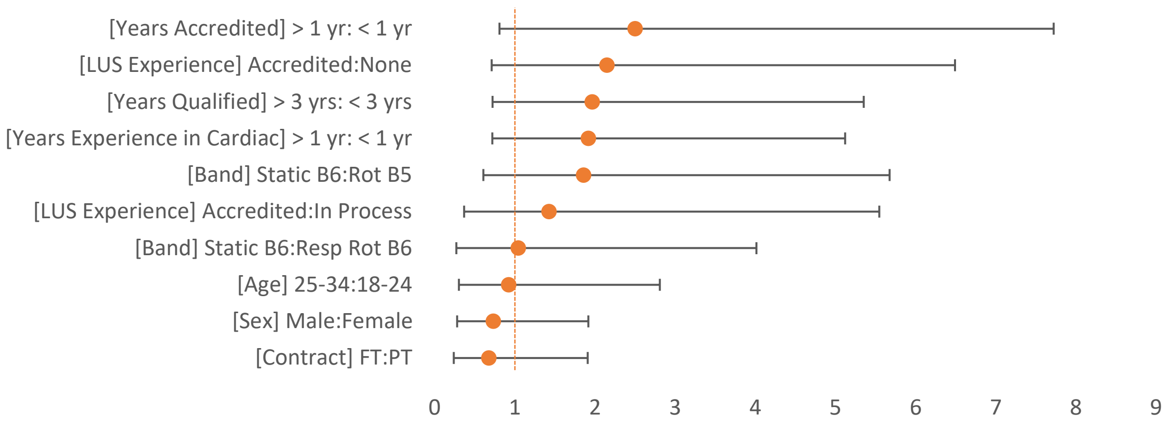


Figure 4.23 Physiotherapist Demographics & Experience Odds Ratios – Change in Binary Categorisation of Pleural Fluid.

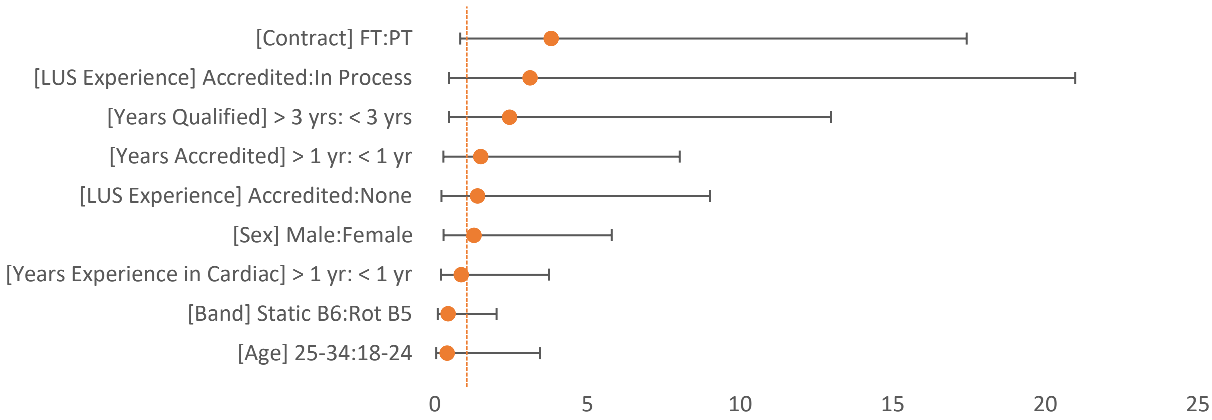


Figure 4.24 Physiotherapist Demographics & Experience Odds Ratios – Change in Binary Categorisation of Pneumothorax.

4.7 Summary of Quantitative Findings

The first part of this chapter presented the demographic data of both the physiotherapists and patients, descriptive statistics, and results from regression analysis of the data collected from the quantitative phase of the study.

The quantitative phase of the study empirically assessed the impact LUS has on the participating physiotherapists' practice. Lung ultrasound would have seldomly been ordered for the patients in this phase. Despite this finding, LUS demonstrated to have an influence on pathology identification. Lung ultrasound changed the physiotherapist's best guess as to the probability of the pathologies by more than 25% in the majority of cases. The quantitative findings also found a high discordance in clinical impressions with a re-categorisation of the pathologies occurring for over half of the patients. The strength of the physiotherapists' best guess as to the probability of the pathologies increased overall following LUS, showing confidence in identification in the majority of cases after LUS. There was also an evident reduction in the physiotherapists' uncertainty with the pathologies following LUS. Overall, there was a larger change in perceived probability, uncertainty, categorisation, and confidence for pleural fluid out of the three studied pathologies, showing LUS to have the largest influence on the identification of pleural fluid in this study. Management overall, however, was not changed often due to LUS. There was a low rate in management change despite the high rate in clinical impression discordance. When management did change, it was due to a change in perceived severity of the patient's condition and was associated with re-categorisation of one or more pathologies in half the cases.

There appeared to be an association between the level of experience held by the physiotherapists and concordance of patient impressions based on significant results and large odds ratios from regression analysis. The absence of relevant past medical history and minimally invasive surgery, details that could lead one to believe a decreased risk of pathology, were significantly associated with a change in management due to the pathology being more severe than initially thought following LUS. Minimally invasive surgery was also significantly associated with a change in the perceived presence of atelectasis, which became more likely than not after LUS. These findings could suggest certain demographic or surgery details could mislead the perceived probability or severity of pathologies. Only about 5% of regressions, however, were found to be significant; five percent of regressions are expected to be significant despite no effect, therefore these results should be interpreted with caution. The next part in this chapter will present the results from the qualitative phase of the same study.

4.8 Considerations for Qualitative Phase

In line with the fully integrated convergent mixed methods design, the preliminary data from the quantitative phase were used to adapt the topic guide with the aim of helping to explain the quantitative data. Explanations were sought as to why the perceived probability of the pathologies shifted and uncertainty universally reduced following LUS. The large difference between in LUS orders and concordant clinical impressions implored further exploration, as well as the lack of management change due to LUS despite a high re-categorisation of pathologies. Preliminary data for the individual physiotherapists were, therefore, used during the interview for comment and discussion, presenting (1) the mean lower quartile, median, and upper quartile for both before and after LUS in the form of two error bars to show the mean shift in perceived probability and uncertainty; (2) concordance in clinical impressions organised by whether LUS would have normally been ordered in the form of a stacked bar chart to show the relationship and (3) a pie chart showing frequency of management change. An example is presented in Appendix 19.

4.9 Demographics – Qualitative Phase

The first half of this chapter presented and discussed the results from the quantitative phase of the mixed methods study. The following sections will now present the results from the qualitative phase of the same study. Seven out of the ten physiotherapists who took part in the quantitative phase (participants) volunteered to also take part in the semi-structured interviews (Table 4.5). Most participants were between the ages of 25 and 34 (n=6, 85.7%), were Band 6 (n=5, 71.4%), full-time (n=4, 57.1%), female (n=4, 57.1%), and received a Bachelor of Science (honours) in physiotherapy (n=6, 85.7%). The participants had been qualified as physiotherapists for a mean of 3.8 years (±2.4) and had a mean of 1.4 years (±1.6) of experience with cardiac surgery patients. Five participants were either accredited or in the process of becoming accredited in LUS while two participants had no formal training with LUS. For those accredited in LUS (n=3), accreditation had been held for a mean of 1.5 years (±1.4). The length of the interviews ranged from 30 minutes and 23 seconds to 51 minutes and 42 seconds, with a mean interview length of 39 minutes and 18 seconds. The unique identifier of the participant is listed after each quote, along with their LUS experience.

Table 4.5 Physiotherapist demographics and characteristics (n=7)

Participant Demographics	n(%), mean±SD
Age Range	
18-24	1 (14.3%)
25-34	6 (85.7%)
Sex	
Male	3 (42.9%)
Female	4 (57.1%)
Qualification	
BSc (honours) Physiotherapy	6 (85.7%)
MSc Physiotherapy (pre-registration)	1 (14.3%)
Years Qualified	3.8±2.4
Job Post	
Rotational Band 5	2 (28.6%)
Respiratory Rotational Band 6	2 (28.6%)
Static Band 6	3 (42.9%)
Contract	
Part-time	3 (42.9%)
Full-time	4 (57.1%)
Experience with Cardiac Patients (years)	1.4±1.6
Experience with LUS (years)	
None, but interested	2 (28.6%)
In the process of accreditation	2 (28.6%)
Accredited	3 (42.9%)
If Accredited, Years of Experience with LUS (n=3)	1.5±1.4

4.10 Categories, Classes, and Themes

The Framework approach was used to identify numerous dimensions from the data. Dimensions with similar meanings were then organised into 39 categories. An example of organising dimensions into categories can be found in Appendix 20. The 39 categories were organised into ten classes, and finally into three overarching themes (Table 4.6), which are now discussed in turn.

4.10.1 Themes

Theme #1: Views of physiotherapists on the use and influence of lung ultrasound in the cardiac surgery population.

Theme #2: Views of physiotherapists on skill development in lung ultrasound and importance within the field of respiratory physiotherapy.

Theme #3: Barriers and facilitators to the use of lung ultrasound by physiotherapists within the cardiac surgery population.

Table 4.6 Categories, classes and themes.

Categories (Contributing participants)	**Classes**	**Themes**
LUS having multiple roles (1,5) Using LUS for quick real-time images (1,5,10) Using LUS as an assessment tool (1,3,5,6,7,9,10) Using LUS to monitor and track patient status and disease progression (1,3,6,7) Further investigation as an indication for LUS (1,3,5,6,7,9,10) The positive impact of LUS on clinical reasoning (5,6,7,10) Views on the impact LUS has on pathology identification and assessment (1,3,5,6,7,9,10) Views of LUS in relation to other assessment tools (1,3,5,6,7,9,10) Using LUS in management planning (1,3,5,6,7,9,10) Views on the impact LUS has on management planning (1,3,5,6,7,9,10) Potential impact of LUS on timely management (1,3,5,7) Reasons why management didn't change during the study (1,3,5,6,7,9,10)	LUS has multiple roles in physiotherapy practice	1. Views of physiotherapists on the use and influence of LUS in the cardiac surgery population.
Using LUS for the right patient (1,9) Acute respiratory issues as an indication for LUS (1,3,5,6,7,9,10) Views on using LUS with routine cardiothoracic patients (1,3,5,6,7,9,10) Views on using LUS with respiratory and critical care patients (1,7,10)	Choosing the right patient for LUS	
Views on physiotherapists performing LUS (1,3,5,6,7,9,10) Views on using LUS within the MDT (1,3,5,7) Performing LUS for colleagues (1,5,6,10) Views on roles of other healthcare professionals and LUS (3,6,10) Views on LUS and MDT working (1,3,5,6,7,9)	The use of LUS by physios in their practice and within the wider MDT	

Categories (Contributing participants)	**Classes**	**Themes**
Views on initial LUS interest and advancing respiratory physiotherapy practice (1,3,5,6,7,9,10) Views on the current impact of LUS on physiotherapy practice (1,3,5,6,7,9,10) Views on the potential for LUS to change the field (1,3,5,6,7,9,10) Views on the future impact and benefit of implementing LUS into practice (1,3,5,6,7,9,10) Views on the essentiality and importance of LUS (1,3,7,9) Views on prerequisites for physiotherapists performing LUS (1,3,5,6,7,9,10) Views on possible indications and roles of LUS (1,3,5,7,9,10)	Growing interest in and the future of LUS	2. Views of physiotherapists on skill development in LUS and importance within the field of respiratory physiotherapy.
Using LUS for intrapersonal reasons (1,3,5,7,9,10) The positive impact of LUS on intrapersonal factors (1,3,5,6,7,9,10)	The impact of LUS on intrapersonal factors	
Service-level barriers (1,3,5,6,7,9,10) Service-level facilitators (1,3,5,6,7,9) Overcoming barriers through service level changes (3,5,6,7,9,10) Lack of experience and exposure to LUS as a barrier (3,6,9,10) Exposure to LUS as a facilitator (1,3,6,7,9,10)	Overcoming barriers to using LUS at the service level	3. Barriers and facilitators to the use of LUS by physiotherapists within the cardiac surgery population.
Accessing and maintaining accreditation as a barrier (1,3,5,6,7,9,10) Overcoming barriers through institutional changes (1,3,5,6,7,9,10) Overcoming barriers through evidence (3,5,6,7,10) Overcoming barriers through external factors (3,6)	Overcoming barriers to using LUS at the institutional level and beyond	

4.11 Theme #1

> ***Theme #1:*** *Views of physiotherapists on the use and influence of lung ultrasound in the cardiac surgery population.*

This theme was constructed from three classes and 21 categories. This theme concerned the multiple roles of LUS and populations that would benefit from LUS-use. This theme also explored the use of LUS by physiotherapists and other healthcare professionals and the influence LUS has on perceived professional roles.

4.11.1 LUS has multiple roles in physiotherapy practice

LUS was described as a tool with multiple uses, including for assessment, monitoring, and planning patient management.

> *"I use it for a couple of roles, really, to assess and to continually track people's progress. But mainly their assessment." (PT1, accredited)*

Within patient assessment, it was used as part of the overall assessment as a diagnostic tool, enhancing the overall picture of the patient's respiratory status.

> *"Lung ultrasound is a diagnostic tool that medical professionals use, and it gives you an overall picture of how the mechanics of someone's breathing might be working from an ultrasound perspective, but also identifies either physiological changes or deterioration that can happen within the patient's lungs, for example, and around the interstitial fluid and tissue around the actual lungs itself." (PT10, no formal training)*

The most common pathologies found by LUS in day one non-emergency cardiac surgery population were reported to be atelectasis, consolidation, and pleural effusions.

> *"We can identify things such as pleural effusions, any consolidations, collapse." (PT5, accredited)*

All participants felt LUS played a role in and had an impact on their ability to identify pathologies. Lung ultrasound was described to improve and support pathology identification. The use of LUS reportedly provides clarity, confirmation, and confidence in identification, as well as reassurance to physiotherapists on their assessment skills.

> *"[LUS is] definitely a way to get a better understanding of our patient's pathology and the impact that the pathology has on us and the impact we can have on pathology. It's just another addition to get a better, more accurate idea of what's going on." (PT3, accredited)*

Several participants described LUS as having a role in tracking patient status and disease progression during their length of stay. Lung ultrasound was also reported to have a role in assessing the success of physiotherapy treatment by using LUS as an outcome measure before, during, and after treatment.

> *"Tracking patients – the long-termers – just to keep an eye on if they're going through weans, keeping an eye on their consolidations. And again, if you're doing treatment options like the Cough Assist or the Bird with them, then keeping an eye that we're actually achieving something rather than just doing it for the sake of doing it." (PT1, accredited)*

It was suggested LUS could have a role in disease prevention by identifying pathologies early on before severity increases.

> *"I think it could be used more frequently and maybe also earlier than maybe what we use it for now as a preventative strategy." (PT7, accreditation in progress)*

Most described LUS to have a role in differential diagnosis. A lack of patient improvement, a suspicion of a specific pathology, uncertainty after reviewing other imaging, and uncertainty of the cause of the patient's condition were all reported as indications for performing LUS.

> *"I would probably decide to do [LUS] if there's an inkling that maybe there's an effusion or if the patient's not progressing respiratory-wise, we're struggling to wean them off oxygen, and I just want to see what's going on properly, to see if it's anything I can help resolve or not." (PT5, accredited)*

> *"I think it's a case of when I'm not 100% certain based on my own assessment. Whether it might be a chest x-ray or something on there that doesn't quite fit the presentation or background of the patient." (PT9, no formal training)*

Participants felt LUS provides a clearer and more accurate picture of what is going on with the patient. Lung ultrasound was reported to improve the 'view' of the patient's chest, with physiotherapists performing LUS to view real-time live images of the patient's lungs during their assessment or treatment.

> *"So, if you want to know what's going on, right here, right now, then [LUS is] a brilliant tool to use because it's literally there in front of your eyes." (PT5, accredited)*

The perceived influence of LUS on identification varied slightly between the individual pathologies. Atelectasis was reported as easier to identify with or without LUS. Regardless, participants expected to be even more confident in their identification of atelectasis following LUS. Lung ultrasound was reported to be able to clearly identify pleural fluid.

> *"I think for me, the atelectasis is probably one of the easier things to know because there's more things that point in that direction… atelectasis is core to physio and more of our assessment techniques would look at that and indicate that. So, you'd be a bit more confident in saying that that was there or not." (PT1, accredited)*

> *"…lung ultrasound picks up quite clearly pleural fluid… obviously before the scan, it's a guess, isn't it? After the scan, it was very clear that it was yes or no. I think because it's such an easy pathology to identify with scanning, that just made me more certain of that." (PT3, accredited)*

A minority view was that LUS had a low impact on identifying pneumothorax for physiotherapists because it's rarely seen. It is reportedly difficult to identify pneumothorax with LUS and, therefore, participants reported performing LUS in addition to other resources in their assessment when suspecting a pneumothorax.

> *"In terms of a pneumothorax, I wouldn't solely use lung ultrasound to look for a pneumothorax. I'd probably still look for an x-ray" (PT3, accredited)*

> *"…finding a pneumothorax on a lung ultrasound is quite difficult as is it." (PT1, accredited)*

The physiotherapists reported incorporating CXR interpretation into their assessment more prior to becoming accredited to perform LUS. Lung ultrasound reportedly provides different imaging than either CXR or computerised tomography (CT). Others believed LUS to be better than CXR and auscultation, with LUS being more in-depth than auscultation. There were reported downsides to using CXR during assessment: the time between when the CXR was taken and the physiotherapist's assessment could show an inaccurate picture of how the patient is currently presenting; LUS shows pleural fluid more clearly than a CXR; a CXR is two dimensional and does not show function; LUS is quicker than waiting for a CXR if one has not been done yet; there is difficulty in differential diagnosing with CXR.

> *"Prior to using lung ultrasound, we did use – I mean, we still do – but we check out x-rays an awful lot. But obviously, if we have a look at an x-ray, it might have been done the day before in the evening and a lot can change in that time… obviously, it's more in-depth than the auscultation, as well. So, in terms of identifying pathologies, [LUS is] quite clear through that." (PT5, accredited)*

> *"…chest x-rays are two dimensional, it doesn't give you a 3D holistic viewpoint of what's actually going on and that real-life capture of how the patient's presenting from a lung perspective and how they're breathing." (PT10, no formal training)*

> *"…sometimes on the chest x-ray or even auscultation, it could be one of a few things in terms of differential diagnosis or treatment…[LUS] just helps to direct the team a little better in terms of differential diagnosis." (PT7, accreditation in progress)*

The participants universally felt LUS plays a role in and has an impact on their physiotherapy management planning. Participants shared that they chose to perform LUS when they were deciding which treatment option would be most appropriate for their patients. Lung ultrasound was reported to have a role in 'ruling out' contraindications to treatment, particularly 'ruling out' a pneumothorax to provide treatment with intermittent positive pressure breathing.

> *"Then if you're going to do something that might be imperative to the patient, how he's going to be in his treatment, and you want to be sure – like with positive pressure and things like that – you want to be sure, then, yeah." (PT9, no formal training)*

Some participants felt that prior to becoming accredited in LUS, they felt they provided ineffective treatment.

> *"Like I said, you can just indicate or contraindicate what treatment you're choosing. I use [LUS] an awful lot for that. I think in the past, I probably would have done a lot more that might not have benefited the patient. It might make me feel better that I feel like I've done something, but realistically, it's not going to help that patient. So, why am I doing it? You wouldn't normally do that. You wouldn't walk someone who's got a broken leg because you feel better for walking them. So, why would you? Yeah, it's exactly the same. You can't fix that problem. We just want to be able to fix it. But you might not necessarily be able to." (PT1, accredited)*

Most felt LUS helps to indicate physiotherapy management, providing clarity and confidence in treatment plans and facilitating team discussions. Many felt LUS has an impact on their clinical reasoning and felt that it could confirm or change their initial reasoning.

> *"It could maybe change people's clinical reasoning and have an impact on clinical reasoning what their next treatment is." (PT6, accreditation in progress)*

Lung ultrasound is reportedly used to decide if a patient is appropriate for physiotherapy treatment or if the patient requires medical management prior to physiotherapy input. Instead of spending time trying to treat a medical problem with physiotherapy, the participants shared that they could perform LUS and redirect the patient for appropriate medical management, which the participants reported could allow for quicker overall management of the patient.

> *"…I think it can identify pathologies which we may be able to help, which obviously then we've got a clear understanding it is this and we can have an effect on this, or it might actually identify pathologies which we can't help, but we can redirect them to the correct management so that that can be resolved first prior to us treating them…get that treated in a quicker time than if we're just guessing through x-rays or awaiting different reviews or scans…" (PT5, accredited)*

Many shared stories in which LUS changed their management in practice or described how LUS could possibly change treatment plans. In a minority view, however, some felt that LUS did not often change the management plan they already had in mind, but rather confirmed it or added on to it.

> *"It might mean that we do something more regularly. For example, if we're going to use positive pressure or the Bird, if we can see the significance of the lung ultrasound, we might want to do it twice a day rather than, before, we might have been thinking, "Oh, we'll just do it as a one-off." So, it might influence it from that point of view and keeping a closer eye on the patient." (PT7, accreditation in progress)*

Participants shared that they did not feel like they changed their management during the study due to LUS. Most felt their management did not change because their management plan pre-LUS remained suitable. Others felt it was because their patients were straightforward, routine patients.

> *"Because they're only day one patients, they weren't that complex, the ones I had as well, there was only so much you could do in the first day anyway. Your patients are either really tired – most of the time they're very fatigued day one – or they're in a lot of pain, and they're not willing to do that much. That's probably why I would say that my management wouldn't really change." (PT9, no formal training*

As most day one cardiac surgery patients tend to still have chest drains in, if pleural fluid was unexpectedly found with LUS, the participants reported that they anticipated that the fluid should drain and resolve, therefore not requiring the participants to take any further action.

> *"…because they did have a drain in, my thoughts would be that this would improve over the next day or so prior to taking the drains out. So, I don't think my physio intervention would have had any influence on that." (PT5, accredited)*

Weighing the risks of more aggressive treatment was another reported reason for not changing management upon seeing LUS results.

> *"Obviously, it's not all benefits from doing the aggressive treatment sooner. It can be more painful. It can lead to more cardiovascular instability, things like that. So, for me, it's not always 'Yes, they've got worse pathology than I thought, I should definitely do more aggressive treatment.' It's having the awareness that they have got this pathology going on and if they were not to improve or to show some small deterioration, then I'd escalate the treatment from there." (PT3, accredited)*

4.11.2 Choosing the right patient for LUS

The participants felt LUS is not beneficial for every patient and needs to be indicated due to limited clinical time. Several LUS indications were shared, including many acute respiratory issues. The most common indications reported were increased oxygen requirement, deterioration, and/or a patient struggling to wean oxygen or ventilation. Other reported indications included:

- Sputum retention
- Poor arterial blood gases
- Ventilated patients
- Patients with a tracheostomy
- Poor respiratory function
- Chest drains removed
- A non-routine patient
- A patient requiring continued chest physiotherapy input
- Patients treated during on-call

> *"So today, we've had a patient that's been on oxygen for the last two weeks flicking between the high flow nasal cannula and who we've been using positive pressure with, and then his CO2 has maybe just starting to creep up a little bit again. So, we had an auscultation, his bases sounded quiet. He's had a recent chest x-ray, which looks worse. So, for me, I felt that was a good indication to then do another [LUS] scan because he's not had one for two weeks." (PT6, accreditation in progress)*

Several believed that LUS is not as indicated for routine patients, particularly cardiothoracic patients or for the study population, day one post-cardiac surgery patients.

> *"I just don't think [LUS is] as indicated in the cardiothoracic population as much if they're more routine." (PT1, accredited)*

In contrast, a minority view was there were benefits to performing LUS on day one cardiac surgery patients, sharing that performing LUS helps with initial management and that LUS seemed to identify more pleural effusions during the study by performing LUS on every patient volunteer.

> *"Overall, it seemed to be that pleural effusions were picked up more than maybe if we didn't do the [LUS] scan on those day one patients." (PT7, accreditation in progress)*

LUS was reported to be indicated more for the general ITU population or for the long-term population.

> *"I used it more in general ITU, don't use it as much on Cardiothoracics, but on general, I use it every day without fail." (PT1, accredited)*

Lung ultrasound was suggested to play a role in weaning patients from oxygen or ventilation.

> *"In ICU, it could be helpful to guide weaning from ventilation." (PT3, accredited)*

Lung ultrasound was also suggested several times to be a valuable tool to use for assessment during on-call callouts.

> *"If I get called to any on-call, I'll take the scanner with me. I've got that straight away. I've got that there with me that I can use it as another technique to track my progress with my treatment. Or a lot of the times you come to these on-call type stuff and they'll say one thing and then it's completely opposite." (PT1, accredited)*

One participant felt LUS was in fact indicated in the CITU population. Other suggestions for populations indicated for LUS-use included patients on respiratory wards, GP practices with respiratory clinics and patients with chronic respiratory conditions.

4.11.3 The use of LUS by physiotherapists in their practice and within the wider MDT

Participants felt that physiotherapists should be the ones using LUS for physiotherapy purposes rather than other healthcare professionals, explaining it is part of their assessment and should be used in real-time at the time of treatment. As LUS is part of assessment and treatment, it was suggested it should then be the treating physiotherapist who performs LUS for their own patient.

> *"I think it is our responsibility because that's part of our assessment and our treatment. We wouldn't ask somebody else to auscultate and then we'll treat*

> *them off what they say because it's on our back, how we treat them, isn't it?" (PT5, accredited)*

If the treating physiotherapist is not accredited, it was suggested the treating physiotherapist should ask for someone who is accredited to perform LUS for them, with the accredited physiotherapist demonstrating and explaining the LUS findings for learning purposes.

> *"But obviously, in cases where the person isn't lung ultrasound trained, then they'll have to get someone that is. But, if that is the case, then I always think that the person who is doing the scans should be explaining to the physio that has asked for the scan to indicate them for their treatment." (PT1, accredited)*

Participants reported that their ability to perform LUS enhances patient care and gives physiotherapists more responsibility in patient care. It was suggested this could attract more people to the profession and speciality.

> *"It obviously would mean that physios have more responsibility when it comes to patient care because lung ultrasound is not just used for physio management, it's used for medical management. So, the role of physio would become more prominent, I'd say." (PT3, accredited)*

Participants felt comfortable with someone on their own team performing LUS on their patient for them, but some shared they may not feel the same with professionals outside of their department.

> *"I think in this office, because we've all had the same training, I would be confident letting somebody else scan my patient and telling me. If I went onto another team somewhere, I might feel different because I don't know them." (PT5, accredited)*

In contrast, some participants reported that although they feel physiotherapists should perform LUS for themselves, they have reportedly used LUS images captured by other healthcare professionals to indicate their treatment previously.

> *"A lot of the time we'll look at their scans and use that as evidence for our treatment, but it's normally nicer to get that picture yourself." (PT1, accredited)*

The LUS scans performed by physiotherapists could reportedly be used for medical management, and if it supported their own clinical reasoning, some reported they would perform LUS on a patient for medical staff if they requested. It was reportedly nice to help the medical staff by performing LUS for them.

> *"I think the doctors do appreciate it as support for their medical plan as well as our physio plan." (PT3, accredited)*

Participants feel since physiotherapists started becoming accredited in and performing LUS, there has been an increase in respect from medical staff.

> *"I think they've seen that we've got those more expert skills." (PT1, accredited)*

Doctors have reportedly begun to ask physiotherapists to perform LUS for them. In particular, the participants report doctors ask physiotherapists to perform LUS to identify and measure the size of pleural effusions, which they report is out of their scope of practice. Some participants shared they have been asked by doctors to help inform decisions on chest drain insertions, which they reported is also out of their scope of practice. It was shared this has sometimes resulted in the physiotherapists having to tell the medical staff no to their request, and most feel performing LUS for these reasons is not within the physiotherapist's job role.

> *"…we might have the doctors asking us to scan because they want to know if they can put a drain in and I don't think that's our responsibility. We shouldn't be there to be measuring the size of pleural effusion and whether that's appropriate for a drain or not because we don't insert the drains. I don't think that should be on us. We tell them no anyway." (PT5, accredited)*

However, there were mixed views from the participants on LUS-use and MDT working. It was felt that previously, doctors may not have been interested in the discussion around physiotherapy treatment. Lung ultrasound, however, reportedly gives them common ground since it is performed by both professions.

> *"You have a mutual ground to talk about because there are other professions that are also using lung ultrasound. So, when you're talking to them about your findings or what you thinking, they understand, whereas sometimes if you're*

> *talking to them about exercises, as an example, that we use as physios, they're not interested because it doesn't benefit them. They don't need to know what they don't need to know, whereas this will bring a common ground…" (PT7, accreditation in progress)*

LUS reportedly provides evidence of inappropriate physiotherapy referrals and provides the confidence to discuss the need for medical management with the MDT. Overall, many felt their ability to perform LUS promoted more MDT conversations.

> *"…the massive positive from it is that you do get involved in more of the advanced discussions that you probably wouldn't have done before. So then when you've then got other issues that you need to discuss, whether it's with a wean or something else treatment-wise that you think is relevant, you're already respected because you've got those skills that you can feel like you can approach the doctors and the consultants to have further discussions." (PT1, accredited)*

4.12 Theme #2

> ***Theme #2:** Views of physiotherapists on skill development in lung ultrasound and its importance within the field of respiratory physiotherapy.*

This theme was created from two classes which encompass nine categories. The theme explores the participants' initial interest in LUS, their thoughts on the current impact and essentiality of LUS in their practice, their thoughts on who should be performing LUS within the physiotherapy team, and the potential impact and change LUS could bring to the field in the future.

4.12.1 Growing interest in, and the future of, LUS

The participants reported several reasons for their initial interest in LUS. Some had an interest in respiratory physiotherapy which led them to become interested in LUS. Lung ultrasound was recognised as an advanced respiratory skill associated with seniority and experience, and therefore many reported becoming interested in LUS for personal and professional development. Some shared they wanted to add LUS as another tool in their toolbox while others shared they became interested in LUS due to the impact it has on physiotherapy practice.

> *"And then when I started, I just liked respiratory and it was just an advanced skill in respiratory that I knew people were using, and so I tried to get myself into the training as quick as possible…" (PT1, accredited)*

> *"It's learning a new skill. It was quite a new upcoming skill in physio. It's obviously still only a hundred or so people in the country that can do it." (PT3, accredited)*

When asked if they felt LUS had an impact on physiotherapy practice, the majority reported that it does.

> *"Yeah, absolutely. I mean it definitely gives you, like I said before, the accurate picture of what's going on with the patient… Obviously, I believe it's beneficial. It's just to improve the accuracy of what we think is going on." (PT3, accredited)*

Some felt the level of impact was dependent on the area and team where LUS was performed. Specifically, some felt LUS would impact respiratory and critical care areas.

> *"Obviously, the critical care areas, as we've spoken about, I think they would impact from it." (PT6, accreditation in progress)*

Less commonly, some held mixed views on whether LUS would impact physiotherapy practice.

> *"Yes and no. Yes, because it's nice to sometimes confirm what you're already thinking for the patient and it gives you that extra clinical reasoning. Everything else that you've already used in your assessment, your auscultation, your chest x-ray, your physical assessment, all of those things, it just adds further confirmation. But when I've been writing my conclusions as to what I'm going to do for the patient, most of the time I was already thinking I was going to do that anyway." (PT7, accreditation in progress)*

While one participant was hesitant on who should perform LUS within the physiotherapy team, most felt LUS requires experience in respiratory physiotherapy and seniority. Some specified LUS should be performed by Band 6 physiotherapists and above. Band 5 physiotherapists were not ruled out by the participants, but it was suggested it would be difficult for Band 5 physiotherapists to become accredited due to short rotations into possibly non-respiratory areas. It was added that not everyone can be trained who rotates into their department because it would be too much for their trainer.

> *"I'm hesitating here because you could obviously argue it a little bit. Definitely Band 6 and above. There's no reason why maybe Band 5 couldn't do that, but it would depend on that individual as a person, how long they've been practising for, how long they've been working in that certain area, how confident they would feel to do it. I think that's a little bit more subjective. I wouldn't want to say I'd rule that out." (PT7, accreditation in progress)*

> *"I mean, it should be respiratory practitioners. In terms of the resource… you can't train everybody. It's too much for [the trainer] to control. I think the more experience you've had with that population, the better." (PT1, accredited)*

The participants universally felt physiotherapy would benefit from implementing LUS into practice, with views that LUS might result in more prominent roles and responsibilities for physiotherapists and LUS may reportedly increase interest in respiratory physiotherapy. Increasing awareness of LUS was suggested as a way to improve the impact and benefit it could have on the field.

> *"I think overall, yes… I'm just thinking holistically in terms of other respiratory patients and not just in a CITU environment, in different environments, [LUS] could be beneficial." (PT10, no formal training)*

> *"It might be that students that are interested in the medical side, medical management of things, they may be more interested in going down the physio route. I know respiratory is not always seen as a desirable area to specialise in. So, I definitely can see [LUS] attracting more interest…" (PT3, accredited)*

There were mixed views on whether LUS would change the field. Some felt LUS would change the field of respiratory physiotherapy significantly. Most shared they felt LUS could possibly significantly change the field for specific areas of physiotherapy practice and/or populations.

> *"Yeah, quite significant. I think if you did your study across the whole field of respiratory physio, I think you'd find that a lot of the time it would indicate that you may change treatment or that people would have ordered them and indicated there's something different than they thought in the first place." (PT1, accredited)*

In contrast, some felt that LUS would not necessarily change the field. Others felt if LUS did change the field, the change would not be significant, explaining service-level barriers could prevent the change from being significant.

> *"We might scan somebody, but it doesn't mean we make all decisions about the treatment of that patient. So, it might make a significant improvement of identifying pathologies quicker. But whether that means they get treated quicker or not I think depends on the wider team, doesn't it?" (PT5, accredited)*

Some expressed LUS plays an important and valuable role for them in their practice. Lung ultrasound is reportedly always appreciated by other members of the team and there's always something to learn from the findings. However, it was felt LUS is not essential or necessary for every patient and it was cautioned LUS should be clinically reasoned to use.

> *"I think it has its place, but I don't think it necessarily needs to be used on every single patient routinely. I think it should still be clinically reasoned to use if we feel it's going to change the management or change the benefits to the patient or to the physio for learning and clinical reasoning." (PT7, accreditation in progress)*

After hearing the quantitative results, the participants shared several ideas on potential roles and indications for LUS. It was reflected that they may need LUS more than originally thought, expressing LUS may potentially have a role in finding unexpected pathologies if used more often.

> *"But obviously, the results show that there is maybe more potential for it than what we realised at the time because it's then found things." (PT7, accreditation in progress)*

Even if a pathology is identified that is not an immediate concern, it was commented LUS could increase awareness of any pathology that may risk deterioration, which could then allow for quicker escalation in treatment if deterioration begins.

> *"I felt from the experience that I had that quite often it wouldn't always change my immediate actions, but it definitely made me consider escalating the treatment sooner if the patient didn't improve or showed deterioration. I'd be more aware of the reason why and be able to escalate the treatment probably sooner." (PT3, accredited)*

One participant felt that this could result in less callouts out of normal working hours. Emergency cardiac surgery patients were suggested to possibly be more indicated for LUS rather than patients on the elective or inpatient pathway. Lung ultrasound was also suggested to potentially benefit community respiratory patients.

> *"Maybe your emergency patients rather than your elective? I think with your elective ones… obviously, they have the pre-operative clinics and they kind of know what to expect… whereas, obviously, an emergency patient, it's all a bit of a shock to them and they might not want to do any of these exercises. And actually in turn, that can have an adverse effect on their recovery." (PT5, accredited)*

Others suggested if the study was done several days or a week after surgery, there may have been more pathologies discovered or changes in management.

> *"…I would probably request a lung ultrasound further down the line maybe. I think it would show probably a bit more." (PT9, no formal training)*

4.12.2 The impact of LUS on intrapersonal factors

LUS was reported to have a role in confirming or clarifying pathology identification and/or management planning. Lung ultrasound was shared to provide peace of mind when worried about a patient. Others discussed that LUS had a role in learning and development, with those with less experience discussing the role of LUS in improving confidence in their respiratory physiotherapy practice.

> *"When I did it, I did feel – with having the inexperience and being only about four or five weeks into this respiratory rotation – I think having that ability to have that opportunity to have lung ultrasound there and available to help with my assessment did actually help massively with my confidence…" (PT10, no formal training)*

> *"…in terms of getting the lung ultrasound, maybe I was just worried about the patient, and it was peace of mind I was looking for or maybe they weren't doing very well, but it was for the reasons that I already thought." (PT3, accredited)*

Most shared that LUS has improved their confidence, with one participant sharing there may have been false sense of confidence before engaging with LUS.

“Well, I think it’s obviously interesting that the ones that I thought I was quite happy with actually were the ones that it was more likely that something was there that I wasn’t expecting.” (PT3, accredited)

Lung ultrasound was reported to provide clarity, with some describing how LUS provides confirmation of their clinical reasoning and what they were already thinking.

“I think it's with confidence, really. It helps you become more confident that, "Oh yeah, that is definitely what I'm seeing." I do think it was helpful in that way, especially for me, learning still, in the beginning, it just gives you more confidence that, okay, I'm going to treat this patient better because I'm able to identify that this is the exact pathology that they have.” (PT9, no formal training)

4.13 Theme #3

Theme #3: *Barriers and facilitators to the use of lung ultrasound by physiotherapists within the cardiac surgery population.*

Nine categories were organised into the two classes that this theme comprises. This theme explores overcoming barriers from two different levels: service and institutional.

4.13.1 Overcoming barriers to using LUS at the service level

The participants reported multiple barriers, facilitators, and ways of overcoming barriers at the service level. There were many reported facilitators to performing LUS with most reporting that they had access to machines which might not be as readily available in other hospitals. It was a common view of the participants that their use of LUS is well-supported by the MDT and departmental staff with accredited staff available to support and facilitate use for those without accreditation. Their access to LUS training was seen as a facilitator as this department was reported as having many mentors available to support trainees.

“Here in particular, we have [lead/trainer]. That makes it much easier to do it here than it would do maybe in a different hospital for someone that doesn’t have a main lead or a main trainer… We do have scanners in the area that we work on

> *here, which is a benefit because other areas might not necessarily have them to hand." (PT7, accreditation in progress)*

> *"The medical teams as well, I guess like on ITU and on here, they're quite – respect that we can do it and that they'll value our findings." (PT1, accredited)*

Most became interested in using LUS in their practice due to exposure through their university, placement, clinical rotations, and/or social media.

> *"They invite the students that we have to go and sit in on the courses as well, which I think is good for them to get an insight because maybe when they become qualified, it might be something that they endeavour to complete to build in the workforce." (PT6, accreditation in progress)*

> *"It's getting a bigger presence on social media." (PT3, accredited)*

Time was reported to be a barrier at the service level. Time to conduct LUS was found to be a challenge due to issues such as staffing pressures and competing demands, i.e., performing LUS at the expense of clinical time with patients. Those not accredited to perform LUS reported that it took time to find someone accredited to perform the LUS for them.

> *"So, the time it would take to go and get the scanner, do the scan, return the scanner, it could take a good 25 minutes, half an hour. You've got to be pretty sure that that assessment technique now is indicated because that's a good chunk of your time and the chunk of your day that you need or could be seeing someone else. But if the resource was there 24/7 and it's always there available, then we'd probably use it a lot more." (PT1, accredited)*

A lack of easily accessible LUS equipment either due to the location of equipment or the low number of machines available at any one time was reported as a barrier, as well as the low quality of certain machines.

> *"I like to use the equipment that's in department and not the scanner that's on CITU because it's not a very good scanner. So, obviously, then I'd have to walk to the department, which is the opposite end of the hospital, so it can just be about convenience and time, etc." (PT7, accreditation in progress)*

Despite the participants reporting having access to accredited staff to perform LUS when not accredited themselves, some still described having to get another member of staff involved as a barrier to using LUS to support their own practice. There was reportedly hesitation to request LUS due to the required time and resources if it wasn't clear anything would change for the patient. A lack of staff support from within the department or the wider MDT was mentioned as a possible barrier outside of this hospital, but most felt they were well-supported in their own department. A minority view was that the appropriateness of LUS for the patient could be a barrier, such as large amounts of adipose tissues or difficulty in positioning the patient.

> *"…do I need them to go and get someone and then them to diagnose it – we're obviously timebound as well, so they're going to take time out of their day to come and do it, to then find something that I was already thinking of that could potentially be there. So, I think that was the reason why I wouldn't have ordered them." (PT10, no formal training)*

Some felt their inexperience and incompetency in the respiratory and cardiac populations was a barrier to using LUS in their practice.

> *"I haven't done only because mostly at the minute I'm still learning everything and I don't think it's very easy" (PT9, no formal training)*
>
> *"…it's so early within my career, still getting my head around all the other aspects of doing respiratory physio on the intensive care unit that that's my focus at the moment" (PT10, no formal training)*

There was also a mention by other participants that a lack of awareness of LUS is a barrier to using it in practice.

> *"Not necessarily actually training on [LUS], but knowledge of what it does and that it is something that physios can train in. I don't think many people would be fully aware that it is something that they can do." (PT3, accredited)*

The participants discussed several strategies to overcome barriers at the service level. Peer support for those in the process of accreditation or already accredited was suggested as a way to increase the number of mentors and those performing LUS in practice.

> *"Whether there could be more network between existing mentors and support, things like that, to try and offer more support between existing mentors to help bring through more experience and more people." (PT3, accredited)*

It was suggested LUS should be introduced through clinical rotations, introductory CPD, and presenting LUS research at conferences to further increase the education on and exposure to LUS.

> *"I just think there should be just a bit more education on it when new rotational band fives or sixes do come on just to explain that, 'Oh, this is this as well, and this is when we can use it.' Just a bit more education on it. If it's available and who's available to do it… just a little bit more information." (PT9, no formal training)*

The more LUS is integrated into practice, the more it was felt it may drive institutional change to facilitate regular use in practice.

> *"Yeah, I think if it was used more often and it was recognised as a national tool for physios to use and not just one that's ad hoc within each trust. Can it be implemented into university studies, etc, as a tool that we can use?" (PT6, accreditation in progress)*

Managing the caseload distribution during morning handovers was suggested to allow for time to perform LUS clinically or allow those training to perform training scans.

> *"You could look at case management, and then you could even cluster your patients that need lung ultrasound and put them into an order and prioritise them, or you could spread them out over the day depending on what's being handed over in the morning. And then you could, in terms of effective timing, go to your most priority ones that may be day ones, it could be someone who's gone off from a chest point of view." (PT10, no formal training)*

4.13.2 Overcoming barriers at the institutional level and beyond

There were many views surrounding barriers, facilitators, and overcoming barriers at the institutional level and beyond. All the participants discussed barriers associated with accessing and maintaining LUS accreditation. Time to become accredited was expressed as a barrier. Many discussed barriers to accessing training in the first place, such as access to funding, location of training, and prerequisites (e.g., band 6 job post). A lack of mentor availability in other health boards was thought to possibly impact the number of LUS accreditations.

> *"Accessibility to the mentors to take your through the supervised scans. Access to the actual introduction course… The regional spread, like I said earlier, it's not good at the minute in terms of having equal opportunity across the country. It's just not there at the minute… I know from speaking to [a friend] that's something they would be interested in, but it's just not supported in their trust. Unless you really push for it, it's not easy to come by." (PT3, accredited)*

> *"I'd expressed an interest for quite a while, maybe in the last 18 months, I would say. The criteria changed within the trust… Declined a couple of times due to the area that I was on, and then was allowed to go in it when I was moved on to respiratory..." (PT6, accreditation in progress)*

Maintaining LUS skills after accreditation was also seen as a barrier.

> *"…I have heard that you need to keep up with the practice and if you are rotating to a different area, you won't be doing it. Then it goes to waste, all of the time that you would spend accrediting someone." (PT9, no formal training)*

The participants discussed strategies on how barriers at the institutional level could be addressed. More funding was thought to allow for increased accessibility of quality equipment and training, but some recognised gaining funding may be difficult to achieve. To gain funding, it was suggested to show the importance of LUS through producing research evidence and building business cases to present to health boards for funding.

> *"We could apply for funding through our [organisation] charity to purchase equipment or maybe have meetings with the stakeholders on cardiac to potentially fund better equipment from their budget. Maybe doing some [continuing professional development] events to speak more about the lung ultrasound." (PT6, accreditation in progress)*

> *"It's obviously looking at something that's new and upcoming, which is hugely important. I think any support that we can get from research to suggest that it's an important role, it will help roll it out further across the country." (PT3, accredited)*

Some felt there was a need for more mentors to support training physiotherapists but suggested that this may just require more time for experience to grow.

> *"I think it just needs time… We need more mentors, but to become a mentor, you need experience. You need time to get used to the skills." (PT3, accredited)*

Box 4.1 Barriers & Facilitators to engaging with LUS.

Facilitators

- Access to LUS equipment
- Support from the MDT and departmental staff
- Availability of LUS accredited staff
- Access to LUS accreditation
- Access to mentors
- Exposure to LUS

Barriers

- Time
  - Time to conduct LUS
  - Time to find someone accredited in LUS
  - Time to obtain a quality LUS machine
- Access to quality LUS equipment
- Lack of staff support
- Staffing pressures
- Inexperience/Incompetency
- Lack of LUS awareness
- Accreditation
  - Lack of access to accreditation pathways
  - Lack of mentors
  - Difficulty maintaining competency

Potential Solutions

- Peer support for those accredited, gaining accreditation, and mentors
- Increase exposure to LUS
- Integrate LUS into practice further
- Caseload management
- Funding
- Building a business case with evidence of benefits

4.14 Summary of Qualitative Findings

The qualitative phase has explored a range of views on the use of LUS by physiotherapists in the cardiac surgery population and throughout the field of respiratory physiotherapy. This is the first piece of qualitative research to be conducted with cardiothoracic physiotherapists on the use of LUS in their practice. This work adds to the limited knowledge base on the perceptions and experiences of physiotherapists who are performing LUS as part of their practice.

The most commonly reported roles of LUS within respiratory physiotherapy practice was for pathology identification and management planning. The participants described using LUS to track patient status and pathology progression, for real-time live imaging, and for intrapersonal reasons, as well. While most of the participants didn't seem to find LUS to be indicated for the study population, many suggested populations in which LUS may be more indicated, mainly acute respiratory patients and those with poor respiratory status. Lung ultrasound was described by some of the participants as a tool for further investigation when there is an unknown cause for the patient's presenting condition and found LUS to provide clarity in these situations. The main facilitators to engaging with LUS reported in the qualitative phase were support from staff and the MDT, exposure to LUS, access to equipment, and access to mentors. The main service-level barriers to engaging with LUS were time, access to quality equipment, and staffing pressures; the main institutional-level barriers were accessing and maintaining accreditation, time to become accredited, and a lack of available mentors. The participants shared several ways of overcoming service-level barriers to engaging with LUS, including peer support for those accredited or in the process of accreditation; increasing education and exposure to LUS through university modules, clinical rotations, CPD, and social media; integrating LUS into practice to drive institutional change; and managing the caseload to support LUS training and use. Several solutions for institutional-level barriers were also shared, including more funding for quality equipment and access to accreditation; conducting further research; and collating evidence to build a business case for funding.

4.15 Conclusion

This chapter reported the results from the primary research. The quantitative phase empirically assessed the influence of LUS on the assessment of day one non-emergency cardiac surgery patients, finding a high influence on pathology identification and confidence, but a low influence on management planning. Lung ultrasound appeared to influence the identification of and confidence in pleural fluid the most of the three pathologies. The topics explored in the qualitative phase were organised into three themes and discussed the range of views held by physiotherapists on the use and influence of LUS in the cardiac surgery population, skill development, current and future use, importance, and barriers and facilitators. The next chapter begins by integrating the data at the interpretation and reporting level through a statistics-by-themes joint display, the construction of meta-inferences, and weaves both of the quantitative and qualitative findings together narratively. The chapter continues with an in-depth discussion of the findings within the broader context.

5. DATA INTEGRATION & DISCUSSION

The previous chapter presented the results from the primary doctoral research. The preliminary data from the quantitative phase informed the qualitative phase. The data from both phases were then analysed and interpreted separately. The next stage of the fully integrated convergent mixed methods study was to merge and integrate the datasets. This next chapter presents the integration of both phases, placing the quantitative and qualitative findings side by side in a statistics-by-themes joint display (Fetters, Curry and Creswell 2013), and presents the meta-inferences (Teddlie and Tashakkori 2009) from the study. The chapter then continues by discussing the culmination of this body of research, how this doctoral work addressed the research objectives, and placing the findings into the larger context of physiotherapy practice.

5.1 Convergent Mixed Methods Data Integration

The findings from both the quantitative and qualitative phases were integrated in the form of a joint display, presented in Table 5.1. The first and second column present the inferences from the quantitative and qualitative phases with exemplar statistics and quotes. The third column presents the merging of the inferences from both phases and the wider literature along with the correlating meta-inference(s). This study resulted in ten meta-inferences, seen below. The following sections further explore the integrated analysis, weaving statistics and themes narratively, while addressing the research objectives.

5.1.1 Meta-inferences

Meta-inference #1: Lung ultrasound has an influence on pathology identification.

Meta-inference #2: Lung ultrasound may find unexpected pathologies.

Meta-inference #3: Lung ultrasound can change the perceived presence or absence of pathology.

Meta-inference #4: Atelectasis is easier to identify by standard physiotherapy assessment than pleural fluid or pneumothorax.

Meta-inference #5: Lung ultrasound influences the identification of pleural fluid by physiotherapists more than atelectasis and pneumothorax.

Meta-inference #6: Lung ultrasound improves confidence and certainty, providing clarity and confirmation in pathology identification for physiotherapists.

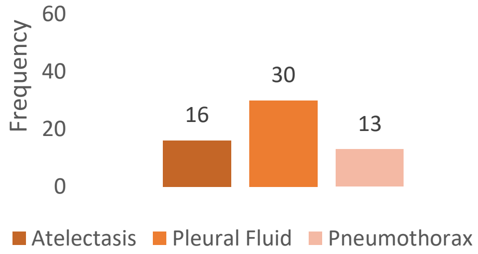
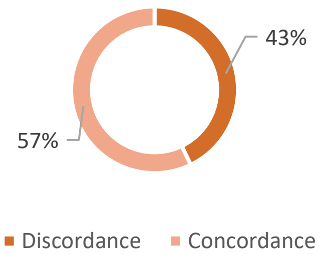
Meta-inference #7: Lung ultrasound may have more influence on pathology identification for physiotherapists with less experience.

Meta-inference #8: Lung ultrasound seldom influences physiotherapy management for day one non-emergency cardiac surgery patients for several reasons.

Meta-inference #9: Lung ultrasound is seldom performed by physiotherapists for day one non-emergency cardiac surgery patients for several reasons.

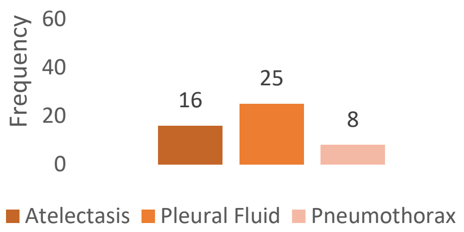
Meta-inference #10: Indications for Lung ultrasound may be based on patient presentation rather than demographic or surgery related.

Table 5.1 Data Integration Joint Display.

Quantitative Inferences	Qualitative Inferences	Meta-Inferences
Pathology Probability: LUS changed the physiotherapist's best guess as to the probability of the pathologies by more than 25% in 66.2% of cases (n=51). 	**Views on the impact LUS has on pathology identification and assessment:** It was universally agreed LUS influences pathology identification. *"It just gives a clearer identification and at that moment in time… obviously, it's more in-depth than the auscultation, as well." (PT5, Static B6, accredited)*	**Confirmed.** Lung ultrasound was reported to have an influence on pathology identification in the interviews, demonstrated by more than half of the cases seeing a shift in probability of more than 25%. This agrees with the literature which shows LUS to be a more accurate and reliable diagnostic tool than CXR and auscultation for all three pathologies. *1. Lung ultrasound has an influence on pathology identification.*
Discordant Clinical Impressions: The physiotherapists' and LUS Scanners' clinical impressions were discordant in 43% of cases (n=33). 	**Views on possible indications and roles of LUS:** LUS was reported to have a potential role in identifying unexpected pathologies. *"…the results show that there is maybe more potential for it than what I realised at the time because it's then found things." (PT7, Static B6, accreditation in progress)* *"Sometimes it all looks okay, but it might not necessarily be when you look at different ways of identifying issues." (PT1, Rot Resp B6, accredited)*	**Expanded.** Lung ultrasound was described as having a role in identifying unexpected pathologies and explains why the LUS Scanners identified something unexpected in 43% of cases. While the qualitative findings confirm the quantitative, the LUS literature is varied regarding discordance rates likely due to different populations and settings. The study findings are neither confirming nor discordant with the literature, but rather they expand the knowledge base for this specific population. *1. Lung ultrasound has an influence on pathology identification.* *2. Lung ultrasound may identify unexpected pathologies.*

Quantitative Inferences

Re-categorisation Post-LUS:
LUS changed the physiotherapist's perception on whether one or more of the pathologies was present or absent in 57.1% of cases (n=44).



Qualitative Inferences

Views on the impact LUS has on pathology identification and assessment: Participant felt pneumothoraces are rarely seen, atelectasis is easier to identify with or without LUS, and pleural fluid was more difficult to identify without LUS.

"I think for me, the atelectasis is probably one of the easier things to know because there's more things that point in that direction. Whereas pleural fluid is a bit more difficult to decide. It might be just because we don't potentially have a huge impact on that; so, an awareness of the chest drains and the fluid balance and what medications they're needing to sustain their BP in theatre, what products they've needed, it's not as looked at in detail when it comes to a physio assessment as the indications for atelectasis." (PT3, Rot Resp B6, accredited)

"Overall, it seemed to be that pleural effusions were picked up more than maybe if we didn't do the [LUS] scan on those day one patients." (PT7, Static B6, accreditation in progress)

"In terms of pneumothorax, I've not seen one yet on the lung ultrasound, so it's not something that I would necessarily say has an impact on physiotherapy." (PT4, Static B6, accreditation in progress)

Meta-Inferences

Expanded. The pathology re-categorisation following LUS in over half of the cases is explained by the reported impact LUS has on pathology identification from the interviews. It was explained atelectasis is an easier pathology to identify with or without LUS, explaining the lower rate of re-categorisation. Participants reported pleural fluid to be difficult to identify without LUS, while also reporting LUS clearly identifies pleural fluid, explaining the higher rate of re-categorisation for pleural fluid. Pneumothorax was reportedly rarely seen which may explain the low rate of re-categorisation if a pneumothorax is not anticipated. The qualitative findings confirm the quantitative, the overall study findings agree with a portion of critical care LUS literature and expands the knowledge base concerning this specific population and setting.

1. Lung ultrasound has an influence on pathology identification.

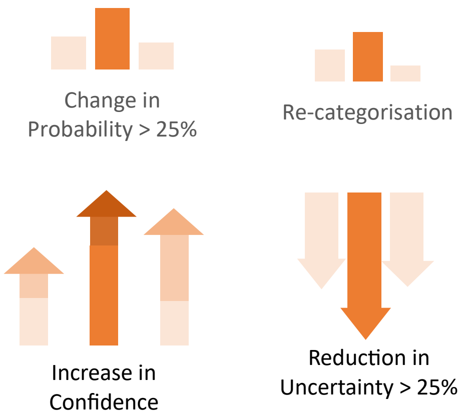
2. Lung ultrasound may identify unexpected pathologies.

3. Lung ultrasound can change the perceived presence or absence of pathology.

4. Atelectasis is easier to identify by standard physiotherapy assessment than pleural fluid or pneumothorax.

Quantitative Inferences

Identifying Pleural Fluid:
The identification of pleural fluid was affected by LUS more than atelectasis and pneumothorax.



Qualitative Inferences

Views on the impact LUS has on pathology identification and assessment: LUS was reported to clearly identify pleural fluid, even describing identifying pleural fluid with standard assessment tools as a guess and was frequently used as an example of the impact LUS has on pathology identification. Participants were surprised at the amount of unexpected pleural fluid identified in the study population.

"I think that was probably when it's clarified whether they've had an effusion or not, because like you said, I wouldn't have been able to identify that 100% by an x-ray or auscultation, whereas following the lung ultrasound, it's obviously come up with that." (PT5, Static B6, accredited)

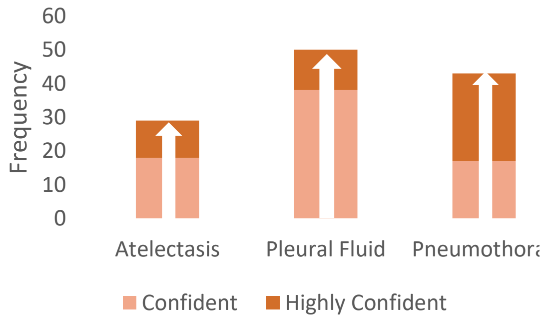
Meta-Inferences

Expanded. The larger effect LUS had on the identification of pleural fluid was explained by the qualitative findings which found LUS more clearly identifies pleural fluid than standard assessment tools. The findings from this study agree with the literature, which finds LUS to have a high diagnostic accuracy for pleural fluid and expands the knowledge base with the new knowledge that LUS may be more influential towards the identification of pleural fluid than atelectasis or pneumothorax.

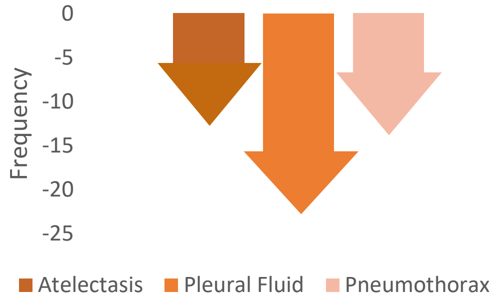
5. Lung ultrasound influences the identification of pleural fluid by physiotherapists more than atelectasis and pneumothorax.

Quantitative Inferences

Increase of Confidence in Probability & Reduction in Uncertainty:
LUS increased the strength of the physiotherapist's best guess as to the probability of the pathology in most cases (n=65; 84.4%) and there was a clear reduction in uncertainty for all pathologies.



Reduction in Uncertainty more than 25% Post-LUS



Qualitative Inferences

The positive impact of LUS on intrapersonal factors: Most participant reported LUS improved their confidence, providing confirmation and clarity.

"…it's nice to sometimes confirm what you're already thinking for the patient and it gives you that extra clinical reasoning. Everything else that you've already used in your assessment, your auscultation, your chest x-ray, your physical assessment, all of those things, it just adds further confirmation." (PT7, Static B6, accreditation in progress)

"The more things that point a certain direction, the more confident and more happy you'd be able to be sure of your diagnosis… I'd feel more confident and then maybe be more confident overall putting it higher up the scale" (PT3, Rot Resp B6, accredited)

"I think it's with confidence, really. It helps you become more confident that, 'Oh yeah, that is definitely what I'm seeing.' I do think it was helpful in that way, especially for me, learning still, in the beginning, it just gives you more confidence that, okay, I'm going to treat this patient better because I'm able to identify that this is the exact pathology that they have." (PT9, Rot B5, not accredited)

Meta-Inferences

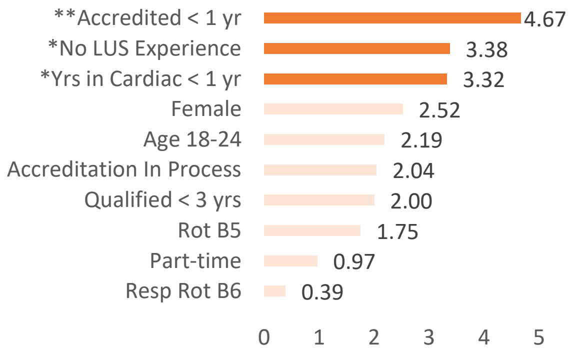
Expanded. The universal increase of confidence in probability and reduction in uncertainty for all pathologies was explained by the reported role of LUS in enhancing confidence, confirmation, and clarity. This study expands on the current literature which also finds LUS to improve confidence by providing confirmatory qualitative findings.

1. Lung ultrasound has an influence on pathology identification.

6. Lung ultrasound improves confidence and certainty, providing clarity and confirmation in pathology identification for physiotherapists.

Quantitative Inferences

Discordant Clinical Impressions & Less Experience:
Less than a year of experience with cardiac surgery patients ($OR_{>1:<1}=3.32$, $p=0.014$), no lung ultrasound experience ($OR_{accredited:none}=3.38$, $p=0.026$), and less than a year accredited or absence of accreditation ($OR_{>1:<1}=4.67$, $p=0.007$) were significantly associated with and had higher odds for discordant clinical impressions.



Qualitative Inferences

Views on the impact LUS has on pathology identification and assessment: Those with more experience reported having higher confidence in their clinical impressions due to their experience, and those with less experience reported feeling like their inexperience impacted their experience with LUS.

"That didn't surprise me as much. I've worked on it long enough to feel like I have good enough eye for it." (PT1, Rot Resp B6, accredited)

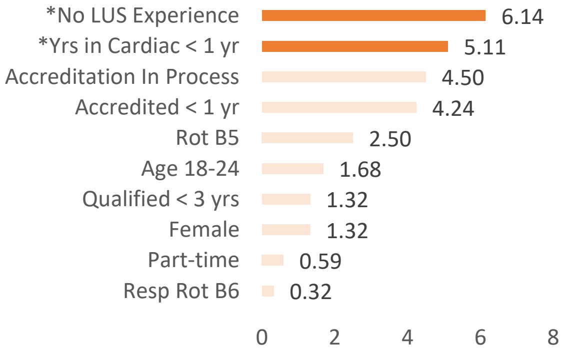
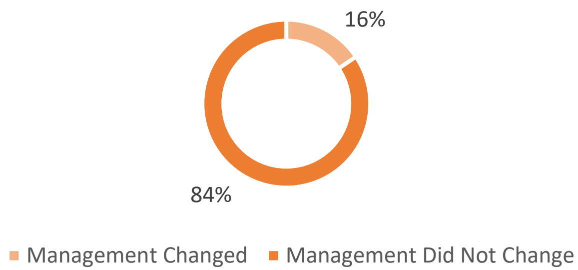
"I didn't know that much about [LUS]. When we should use it and things like that… for someone to request one, you'd have to know what you're looking for." (PT9, Rot B5, not accredited)

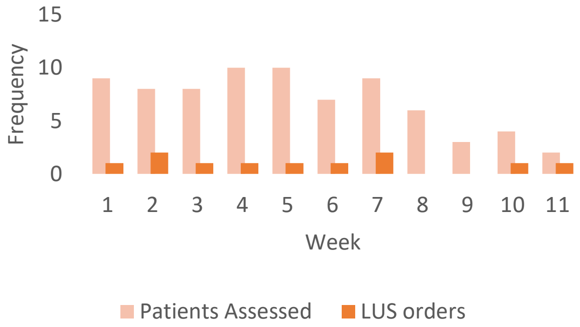
Meta-Inferences

Confirmed. Those with less experience with the study population, no LUS experience, and/or less than a year of LUS accreditation having higher odds of discordant clinical impressions was explained by the reported confidence of the participants. The findings are consistent with the literature which finds novice physiotherapists experience more uncertainty and surprise during the clinical decision-making process.

1. Lung ultrasound has an influence on pathology identification.

7. Lung ultrasound may have more influence on pathology identification for physiotherapists with less experience.

Quantitative Inferences	Qualitative Inferences	Meta-Inferences
Re-Categorisation for Atelectasis & Less Experience: Less than a year of experience with cardiac surgery patients ($OR_{>1:<1}$=5.11, p=0.018) and no lung ultrasound experience ($OR_{accredited:none}$=6.14, p=0.028) were significantly associated with re-categorisation of atelectasis following LUS. 	**Views on the impact LUS has on pathology identification and assessment:** Those with more experience reported atelectasis to be easier to identify with standard assessment tools, while those with less experience discussed several differentials for atelectasis. *"…atelectasis is core to physio and more of our assessment techniques would look at that and indicate that. So, you'd be a bit more confident in saying that that was there or not." (PT3, Rot Resp B6, accredited)* *"When I was comparing lung ultrasound to chest x-ray, haziness could be consolidation, atelectasis, or it could be long-term COPD. It could be quite a lot of pathologies that look similar to atelectasis." (PT10, Rot B5, not accredited)*	**Confirmed.** Those with less experience with the study population and/or no LUS experience had a higher chance of re-categorising atelectasis after LUS; this is explained by the qualitative phase which found atelectasis was reported by B6s to be one of the easier pathologies to identify without LUS, while one B5 reported many pathologies could look like atelectasis. The findings are consistent with the literature which finds novice physiotherapists experience more uncertainty and surprise during the clinical decision-making process. *1. Lung ultrasound has an influence on pathology identification.* *7. Lung ultrasound may have more influence on pathology identification for physiotherapists with less experience.*
Change in Management: LUS changed physiotherapy management in 16% of cases (n=12). 	**Reasons why management didn't change during the study**: The participants provided several potential explanations for management seldomly changing during the study despite the high rate of discordance in clinical impressions, including the study population being straightforward and routine, the presence of chest drains, and the management plan pre-LUS remaining appropriate. *"Because they're only day one patients, they weren't that complex, the ones I had as well, there was only so much you could do in the first day anyway. Your*	**Expanded.** Management seldom changed in this study despite the high rate of discordance in clinical impressions and the reported impact of LUS on management planning; several explanations were provided by the participants. This study expands on the literature, providing qualitative findings as to why management may not change. *8. Lung ultrasound seldom influences physiotherapy management for day one non-emergency cardiac surgery patients for several reasons.*

Quantitative Inferences	Qualitative Inferences	Meta-Inferences
	patients are either really tired - most of the time they're very fatigued day one - or they're in a lot of pain, and they're not willing to do that much. That's probably why I would say that my management wouldn't really change." (PT9, Rot B5, not accredited)	
LUS Orders: LUS would have been ordered for 14% of non-emergency day one cardiac surgery patients (n=11).  	**Views on using LUS with routine cardiothoracic patients:** Participants provided several factors they consider when deciding whether to engage with LUS, including the population, the anticipated influence on management, intrapersonal factors, and/or service-level barriers and facilitators. Participants felt routine day one cardiac surgery patients were less of an indication for LUS. *"I think that's probably why I said in some cases that I wouldn't have ordered one either, because I didn't want to use someone's time to do one if I didn't feel it was going to change my management." (PT7, Static B6, accreditation in progress)*	**Confirmed.** Many of the participants reported they would not have normally engaged with LUS for this study's population, as seen in the low percentage from the questionnaire, but may have engaged with it more in other populations or scenarios. There were numerous factors considered when deciding whether to engage with LUS, including patient population, the anticipated impact on management, intrapersonal factors, and service-level barriers and/or facilitators, which agree with the literature. *9. Lung ultrasound is seldom performed by physiotherapists for day one non-emergency cardiac surgery patients for several reasons.*

Quantitative Inferences	Qualitative Inferences	Meta-Inferences
Significant Patient Regressions: Five of 97 regressions were significant (5.2%). *Change in Management* Decreased odds of a patient with **relevant past medical history** having a change in management ($OR_{none:PMH}$=0.24, p=0.032) Increased odds of a patient with a **minimally invasive surgery** having a change in management ($OR_{sternotomy:MIS}$=6.78, p=0.032) *Discordant Clinical Impressions* Decreased odds of a physiotherapist having a discordant clinical impression for a patient **65-75 years old** ($OR_{under65:65-75}$=0.33, p=0.043) *Change in Probability more than 25%* Decreased odds of a change in the physiotherapist's perceived probability of atelectasis by more than 25% for a patient **75+ years old** ($OR_{under65:over75}$=0.17, p=0.018) *Re-Categorisation of Atelectasis* Increased odds of the physiotherapist re-categorising atelectasis for patients with **minimally invasive surgery** ($OR_{sternotomy:MIS}$=9.67, p=0.014)	**Acute respiratory issues as an indication for LUS**: Reported indications for LUS were physiologically based with no mention of patient demographics or surgery details. *"So today, we've had a patient that's been on oxygen for the last two weeks flicking between the high flow nasal cannula and who we've been using positive pressure with, and then his CO2 has maybe just starting to creep up a little bit again. So, we had an auscultation, his bases sounded quiet. He's had a recent chest x-ray, which looks worse. So, for me, I felt that was a good indication to then do another scan because he's not had one for two weeks." (PT6, Static B6, accreditation in progress)*	**Confirmed.** Although there were a handful of regressions found to be significant, this is to be expected as five in one hundred regressions will be significant with no effect. The participants reported physiological indications for LUS and did not report any patient demographics or surgery details as indicators, which explains why most regressions were found to be non-significant. The qualitative findings agree with the literature. *10. Indications for LUS may be based on patient presentation rather than demographic or surgery related.*

5.2 The Influence of LUS on Physiotherapy Practice

The following section will discuss how the study addressed Research Objectives #1 and #2, as well as Meta-inference #1-8.

> ***Research Objective #1****: To explore the influence of LUS on respiratory physiotherapists' identification and management of postoperative pulmonary complications after cardiac surgery.*

> ***Research Objective #2****: To explore respiratory physiotherapists' perceptions and experiences of LUS, with particular reference to:*
> *a. Their views on the role of LUS in identifying and managing PPCs after cardiac surgery.*
> *b. Their views on the indications for LUS in the cardiac surgery population.*
> *c. Their views on the impact LUS might have on patient outcomes.*

5.2.1 Pathology Identification

The following section discusses the findings in relation to pathology identification and Meta-inferences #1-5.

> ***Meta-Inference #1****: Lung ultrasound has an influence on pathology identification.*

This study found that LUS has an influence on pathology identification. In most cases, the median probability of one or more pathologies shifted by more than 25% following LUS, showing LUS to have an influence in how the physiotherapists perceived the probability of the pathology. This finding was confirmed by the qualitative finding that LUS was unanimously agreed to have an influence on pathology identification. This finding was expected due to the high sensitivity, specificity, and diagnostic accuracy for the study pathologies reported in the literature in comparison to the lower accuracy of the tools currently used by physiotherapists, CXR and auscultation (Hansell et al. 2021). The following sections will discuss in more detail how LUS influences pathology identification, including its role in finding unexpected pathologies, the influence of LUS on the individual pathologies, and confidence.

> ***Meta-inference #2:*** *Lung ultrasound may find unexpected pathologies.*
>
> ***Meta-inference #3:*** *Lung ultrasound can change the perceived presence or absence of pathology.*

The study found there was discordance in clinical impressions for 43% of cases which was explained by the qualitative finding that LUS has a role in identifying unexpected pathologies. A study looking at the impact of thoracic ultrasound on the decision-making of critical care physiotherapists when treating hypoxaemic ICU patients found discordance in 64% of cases (Le Neindre et al. 2023). Another study assessing the impact of LUS on clinical decision-making of physicians treating mechanically ventilated patients found a discordance rate of 30% (Xirouchaki et al. 2014).

There is limited literature which reports on concordance of clinical impressions using LUS within the respiratory field, and the research that is available reports variable discordance rates that may be due to factors such as patient population, clinical setting, and profession of participants. The study by Le Neindre and colleagues (2023) observed patients in the general ICU, a population that LUS was reported in this study to be potentially more indicated for and was thought to have likely led to more changes in diagnoses if it was the study's population due to the complexities of the setting. The patients in the study by Le Neindre and colleagues were also hypoxaemic, which is a suggested indication for LUS within this study and in the literature (Kruisselbrink et al. 2017; Lau, Hayward and Ntoumenopoulos 2023); meanwhile, every consenting day one non-emergency cardiac surgery patient was assessed with LUS in this study regardless of whether there was an indication, which may have resulted in less discordance for cases where LUS was not normally required and pathology was able to be identified with standard physiotherapy assessment. The study by Xirouchaki et al. (2014) involved physicians, a profession that has been using LUS for longer than physiotherapists (Lichtenstein 2009), which may have influenced the difference in discordance rates. The experience and background of the primary physicians involved in the study was not reported, but it may be possible that the higher rate of discordance in this study was due to the involvement of junior staff who have less experience with the study population. There are numerous factors that may explain the difference in discordance rates, therefore it is difficult to say whether the findings in this study were discordant with that of the wider literature. What this study does provide is an expansion of the knowledge base, providing a discordance rate for this specific profession and patient population that can be built upon by future research and investigation.

This study also found that re-categorisation occurred for one or more pathologies in 57.1% of the cases and is explained by the qualitative findings that LUS identifies pathology better than standard physiotherapy assessment tools, provides more clarity regarding pathology identification, and finds unexpected pathologies. In this study, the focus was on the physiotherapists' perceptions of pathologies and diagnosis was not confirmed due to a lack of resources and funding, therefore a change in the probability becoming more or less likely after LUS was not described as a change in diagnosis, but a change in the perceived probability of the pathology. A systematic review by Heldeweg et al. (2022) involved studies that also did not confirm diagnosis and found a similar percentage change in diagnosis due to LUS in 43.8% of cases in the ICU. Within this study, the qualitative findings confirm the quantitative findings, demonstrating LUS can change the perceived presence or absence of pathology. However, a comparison to the wider literature is difficult due to the unique design of this study and the limited literature on the influence of LUS on diagnosis changes.

Reflections on the quantitative phase left participants wondering if LUS should be used earlier to find unexpected pathologies sooner. Doing so could increase awareness of any dwelling pathology which may improve the physiotherapist's ability to escalate management if required. The identification of an unexpected pathology adds new information that may be considered when testing clinical hypotheses, such as with the hypothesis categories framework (Higgs et al. 2019). Finding a pathology that was not expected may change clinical reasoning, and therefore the clinical impression as seen in the study findings, which leads to how management is decided. The finding that LUS plays a role in finding unexpected pathologies therefore also supports the role of LUS in clinical reasoning.

> ***Meta-inference #4:*** *Atelectasis is easier to identify by standard physiotherapy assessment than pleural fluid or pneumothorax.*

The influence of LUS on the pathology identification of the participants varied for each pathology. Re-categorisation of pneumothorax was the lowest of all three pathologies (10.4%). The low rate of re-categorisation may be due to the rarity of a pneumothorax in the cardiac surgery population, with a large-scale international multicentre incidence study finding a pneumothorax in only 4% of patients (Fischer et al. 2022). Pneumothorax was perceived as unlikely for the majority of cases, both pre-LUS (n= 72; 94%) and post-LUS (n=74; 96%), suggesting the participants felt it is unlikely for patients to have pneumothorax on day one; the qualitative findings confirmed that pneumothoraces are not often seen in this population and can therefore be more easily 'ruled out'.

The data, however, do not necessarily suggest it is easy to identify pneumothorax with standard physiotherapy assessment. The findings revealed it is difficult to identify a pneumothorax with LUS, often requiring other diagnostic imaging to confirm, which is discordant with LUS's high diagnostic accuracy for pneumothorax (Xie et al. 2020). However, suboptimal patient positioning can lead to misdiagnosis of a pneumothorax (Schrift et al. 2017), which was one of the reasons provided in the study for the difficulty in identifying pneumothorax. A pneumothorax may be rare, but it appears for the patients who may develop a pneumothorax, cardiothoracic physiotherapists may struggle to identify it even with LUS despite its high accuracy for the pathology due to positioning. The international LUS recommendations by Volpicelli et al. (2012) recommend the patient to be in supine to allow exploration of the least gravitationally dependent region where air is most likely to rise. Schrift and colleagues (2017) stress the importance of the patient being in supine with the head of the bed at zero degrees, as the pulmonary ultrasound team initially performed LUS with the head of the bed positioned at 30 degrees, but the pneumothorax was not seen until the head of the bed was at zero degrees. Positioning a patient with the head of the bed at zero degrees can be uncomfortable and can be made more difficult with lines, attachments, and bandaging restricting movement. With the rarity of pneumothorax in this population, there may be hesitance to place patients in this position to assess for one, but this may also increase the risk of missing a pneumothorax.

The finding that there was a lower rate of re-categorisation of atelectasis than pleural fluid was confirmed by the qualitative findings with participants explaining that atelectasis is relatively easy to identify with or without LUS compared to pleural fluid because atelectasis is 'core' to physiotherapy. This finding concurs with the literature, as some degree of atelectasis is expected after cardiac surgery due to general anaesthesia and CPB, and while atelectasis can be responsive to physiotherapy, pleural fluid and pneumothorax are inaccessible to physiotherapy (Hough 2018) which may translate to atelectasis being more 'core' to the profession. Regardless, the perceived probability of atelectasis still increased in 81.8% of cases following LUS. With LUS having a high specificity for atelectasis (Wang et al. 2020) this finding was expected as LUS can help to 'rule in' atelectasis further, even with the anticipation of the presence of atelectasis following cardiac surgery. Based on the findings of this study and the wider literature, atelectasis appears to be easier to identify by standard physiotherapy assessment than pleural fluid and pneumothorax, but identification still improves with the use of LUS.

Meta-inference #5: *Lung ultrasound influences the identification of pleural fluid by physiotherapists more than atelectasis and pneumothorax.*

LUS appeared to have the largest influence on the physiotherapists' ability to identify pleural fluid with the largest change in probability, highest rate of re-categorisation, largest increase of confidence in identification, and the largest reduction in uncertainty. This finding was confirmed by the qualitative findings, with pleural effusion explained to be one of the most common pathologies detected with LUS with high clarity. The scoping review from Chapter 2 also found pleural effusion to be the most common pathology in the literature surrounding LUS-use within the cardiac surgery population (Farrell et al. 2023), adding further confirmation to the findings. The interest in pleural effusions may be due to the high incidence of pleural effusion in cardiac surgery patients; the international incidence study by Fischer et al. (2022) found pleural effusion to have the highest incidence of the three studied pathologies at 32%, with another large propensity-matched analysis study (n=11,037) finding an incidence rate of 41.5% (Schiefenhövel et al. 2022).

This study demonstrated pleural effusion can be difficult for physiotherapists to differentially diagnose with standard assessment tools. Some of the ways pleural fluid presents are as a dry cough, dyspnoea (shortness of breath), and/or diminished or absent breath sounds on auscultation (Hough 2018). All these symptoms can be related to several other conditions, e.g., diminished or absent breath sounds could be airway obstruction, hyperinflation, shallow breathing, obesity, pneumothorax, or pleural effusion (Sarkar et al. 2015). With the added interference from large dressings, such as those for the chest drains and incision wound (Mojoli et al. 2019), pleural fluid can be challenging to diagnose without imaging. A finding of this study was a reported surprise at the amount of pleural fluid found on day one in non-emergency cardiac surgery patients; LUS resulted in 15% of ARF patients requiring drainage for pleural effusion in an observational study in an ICU, which was also unexpected (Barman et al. 2020). These findings that LUS resulted in an increased identification of pleural fluid and the difficulties in diagnosing pleural fluid by standard assessment may be why a suggested indication for LUS is the suspicion of a pleural effusion (Kruisselbrink et al. 2017). The findings of this study and the literature suggest pleural fluid is difficult to differentiate and diagnose in day one cardiac surgery patients by standard assessment techniques and there may be a higher incidence of pleural fluid than anticipated. Although the literature highlights LUS's high accuracy for detecting pleural effusions (Hansell et al. 2021), the findings from this study expand on this knowledge, suggesting that due to the difficulty in identifying pleural fluid using standard physiotherapy assessment, performing LUS could improve the differential diagnosis process for physiotherapists, improving the identification of unexpected pleural fluid that could be raised to medical attention sooner. The potential ability for physiotherapists to detect pleural effusions sooner may also explain why this study found a reported increase of MDT interest in physiotherapists identifying pleural fluid as a way to assist the medical team in diagnosis and management.

5.2.2 Confidence

The following section discusses the findings in relation to confidence and Meta-inferences #6 and #7.

> ***Meta-inference #6:*** *Lung ultrasound improves confidence and certainty, providing clarity and confirmation in pathology identification for physiotherapists.*

The finding of a universal increase in the strength of the participant's best guess as to the presence of the pathologies was explained by the reported role of LUS in increasing confidence and providing clarity and confirmation in both pathology identification and therefore management. This finding is supported by the literature, which reports the ability of PoCUS to reduce clinicians' uncertainty which in turn enhances clinical decision-making (Shokoohi et al. 2020).

Even in cases where the perceived presence of the pathology and management did not change, the quantitative findings showed the participants had a clear reduction in uncertainty. An observational study investigating the use of LUS in patients with ARF found LUS increased the confidence of the clinician in 44% of cases, with a larger increase in confidence in cases where LUS confirmed the clinicians' initial diagnosis. This corroborates the finding from this study that physiotherapists use LUS for intrapersonal reasons, reporting positive emotions when LUS confirms initial clinical reasoning and increased confidence in management plans.

While changes in management and patient outcomes is important, it's arguably just as important to consider the influence LUS may have on the physiotherapist. With the rise in burnout among physiotherapists (Burri et al. 2022), it is worth considering the intrapersonal benefits of LUS. The tools currently used by physiotherapists working with cardiac surgery patients are not reliable (Hansell et al. 2021), putting pressure on the physiotherapist to assess and manage patients with limited information. Lung ultrasound was reported in this study to bring peace of mind when worried about the patient; physiotherapists can become emotionally invested in their patients (Burri et al. 2022) and this pressure of getting the management right for the patient despite the limitations in assessment could be an added risk of burnout. Lung ultrasound was reported in this study to benefit patient care and improve early identification of PPCs. PPCs result in an increased length of stay (Fernandez-Bustamante et al. 2017; Fischer et al. 2022); early identification may reduce this. The reduction in caseload and improvement in overall patient wellness may also contribute to the wellbeing of the physiotherapists. The findings from this study expand upon the literature, exploring the intrapersonal benefits of LUS in more depth; the intrapersonal benefits of LUS and the influence LUS has on those engaging with it are important elements to consider and calls for further investigation.

> ***Meta-inference #7:*** *Lung ultrasound may have more influence on pathology identification for physiotherapists with less experience.*

The higher odds of discordant clinical impressions, change in management, and re-categorisation of atelectasis and pleural fluid for those with less experience is explained by the qualitative findings; Band 5 physiotherapists emphasised the role LUS played in improving their confidence in their assessment skills and management planning while the participants with more experience expressed confidence in their assessment skills. This finding is consistent with previous research, which has found novice cardiorespiratory physiotherapists (Smith, Higgs and Ellis 2007) as well as novice neurological physiotherapists (Wainwright et al. 2011) experience uncertainty during the clinical decision-making process; other research has also found novice cardiorespiratory physiotherapists to have a lower degree of organisation and logic than senior physiotherapists (Case, Harrison and Roskell 2000).

Despite what appears to be a higher influence of LUS on junior physiotherapists, all the participants agreed a physiotherapist should be a senior respiratory practitioner with experience in order to perform LUS, with many specifying they should be a Band 6 or above, which is a prerequisite for training in this cardiothoracic department. The literature suggests the development of clinical decision-making skills continues after entry-level education (Wainwright et al. 2011); considering the reported role of LUS in clinical reasoning in both this study and in the wider literature (Hayward, Innes and Smith 2021; Le Neindre et al. 2023), LUS could be useful to junior physiotherapists who are developing their clinical reasoning skills.

5.2.3 Management Planning

The following section discusses the findings on the influence LUS has on management planning, as well as Meta-inference #8.

> ***Meta-inference #8:*** *Lung ultrasound seldom influences physiotherapy management for day one non-emergency cardiac surgery patients for several reasons.*

Despite the high rate of discordant clinical impressions and re-categorisation of pathologies, management only changed in 16% of cases. Management changed more often due to LUS in other studies. Le Neindre et al. (2023) saw a change in physiotherapy management for hypoxaemic patients in the ICU in 62% of cases, and Xirouchaki et al. (2014) in 47% of cases for mechanically ventilated patients. A systematic review on the impact of LUS on the clinical decision-making across departments found LUS changed management in 42% of cases in the ICU and 48% in the emergency department (ED) (Heldeweg et al. 2022). In both studies by Le Neindre et al. (2023) and Xirouchaki et al (2014), the rate of management change was similar to the rate of discordance in clinical impression; the rate of management change in this study was notably smaller than the rate of discordance meaning management often stayed the same despite the patient having different pathologies than initially expected. The qualitative results found the study population to be routine, and therefore, there was a recognisable pattern that resulted in 'standard treatments.' There are guidelines and protocols centred around the physiotherapy management of cardiac surgery patients because of this recognisable pattern (ACPICR 2016). This pattern may have resulted in the participants of this study predicting the required physiotherapy management or prescribing a more standard management plan that addressed numerous possible pathologies, which corroborates the finding that the management plan often remained appropriate despite the change in pathology identification. This reported routine nature opposes the more unpredictable nature in the ICU and mechanically ventilated patients and may account for the difference in the rates of management change.

There were three cases where LUS resulted in the physiotherapist removing a treatment from their management plan due to the patient's condition being less severe than initially considered, showing cases where the 'standard treatments' may not be required. The participants in this study work within a cardiothoracic centre that assesses and treats every day one cardiac surgery patient. A survey by the ACPICR in 2015, however, found that out of the 22 participating cardiothoracic centres in the UK, only 12 reported seeing all patients on day one after cardiac surgery. The remainder (n=10) only saw 'high risk' patients that required physiotherapy, with five of those centres using a screening tool to vet referrals. Patients who were not seen by physiotherapists were mobilised by the nursing staff (ACPICR 2016). As there are a large percentage of UK cardiothoracic centres without routine physiotherapy assessments on day one, it begs the question of whether day one patients need to be routinely assessed and treated by physiotherapists. This study found LUS has been used to decide whether physiotherapy referrals are appropriate; it may be LUS could be used as part of a screening tool to decide whether physiotherapy assessment and management is required to begin with, which may also address barriers of time and resources.

5.3 Current Use

The following section explores how the research addressed Research Objective #3, as well as Meta-inference #9.

> ***Research Objective #3****: To determine the current use of LUS within a cardiothoracic physiotherapy department in one UK hospital when managing patients after cardiac surgery by measuring:*
>
> *a. The average length of time of LUS assessment.*
> *b. The average number of LUS orders for patients within this population in*
>   *i. A day*
>   *ii. A week*
>   *iii. A month*
>
> ***Meta-inference #9:*** *Lung ultrasound is seldom performed by physiotherapists for day one non-emergency cardiac surgery patients for several reasons.*

LUS took just under six minutes on average to perform. This finding is similar to several studies reporting mean times between 5.1 and 10.8 minutes (Monastesse et al. 2017; Xie et al. 2020; Wang et al. 2020) which is significantly less than the reported time for a CT scan performed as part of a study which takes around 26 minutes (Xie et al. 2020; Wang et al. 2020). Despite LUS taking minutes to perform, there are other time barriers to performing LUS, such as the time to find someone accredited and the time to access quality equipment. A lack of time and quality equipment is a finding not unique to this study; similar findings were reported in literature both within respiratory and MSK physiotherapy (Innes and Jackson 2019; Hayward, Innes and Smith 2022; Lau, Hayward and Ntoumenopoulos 2023).

For day one non-emergency cardiac surgery patients, LUS would have normally been ordered for 14% of patients. The qualitative findings provided several reasons for the seldom use of LUS, including anticipating little influence on management planning or if patients appeared straightforward. The findings suggest that the routine study population and the recognisable pattern resulted in less engagement with LUS.

A finding in this study is a reluctance by Band 5 physiotherapists to engage with LUS due to inexperience and time pressures despite a meta-inference of this study suggesting junior physiotherapists would particularly benefit from engaging with LUS. This should be considered by those looking to implement LUS into their department, as this study found LUS to be a learning tool, confidence builder, and clinical reasoning aid that may benefit the teaching and training of rotational Band 5 physiotherapists.

Although this study found several reasons why LUS was seldomly performed during the study, insight was gained on when LUS would typically have been used. Within this CITU, the participants share they often use LUS a few days or even a week after cardiac surgery. This is reportedly when PPCs tend to arise in the cardiac surgery population. This is discordant with the findings of the scoping review for this thesis which found LUS was most often performed in primary research within two days of surgery (Farrell et al. 2023). The scoping review included five reports which involved physiotherapists, which suggested or performed LUS within two days of surgery and only one case study that occurred on POD9. However, the qualitative findings posed a question of whether physiotherapists should be performing LUS more frequently in the first few days after surgery to catch unexpected pathologies rather than awaiting signs and symptoms to begin.

The study findings open a debate as to how often and when LUS should be performed. In this study, 12% of patients would be scanned a day, and 16% within the week, showing regular daily use in this department but not for every patient. Although the population is reportedly routine and many physiotherapists in the UK do not therefore regularly assess day one cardiac surgery patients, there may also be potential to find unexpected pathologies. Some studies have tested the use of a LUS score as a prognostic or screening tool (Leblanc et al. 2014; de Alencar et al. 2021) which would promote more regular use of LUS. LUS has also been reported to be regularly used by some therapists as part of their objective assessment, with 13% of survey respondents using LUS on every patient (Lau, Hayward and Ntoumenopoulos 2023). Others have cautioned against regular use of LUS, proposing LUS to be used with a focused clinical question in mind to be answered (Shokoohi et al. 2020). The question as to when and how often LUS should be performed in relation to cardiac surgery remains unanswered and likely requires further investigation.

5.4 Potential LUS Indications

The following section discusses how the research addresses Research Objective #4, as well as Meta-inference #10.

> ***Research Objective #4****: To measure potential relationships between certain cardiac surgery patient demographics and/or surgery details and changes to pathology identification, management, and certainty through regression analysis.*
>
> ***Meta-inference #10:*** *Indications for Lung ultrasound may be based on patient presentation rather than demographic or surgery related.*

The goal of Research Objective #4 was to explore possible indications for LUS which could inform a protocol for day one cardiac surgery patients through future research. Out of the 97 regressions conducted against patient demographics and surgery details, five variables were statistically significant. It must be considered that p-values under the null hypothesis are uniformly distributed, and therefore, under the assumption of no effects, it is expected to have five percent of regressions return falsely significant. This suggests there may not be clear indications to perform LUS on day one cardiac surgery populations as part of a proposed protocol based on patient demographics and surgical details. This study found the cardiothoracic population, particularly day one non-emergency routine cardiac surgery patients, were less indicated for LUS and that the study may have discovered more in acutely unwell respiratory or long-term stay populations which may also explain why there were only a few significant regressions.

Although the significant regressions from this study should be interpreted cautiously, the regressions that were significant had an interesting trend. The absence of relevant past medical history and minimally invasive surgery were significantly associated with a change in management due to the pathology being more severe than initially thought following LUS. A systematic review and meta-analysis found minimally invasive surgery decreases the incidence of PPCs following valve surgery compared to a full sternotomy (Mohamed, Cheng and Wei 2021), which may lead clinicians to perceive a decreased risk of pathology. Minimally invasive surgery was also significantly associated with a change in the perceived presence of atelectasis, which became more likely than not after LUS. The quantitative findings could suggest certain demographic or surgery details could mislead the perceived probability or severity of pathologies, demonstrating the potential value of LUS.

Kruisselbrink and colleagues (2017) suggest several indications for LUS using the I-AIM model, including the presence of unexplained respiratory symptoms or signs, unclear chest radiography findings, or suspicion of pneumothorax or pleural effusion. All these indications were confirmed in this study, with the findings demonstrating LUS is performed when there is unexplained deterioration, increased oxygen demand, uncertainty even after reviewing other imaging, suspicions of pleural effusions, or to 'rule out' a pneumothorax. A survey by Lau and colleagues (2023) further supports the findings of this study as they found the most common reasons for LUS-users to perform LUS were changes on CXR or auscultation, subjective symptoms, low $PaO2/FiO2$ ratio, saturations below 94% or inflammatory markers. The indications for LUS suggested by this study and the wider literature mostly involve the patient's physiological parameters and other imaging investigations. This suggests if an informed protocol were to be proposed for when to use LUS, the protocol should consider physiological parameters and patient observations rather than demographics and surgery details.

5.5 Beyond the Quantitative Findings

The first half of this chapter discussed the study meta-inferences and how the research objectives were addressed. Due to the exploratory nature of interviews, topics were discussed in the interviews that were not the focus of the quantitative phase. The following sections discuss these topics within the wider literature.

5.5.1 Physiotherapy and PoCUS

Only one other qualitative study has been conducted with respiratory physiotherapists on this topic exploring the experiences of respiratory physiotherapists in critical care which shared similar findings to this study (Hayward, Innes and Smith 2022). Diagnostic PoCUS, however, is not new to physiotherapy – it is a skill also used by MSK, pelvic health, rheumatology, and neurological physiotherapists (The CSP 2022; Smith et al. 2022, 2023).

The use of ultrasound by physiotherapists is growing with Whittaker et al. (2019) defining four categories of physiotherapy ultrasound applications in MSK physiotherapy: diagnostic ultrasound to diagnose and monitor pathology; rehabilitative ultrasound used during physical tasks to evaluate muscles and soft tissue structures and function; interventional ultrasound to guide procedures (e.g., acupuncture or steroid injections); and research ultrasound to measure, explore structures and function, and develop or evaluate screening tools and interventions. This findings in this study fit well into these four categories, highlighting the role of LUS in diagnosing and monitoring pathology progression, to evaluate physiotherapy treatment, and the potential for LUS to be used as a screening tool. The aim of all PoCUS is to integrate ultrasound imaging into decision-making of patient management and delivery of care (Smith, Hayward and Innes 2022).

The use of diagnostic ultrasound within MSK was first published in 1980 to measure the size of quadriceps muscles (Whittaker et al. 2019). Similar to how respiratory physiotherapists aim to assess with LUS to then treat within the same session, some MSK physiotherapists are proposing 'one stop shop' clinics where shoulders are assessed with ultrasound and steroid injections are provided within the same session (Priest 2020). Pelvic health physiotherapists use ultrasound to differentiate causes of urinary incontinence, assess severity of pelvic organ prolapse, and for several other diagnostic purposes, which helps to guide the type of education and exercises provided to the patient (Abbas Shobeiri and Junginger 2017).

Indications for ultrasound-use by physiotherapists appears to be similar across the different fields. A review of case reports on the use of diagnostic ultrasound imaging in physiotherapy practice with a focus on use within orthopaedic and sports physiotherapy found the most common reasons for performing ultrasound was a differential diagnosis list that includes a serious pathology (Manske et al. 2023); this finding is similar to the suggested indication to perform LUS in this study and the wider literature (Kruisselbrink et al. 2017), which includes suspicion of pathologies which may lead to hypoxaemia (e.g., atelectasis, pleural effusion, and pneumothorax). Another reported reason was due to no change from previous treatments (Manske et al. 2023), which also aligns to the finding in this study that LUS is indicated when the patient is not progressing.

The review by Manske et al. (2023) also found disagreement between the initial diagnosis and final outcome in 37% of case reports and significant changes in physiotherapy intervention due to ultrasound in 67% of case reports, showing ultrasound to influence and change pathology identification and management planning. Diagnostic ultrasound across different fields of physiotherapy seems to have similar roles found in this study of pathology identification and management planning, with the added benefit of immediate treatment based on results rather than awaiting other imaging.

5.5.2 Barriers & Issues to Address

The participants within this study shared common barriers to engagement with LUS which were similar to physiotherapists engaging with PoCUS across other fields. This next section will discuss the current issues to implementing and engaging with LUS and PoCUS. Smith has proposed three PoCUS frameworks for physiotherapists in the fields of respiratory (Smith, Hayward and Innes 2022), pelvic health (Smith et al. 2022), and MSK (Smith et al. 2023). Within these proposed frameworks, Smith introduces the PoCUS framework triangle, which addresses the areas of (1) scope of practice, (2) education and competency, and (3) governance (Figure 5.1). The following sections will address the ongoing issues in each of these areas.

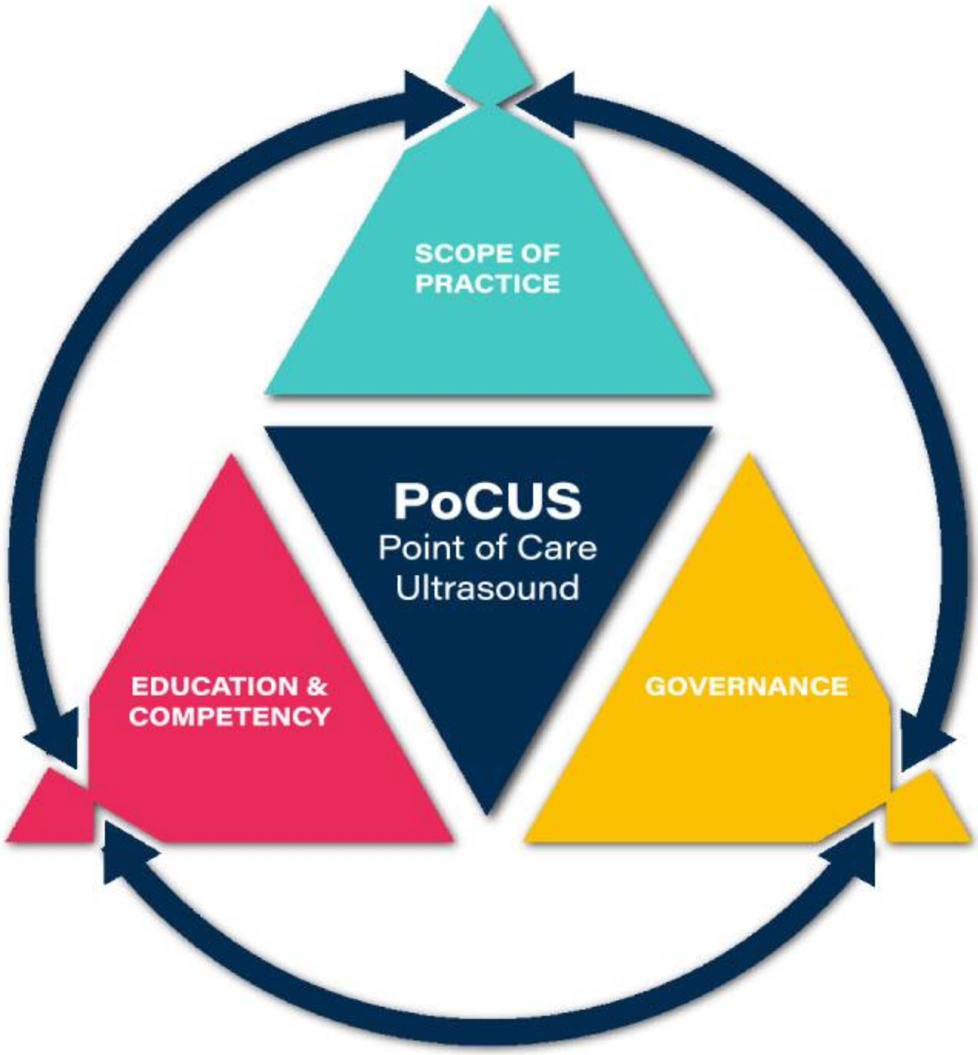


Figure 5.1 PoCUS framework triangle. Used with permission by Dr Mike Smith.

Scope of Practice

The CSP expects for members using PoCUS to be able to understand, define and describe their own personal scope (The CSP 2022), suggesting there is no set rule for what is within the scope of practice for physiotherapists performing LUS. This study found that LUS should be performed by physiotherapists for physiotherapy purposes and should be implemented into the scope of practice for physiotherapists. This study also found that physiotherapists perceived they were being asked to perform outwith their scope of practice, for example, to measure the size of pleural effusions and advise on chest drain decisions. The framework proposed by Smith and colleagues, however, suggests physiotherapists may describe and estimate the volume of a pleural effusion where appropriate as part of the proposed scope of practice. The key term is 'where appropriate', and according to the findings of this study and the CSP, commenting on the volume of a pleural effusion in relation to chest drain advice can be considered inappropriate. Smith et al's proposed framework (2022) also suggests that raising concerns about pleural fluid to the medical team for escalation is part of a physiotherapist's scope of practice; the ability to discuss these medical-related concerns was found to be a benefit in this study as it improved MDT relations and promoted conversations. As there is no concrete definition a physiotherapist's scope of practice when performing LUS, the findings from this study suggest that the decided scope of practice should be well communicated within the physiotherapy department and wider MDT to ensure there is no miscommunication.

When considering what the scope of practice for the individual physiotherapist should be, the proposed framework by Smith et al. (2022) may be considered. Lung ultrasound is proposed to be used to 'rule in' suspected pathologies by testing a priori likely differentials using clinical assessment and reasoning (Smith, Hayward and Innes 2022). The framework suggests it is within the physiotherapist's scope of practice to use LUS to recognise pleural fluid, consolidation, atelectasis, and interstitial syndrome, as well as use LUS to exclude pneumothorax, which is how LUS was found to be used in this study.

Education & Competency

This study found LUS to be an advanced skill within respiratory physiotherapy, which was a motivation for engaging with LUS to enhance personal and professional development. The findings suggest LUS should be performed by senior staff with experience in the field, a similar finding found in surveys of PoCUS-users within respiratory (Hayward, Innes and Smith 2022; Lau, Hayward and Ntoumenopolous 2023) and MSK (Innes and Jackson 2019). Smith and colleagues (2022) also suggest a physiotherapist training in PoCUS and LUS should be at a post-graduate level and have the appropriate level of experience in respiratory care due to the required high level of clinical reasoning skills.

Formal accreditation in LUS can be achieved in one of two ways in the UK: (1) through a Higher Education Institution or (2) through a professional society (e.g., FUSIC, Focused Acute Medicine Ultrasound) (Smith, Hayward and Innes 2022; The CSP 2022). The CSP (2022) expects that all members practicing PoCUS as a part of physiotherapy practice have received training and education that maps to the Consortium for the Accreditation of Sonographic Education standards or equivalent.

However, in a survey of Australian physiotherapists who had recently completed a LUS training course, 97.4% reported not having formal accreditation in LUS (Hansell et al. 2023a). In another survey conducted internationally, it was found out of the 89 that reported to be LUS-users, 45% reported having no formal accreditation (Lau, Hayward and Ntoumenopoulos 2023). This was a similar finding among MSK physiotherapists using ultrasound, with one UK survey finding 48% of their respondents had informal training with only 28% of those respondents having received training on background physics and safety (Potter, Cairns and Stokes 2011) and a New Zealand survey finding 48% of respondents had informal training and 10% had no training (Ellis et al. 2018). The number of formally ultrasound-accredited physiotherapists has risen, however, with an international survey with most respondents working in MSK or sports medicine finding 88% of ultrasound-users attending formal training (Ellis et al. 2020). There appears to be a high rate of physiotherapists using LUS and ultrasound without the recommended formal accreditation; comparison between MSK and respiratory ultrasound accreditation and training courses may provide insight onto how to increase the number of formally accredited respiratory physiotherapists.

The lack of accreditation may be due to the challenges in gaining accreditation. In the survey conducted by Lau and colleagues (2023), they found 97% of survey's respondents know of one or more colleagues in their department interested in pursuing LUS but were unable to due to barriers. This study found numerous barriers to gaining accreditation, with one main barrier being access to mentors. Access to mentorship for accreditation has been reported as a challenge and barrier across the fields of respiratory and MSK physiotherapy (Innes and Jackson 2019; Whittaker et al. 2019; Hayward, Innes and Smith 2022; Hansell et al. 2023a; Lau, Hayward and Ntoumenopoulos 2023). Survey respondents in multiple studies also reported a lack of accreditation courses to be a barrier to pursuing LUS (Lau, Hayward, and Ntoumenopoulos 2023), MSK ultrasound (Whittaker et al. 2019), and ultrasound in general (Ellis et al. 2020), a finding that was also reported by participants in this study. In order to ensure more physiotherapists who are performing PoCUS receive formal accreditation, barriers need to be addressed, including improving the availability and consistency of accreditation programmes.

Governance

Another barrier reported in surveys of both respiratory and MSK physiotherapists is the lack of governance and local policy on LUS-use by physiotherapists (Innes and Jackson 2019; Whittaker et al. 2019; Hayward, Innes and Smith 2022; Lau, Hayward, and Ntoumenopoulos 2023). Innes and Jackson (2019) report participants were keen to engage with professional body guidance, but this was not available at the time. Since then, the CSP (2022) released their information paper on the use of PoCUS by UK physiotherapists. However, 71% of respondents in the international survey by Lau and colleagues (2023) reported their ICU still does not have a local policy in place to guide ICU therapists in using LUS clinically, and this was reported as a barrier. Governance and local policy need further development to aid engagement with LUS by respiratory physiotherapists.

An added barrier to governance is a lack of staff support. The findings in this study suggest the physiotherapists were well supported by the staff and MDT and found this to be a facilitator. The international survey by Lau and colleagues (2023) found a barrier to engaging with LUS was the therapy management team being unsure as to the use of LUS, with 69% of survey respondents suggesting an increase in management understanding would improve engagement with LUS. A similar finding was found for physiotherapists using MSK ultrasound, with a lack of managerial support and opposition from other professional groups as barriers (Innes and Jackson 2019). The CSP (2022) emphasises there should be collaborative MDT working and onward referral pathways in place prior to members using PoCUS clinically as unknown and/or potentially serious pathologies may be identified. Without staff and managerial support, forming and implementing local policies and governance becomes more of a challenge.

5.5.3 Future of LUS for Physiotherapists

Changes to Standard Practice

The findings of this study are in favour of physiotherapists implementing LUS into practice. In the international survey conducted by Lau et al. (2023), 85% of respondents see LUS becoming part of the objective therapy assessment within the ICU in the future. The same survey found that 70% of LUS-users continue to use auscultation as part of their objective assessment and 85% of respondents reported their ICU continues to use CXR instead of LUS. Although this study found LUS was more in-depth than either auscultation and CXR, it was also found LUS is still performed in conjunction with other diagnostic tools, with LUS another 'tool in the toolbox' rather than a replacement of the standard assessment tools. It does not appear LUS will be replacing standard physiotherapy assessment techniques at the present time. Due to LUS's lack of ionising radiation and comparability to CXR, it would be sensible to replace CXR with LUS. Reasons for why LUS may not be readily adopted as an alternative to CXR should be investigated to explore any potential barriers.

Thirteen percent of Lau's (2023) survey respondents scan every patient they assess, while Hansell's (2023a) survey respondents perform LUS less than once a week to inform clinical decision-making. The findings in this study suggest LUS should be indicated and isn't necessary for every patient, which agrees with other literature on PoCUS (Shokoohi et al. 2020; Smith, Hayward and Innes 2022). The department in this study also see every day one cardiac surgery patient while other cardiothoracic centres in the UK do not (ACPICR 2016). There is a wide variation in the frequency and indicated use of LUS; future research should consider the development of guidelines as to the indications for LUS-use by physiotherapists to ensure this resource that already has barriers to use is used efficiently.

Benefits to Patient Care

The study findings suggest LUS has a positive influence on intrapersonal factors for physiotherapists, improving confidence and providing reassurance. Lung ultrasound may provide intrapersonal benefits to patients as well; a case study demonstrated the novel use of LUS to show a patient their respiratory status following failed attempts at weaning from mechanical ventilation due to panic attacks and resulted in reduced anxiety and a successful weaning (Kendrick, Hogarth and Hayward 2022). This novel use of performing LUS for the patient's benefit was also present in the qualitative study conducted by Hayward et al. (2022) where a small number of respiratory physiotherapists observed the LUS imaging process aided in the patient's understanding of their condition and, therefore, suggested LUS may enhance treatment. Within MSK physiotherapy, a service evaluation conducted with patients who attended a physiotherapist-led upper limb/shoulder clinic that involved an ultrasound assessment discovered that the patients felt they better understood their problem, felt more assured about their problem, and felt they were better able to self-manage their problem, with the patients finding LUS overall to have very high value (Lumsden et al. 2017). Lung ultrasound was found to be a learning tool in this study; it appears the learning benefit of LUS may extend beyond healthcare professionals and could aid patients in their care.

Skill Development & Advancing Practice

This study found LUS played a role in learning and improved junior physiotherapist's confidence in their assessment skills. A prospective study comparing the competence, importance, and interest in cardiorespiratory physiotherapy in students before and after clinical placement found there was no significant difference in competence between those with or without a cardiorespiratory placement (Sánchez et al. 2019). It was suggested in this study that LUS should be introduced during clinical placements, encouraging student engagement; lung ultrasound may be a valuable tool to aid both student and junior physiotherapists in developing their assessment and clinical reasoning skills.

Several physiotherapy fields are beginning to expand scope of practice and introduce advanced practice roles, such as First Contact Practitioners for MSK physiotherapy, allied health professions (AHP) consultants, or consultant physiotherapists in a variety of specialities. Lung ultrasound could possibly be a tool used by advanced practitioners or consultant respiratory physiotherapists. As LUS is also used for medical purposes, there may be crossover in roles which require defining, as was a finding in this study with medical staff asking physiotherapists to perform LUS for medical purposes, but this may inevitably benefit both professions during a time when there is a national staffing crisis (House of Commons Health and Social Care Committee 2022).

The presence of this crisis, however, brings into question whether now is the appropriate time to introduce a new upskilling opportunity for physiotherapists. On top of the national staffing crisis, the CSP is reporting that 93% of physiotherapy managers reported that there were insufficient staffing numbers to meet patient needs (CSP 2023). Research is being published concerning the rising levels of burnout and stress among physiotherapists (Burri et al. 2022), particularly because of COVID-19 (Oliveira et al. 2022). There have also been a series of pay strikes in recent years (Triggle and Bailey 2023), demonstrating an added strain of finances. This study found a lack of staffing, time, and funding to be a barrier to implementing LUS; during a time when the NHS is struggling for staffing, time, and funding, the priority for current physiotherapists may need to be shifted to the core responsibilities if resources and energy are not available to further education and upskill. This study shows there is great potential for LUS within the field of respiratory physiotherapy and further exploration is encouraged. The future of physiotherapy is exciting with growing opportunities to advance practice and develop new skills; during a time of crisis, however, it will require a delicate balance to both attend to our core responsibilities and continue to progress our profession. An effort to achieve this balance, however, should still be made despite the current challenges.

5.6 Strengths and Limitations

A challenge of mixed methods research is the required methodological skillset (Regnault, Willgoss and Barbic 2018; Wasti et al. 2022); a strength of this research was the team, which included supervisors knowledgeable on all methods used in this work, particularly evidence synthesis, statistics, and the framework approach. The local PI was knowledgeable of the cardiothoracic department, physiotherapy assessment, and LUS operation as a mentor for FUSIC. The local PI was an integral part of the design and execution of this research, ensuring the study captured data as accurately as possible. The integration of data collection into the participant's daily clinical practice was a strength, only taking a maximum of ten minutes on top of normal assessments. This allowed for the research to more closely capture a realistic representation of the participant's assessments of day one cardiac surgery patients.

Several steps were taken to ensure quality and rigour. The study design was informed by my philosophical stance with close consideration of the research aims and objectives to ensure the design was suitable for the thesis. The design of this study also allowed for a more in-depth exploration of the topic by using the preliminary quantitative data to inform the qualitative data collection to help explain the quantitative findings; mixed methods research allows for stronger inferences and a more holistic understanding (Wasti et al. 2022). All research materials went through numerous rounds of piloting with respiratory physiotherapists and reviewed by the supervisory team to improve design fidelity and quality. The meta-inferences were created with consideration to the current knowledge base to ensure the findings from this study were theoretically consistent. The steps taken during the design and implementation of this study to improve quality and rigour added to the overall strength of the research.

My clinical experience came with strengths and limitations. I had limited respiratory experience during the design and conduction of this thesis; while this made me more dependent upon the supervisory team for the design of the study and construction of the data collection tools, the limited experience allowed for the mitigation of bias during interviews. During the analysis stage, I began clinical work within the acute respiratory environment, gained LUS accreditation, and eventually began work within cardiothoracics and CITU during the write-up stage, aiding me in placing the findings into context. As a novice researcher, errors may have been made in the designing, analysis, and interpretation of the study and its findings; this was mitigated by the involvement of a highly experienced supervisory and research team with numerous checkpoints and secondary reviews.

This study was unfunded and restricted within the timeline of a doctoral degree. The limitations of the degree, combined with the novelty of LUS within physiotherapy leading to several unknown variables (e.g., lack of well-researched standardised LUS protocols, effective time windows for data collection) and small sample sizes, resulted in this study being exploratory in nature and more closely resembling a pilot study. Despite the small available sample size, there was a 100% recruitment rate for the quantitative phase and a 70% recruitment rate for the qualitative phase, which is a strength of this study.

This doctoral work was completed in collaboration with the UK cardiothoracic department which was studied. It was a strength to be able to collaborate with this department, as it assisted in keeping the research applied and relevant. However, there are limitations to studying a single department, especially one that was part of collaboration. There was potential for bias to have influenced the findings because of the investment the department already had in LUS. It was a strength to have access to a department which had implemented LUS into practice despite the novelty of LUS-use within physiotherapy. However, due to the novelty of LUS-use by physiotherapists and the limited availability of accreditation courses, all of the participants who were accredited or in the process of accreditation were trained by the local PI. Receiving the same training may lead to similar perceptions as to the uses, roles, and importance of LUS if these ideas are portrayed in the training. There is a benefit, however, to the participants receiving the same training in that the technique used by the physiotherapists is similar and therefore easier to compare regarding experiences; it is unknown how different techniques and protocols influence physiotherapy practice, and this could lead to different experiences based on technique or protocols rather than experience with LUS in general. Nonetheless, experiences using other techniques and protocols should be explored as this may differ from what was found in this study.

This exploratory study is not generalisable due to studying the influence of LUS on a single UK cardiothoracic department with the potential for bias and the potential influence of the unique circumstances of this department compared to other departments across the UK. It is hopeful, however, that is study can assist in formulating future research questions and aims. This study was the first, to the research team's knowledge, to attempt to measure and understand the influence LUS may have on UK physiotherapy practice within the cardiac surgery and respiratory population. Therefore, a strength of this study is providing foundational work for further research that may lead to generalisable findings to inform future best practice.

Due to the complexity in recruiting emergency cardiac surgery patient volunteers, this population was excluded. Emergency cardiac surgery patients have a higher rate of mortality and have been a focus of NICOR (2023) to improve waiting times and reduce mortality rates. The findings suggest the non-emergency population are less indicated for LUS and therefore excluding the population likely influenced the quantitative results. Nonetheless, this exploratory study contained several unknown variables, complicating the study design; excluding emergency cardiac surgery populations mitigated confounding variables and made connections between variables easier to identify and understand. Future research should include the emergency cardiac surgery population, however, as this insight would be valuable.

The bisection method used to elicit the probability distributions was a method new to all participants, therefore steps were taken to improve design fidelity and mitigate any issues that may have risen by the introduction of this statistical element. All participants went through the same training on how to use the bisection method which included case studies and practice rounds, and all participants had an opportunity to practice using the bisection method during their dry run of the study procedures with the local PI. The LUS Scanners were also trained in how to use the bisection method and were available to assist the participants if questions arose. However, there is a possibility that the participants' ability to make probability judgements may have impacted the results.

The aim of this study was first and foremost to explore the use of LUS by cardiothoracic physiotherapists with few specific questions to address. As the research area was novel, there was no previous research to inform meaningful cut-offs or thresholds, therefore the use of created thresholds and subsequent qualitative labels improved clarity and navigation of the findings, aiding discussion. Although based on thorough exploration of the data, these thresholds and labels were subjective in nature and have limitations. Despite having the assistance of a statistician, there is a risk of bias influencing the discussion of the findings. The dichotomisation of continuous data can also lead to loss of information and statistical power (Cumberland et al. 2016). These concerns were mitigated by providing individual points and ranges within the graphs throughout Chapter 4. Nevertheless, the quantitative findings should be interpreted with caution and will be difficult to compare within the wider literature unless the same thresholds are adopted in future studies.

The intended length of the quantitative phase was four months. Due to staff vacancies and pressures during the time of the study, the quantitative phase had to be reduced to 11 weeks. The projected number of potential assessments was 100-150, with the study ending with 77 assessments.

Lung ultrasound has a high diagnostic accuracy for the pathologies in this study. Nevertheless, there are limitations to LUS. Visualising images using LUS requires the transmission of the ultrasound beams through the chest wall to the lung surface; subcutaneous emphysema and large thoracic dressings, such as the ones used for sternotomy wound dressing and over chest drain insertions, can prevent this transmission (Mojoli et al. 2018). Larger body hiatus may also inhibit evaluation of the pleural line and structures at depth (Marini et al. 2021), which is also a barrier found in this study. These limitations may have prevented the LUS Scanners from achieving a more comprehensive examination on the patients which could have influenced the results. However, the LUS Scanners were physiotherapists with experience assessing and performing LUS on cardiac surgery patients, and therefore knowledgeable on ways to achieve the most comprehensive LUS examination possible despite the limitations.

5.7 Recommendations for Future Research

Due to the exploratory nature of both the scoping review and primary research and the novelty of the research area, there are several recommendations for future research in the area of LUS-use by physiotherapists.

5.7.1 Within the Cardiac Surgery Population

The population of this study was non-emergency cardiac surgery patients who have had a CABG and/or valve repair/replacement. The findings from this study suggest use of LUS by physiotherapists in the emergency or complex (e.g., aortic aneurysm repairs or aortic dissections) cardiac surgery population may be more indicated and should be explored with the same design of this study which would allow for comparison to find if LUS does have more influence within these surgical populations.

Future research should also explore when it is best to perform LUS following cardiac surgery. The findings from this study suggested it may be beneficial to conduct the same study, but several days after surgery, such as postoperative day three or four as this is when PPCs begin to appear and affect patients. This suggested research may closely resemble regular use by these physiotherapists to capture the influence it has on their practice. The initial interest in this doctoral study was whether LUS would identify PPCs earlier on to allow for timely detection of pathologies before they worsen. Due to the restrictions of this unfunded doctoral work, the study was not able to follow patients after day one due to a lack of resources and time. Future research could look to assess when postoperative complications tend to begin before the patient becomes symptomatic with a longitudinal study design.

The study findings suggest LUS may not be necessary for every cardiac surgery patient. The findings from this study, along with other research, suggest indications may be physiologically based. The indications to perform LUS on the cardiac surgery population could also be explored by incidence and prevalence studies with the aim of developing a framework or protocol to preserve time and resources.

A multi-centre study exploring the use of LUS across numerous hospitals and departments would be beneficial to identify if LUS-use varies across hospitals and trusts. The cardiothoracic physiotherapy department within this study is unique, having fully implemented LUS into physiotherapy practice. The study findings and other literature have shared that this may not be the case in other health boards, with the lack of local policy remaining a barrier to engaging with LUS (Hayward, Innes and Smith 2022; Lau, Hayward, and Ntoumenopoulos 2023). A survey of the use of LUS by UK physiotherapists was done in 2020 (Hayward, Smith and Innes 2020); an updated survey of practice may be warranted as the number of physiotherapists using LUS in practice has increased. A comparison should be made between the surveys to gauge progress in implementation and which barriers still require addressing. Service evaluations or observational studies should be conducted to capture the current use of LUS in other hospitals and trusts to compare with this study to see if use is similar. As there is a lack of local policy, investigating how different physiotherapy departments use LUS may help to inform local policy and best practices, especially for those looking to implement LUS into departmental practice.

5.7.2 Other Populations

This study suggests LUS may be more indicated in patients with acute respiratory problems, respiratory patients within the community, or even within GP respiratory clinics. While one observational study has been conducted on the use of LUS by physiotherapists treating hypoxaemic patients in the ICU (Le Neindre et al. 2023), further observational, qualitative, and mixed methods studies should be done exploring the use of LUS by physiotherapists in a range of respiratory areas. It was highlighted in this study that there may be a role for LUS in community respiratory physiotherapy. Diagnostic tools such as CXR and CT are not available at home and would require scheduling an appointment, whereas LUS could be done in real-time, allowing for quicker escalation of care. Use of LUS within the community population or within a GP clinic may allow prevention of respiratory pathologies that would result in admission into acute care. Once studies in these different populations are conducted, comparison between populations may be useful to determine if LUS skills and influence are transferable between populations. This may also clarify which population LUS may be more indicated for and which specialised areas should pursue LUS.

5.7.3 Use of LUS

The scoping review in Chapter 2 and other literature has found heterogeneity in LUS methods within research, making evidence synthesis a challenge (Hayward and Janssen 2018; Heldeweg et al. 2022; Churchill et al. 2023; Demi et al. 2023; Farrell et al. 2023). The international recommendations by Demi et al. (2023) suggest further research is required to define the optimal imaging settings for LUS.

The development of LUS protocols based on current literature and/or expert consensus, such as with a Delphi study, could be beneficial. A Delphi study involves rounds of anonymised questionnaires with iteration and controlled feedback to come to a consensus on best practice (Nasa, Jain and Juneja 2021). Further studies validating the currently performed protocols, particularly when used by physiotherapists, would also be beneficial. In general, the diagnostic accuracy of LUS has been established when performed by physicians, but not for physiotherapists performing LUS, therefore researchers should consider conducting diagnostic accuracy studies with physiotherapists operating LUS to address this gap.

There are several underexplored uses of LUS. The scoping review in Chapter 2 found only eight studies discussing or using LUS as an outcome measure within the cardiac surgery population. This study found LUS is beneficial to evaluating physiotherapy treatment and ensuring treatment is effective. A study recently found substantial inter-rater reliability between ICU physiotherapists when assigning a LUS Score (Hansell et al. 2023b); further exploration on the use of the LUS Score as an outcome measure for physiotherapy treatment through further observational and validation studies is warranted. Qualitative studies which could explore physiotherapists' perceptions and experiences of how LUS updates their clinical reasoning by using LUS and the LUS Score as part of their treatment would also provide valuable insight.

It is also unknown how LUS influences patient outcomes for physiotherapy. A longitudinal study following patients from admission to discharge with a cohort that received regular LUS could provide insight into whether LUS can influence patient outcomes. Outcomes could include length of stay, oxygen weaning time, mortality, or others.

The role of LUS in clinical reasoning was highlighted in this study. A study by Le Neindre et al. (2023) found LUS to have an impact on the clinical decision-making of physiotherapists treating hypoxaemic patients, but further research is required with other populations and settings to determine if LUS influences clinical reasoning for all respiratory physiotherapists or only in certain situations. This would provide further insight into the indications for LUS and whether there are certain populations or settings where LUS may aid clinical reasoning. This study also found LUS had a larger influence on the pathology identification of less experienced physiotherapists. As clinical reasoning continues to develop after entry-level education, studies should include participants of varying experience to explore if LUS influences clinical reasoning differently. A deeper exploration of exactly how LUS influences clinical decision-making is also of interest. This could be explored through qualitative or mixed methods studies using clinical reasoning and decision-making theories as a basis for design.

A barrier found in this research and widely within other literature is the cost and access to machines (Innes and Jackson 2019; Ellis et al. 2020; Hayward, Innes and Smith 2021; Lau, Hayward and Ntoumenopoulos 2023). Participants in this study suggested conducting research and gathering evidence could help to build a business case to local boards and trusts to request funding for equipment. A cost effectiveness study determining the cost of LUS would aid in building a business case to obtain more LUS machines.

5.7.4 Future Qualitative Research

This study interviewed physiotherapists with a Band 5 and 6 job postings, which offered a unique perspective from those either with little to no experience with LUS and those who are in the early years of performing LUS within their practice. It would be beneficial to gain more insight into the use of LUS by those in managerial positions or highly specialised respiratory practitioners through interviews, focus groups, or questionnaires to explore if more experience changes the perceptions of and experiences with LUS. As this study and other literature has highlighted that managerial support could be a facilitator or barrier, this insight may also aid in answering questions around ways to improve lack of support.

5.7.5 Recommended Research Summary

This study identified several areas for future research into the use of LUS by physiotherapists. The following topic areas are considered priorities for future research:

- Establishment and validation of LUS protocols for physiotherapists
- Establishment of LUS indications for physiotherapy practice
- Observation of LUS-use by physiotherapists in other departments, hospitals, and health boards/trusts

- Investigation of LUS-use by physiotherapists within emergency and complex cardiac surgery patients
- Exploration of key timeframes for conducting LUS within the cardiac surgery population
- Qualitative research exploring the perceptions and beliefs in a wide range of physiotherapists
- Investigation of LUS-use by physiotherapists in other respiratory populations

5.7.6 Recommendations for Practice

Making recommendations for clinical practice is difficult due to the exploratory nature of this research. However, this thesis and the available literature are in favour of physiotherapists performing LUS, showing LUS to be a promising tool to influence pathology identification, management planning, and clinical decision-making. Therefore, further investment and investigation is recommended and encouraged. The use of LUS by physiotherapists remains a novel and under researched topic that requires more empirical research, such as the research suggested in this chapter, to begin to inform clinical practice.

Box 5.1 Key Takeaways.

***What was already known*:**

- LUS has high sensitivity, specificity, and diagnostic accuracy for many PPCs.
- LUS is currently used by physiotherapists.
- LUS impacts the clinical decision-making of physiotherapists managing hypoxemic ICU patients.
- There are several barriers and facilitators to implementing LUS into physiotherapy practice.
- LUS should be performed by experienced senior staff.
- There is limited research on the use of LUS by physiotherapists, particularly within the cardiac surgery population.

***What this thesis adds*:**

- In day one non-emergency cardiac surgery patients:
    - LUS is seldom performed in this population for several reasons.
    - Physiotherapists hold a range of views on whether LUS is indicated in this population.
    - LUS influences the identification of atelectasis and pneumothorax, but mainly pleural fluid.
    - LUS finds unexpected pathologies, particularly pleural fluid.
    - Management seldomly changes due to LUS in this population for several reasons.
- LUS improves physiotherapists' confidence in pathology identification and management planning, providing clarity and confirmation.
- LUS may have more influence on the pathology identification of physiotherapists with less experience.
- Physiotherapists hold a range of views on the indications for and roles of LUS in the cardiac surgery population.
- The use of LUS by physiotherapists is changing the perceived role of physiotherapists in the wider MDT.
- Physiotherapists hold a range of views on skill development in LUS and its current and future importance within the field of respiratory physiotherapy.

***Future research priorities*:**

- Establishment and validation of LUS protocols for physiotherapists
- Establishment of LUS indications for physiotherapy practice
- Observation of LUS-use by physiotherapists in other departments, hospitals, and health boards/trusts
- Investigation of LUS-use by physiotherapists within emergency and complex cardiac surgery patients
- Exploration of key time frames for conducting LUS within the cardiac surgery population
- Qualitative research exploring the perceptions and beliefs in a wide range of physiotherapists
- Investigation of LUS-use by physiotherapists in other respiratory populations

6. CONCLUSION

This doctoral thesis has explored the use of LUS by cardiothoracic physiotherapists working with cardiac surgery patients. Chapter 1 introduced the prevalence and severity of PPCs in the cardiac surgery population, and the prime position of cardiothoracic physiotherapists to identify PPCs early. The diagnostic tools currently used by physiotherapists lack reliability, propagating interest in LUS. LUS is comparable to the gold standard for diagnosing PPCs (CT) and superior to the commonly used tools used by physiotherapists (CXR and auscultation). Nevertheless, as LUS is a novel tool for physiotherapists, there is limited literature on the use of LUS by physiotherapists.

A scoping review was conducted and presented in Chapter 2 exploring the use of LUS within the cardiac surgery population across disciplines to better understand what the use of LUS by cardiothoracic physiotherapists within the MDT may resemble. The scoping review extensively mapped the literature and resulted in a peer-reviewed publication (Farrell et al. 2023). The scoping review identified several gaps in the literature, including a lack of empirical research on the use of LUS by physiotherapists within the cardiac surgery population; the primary research of this thesis addressed this gap, resulting in an original contribution to the knowledge base.

I took a pragmatic approach. Holding both a subjective and objective epistemological stance and considering practical and transactional knowing intrinsically worthwhile, a fully integrated convergent mixed methods study was conducted with the aim to improve clinical practice by exploring the use of LUS among physiotherapists working in cardiac care in one UK hospital. The fully integrated convergent mixed methods study began with a quantitative phase which empirically assessed the influence of LUS on pathology identification, management planning, and confidence through questionnaires. The preliminary data from the quantitative phase informed the qualitative data collection with the aim to obtain further explanation of the quantitative findings. The qualitative phase explored the experiences and perceptions of physiotherapists engaging with LUS in their daily practice through semi-structured interviews. This study was the first study, to my knowledge, to measure and explore the use of LUS by physiotherapists working with cardiac surgery patients. The data from both phases were analysed separately and integrated at the interpretation and reporting level through the construction of meta-inferences and a joint display.

Ten physiotherapists working in a cardiothoracic department in the UK participated in the study, completing a total of 77 initial assessments on day one non-emergency cardiac surgery patients over the span of 11 weeks. Seven of those physiotherapists participated in the semi-structured interviews in the qualitative phase. The study resulted in ten meta-inferences and three overarching themes.

The meta-inferences found LUS to have an influence on pathology identification, finding unexpected pathologies and changing the perceived presence or absence of pathology. The meta-inferences also reveal atelectasis is easier to identify by standard physiotherapy assessment than pleural fluid or pneumothorax, and the identification of pleural fluid was influenced the most out of the three studied pathologies. Lung ultrasound improved confidence and certainty, providing clarity and confirmation in pathology identification and management planning, and there appeared to be more influence on the pathology identification of physiotherapists with less relevant experience. Lung ultrasound was seldom performed on, or changed management for, the study population for several reasons.

The qualitative phase resulted in three overarching themes: (1) views of physiotherapists on the use and impact of LUS in the cardiac surgery population, (2) views of physiotherapists on skill development in LUS and its importance within the field of respiratory physiotherapy, and (3) barriers and facilitators to the use of LUS by physiotherapists within the cardiac surgery population. The most common role of LUS is for pathology identification and management, aiding in monitoring and tracking patient status and disease progression. Lung ultrasound may also be used for intrapersonal reasons, such as to improve confidence. Indications for LUS are physiologically based and often relate to acute respiratory symptoms and a lack of progression. The main barriers that persist and require addressing is the lack of mentors, accreditation courses, quality equipment, time, and staff support.

Within the wider context of physiotherapy practice, there remains a lack of formal accreditation among LUS-users, barriers to gaining accreditation, a lack of governance and local policy, and a need to further establish the scope of practice. The exploratory nature of this thesis assisted in identifying several research areas that require further investigation and exploration. Future research should consider establishing and validating LUS protocols for physiotherapists; further exploring indications for LUS; observational studies in different settings, populations, and health regions; establishing key timeframes for conducting LUS; and further qualitative research on the current use and future use of LUS by physiotherapists.

This doctoral thesis has comprehensively quantified, described, and explored the use of LUS by physiotherapists within the cardiac surgery population. This study found LUS may influence physiotherapy practice and physiotherapists hold a range of views as to the role, influence, and future of LUS within the field. The findings of this thesis and the wider literature are in favour of physiotherapists performing LUS as part of clinical practice, and therefore, further investigation is encouraged and considered worthwhile. The original knowledge generated from this doctoral thesis should be considered to guide future research and investigation into LUS-use by physiotherapists. With further research, LUS may prove to be a valuable tool for physiotherapists working with cardiac surgery patients, helping to identify critical PPCs early on with the aim to reduce mortality rates and improve patient outcomes; this thesis found that this potential is not limited to cardiothoracic physiotherapists, but may have an even wider influence on respiratory practice with continued exploration.

REFERENCES

ABBAS SHOBEIRI, S. and JUNGINGER, B., 2017. Ultrasound in Pelvic Floor Physiotherapy. In: S.A. SHOBEIRI, ed. *Practical Pelvic Floor Ultrasonography: A Multicompartmental Approach to 2D/3D/4D Ultrasonography of the Pelvic Floor.* Cham: Springer International Publishing. pp. 305–326. Available from: https://doi.org/10.1007/978-3-319-52929-5_16 [Accessed 15 Oct 2023].

ACOSTA, C.M. et al., 2014. Accuracy of Transthoracic Lung Ultrasound for Diagnosing Anesthesia-induced Atelectasis in Children. *Anesthesiology*, 120(6), pp. 1370–1379.

ALLINGAME, S. et al., 1995. Accuracy and reliability of physiotherapists in the interpretation of tape-recorded lung sounds. *Australian Journal of Physiotherapy*, 41(3), pp. 179–184.

AL-QUBATI, F.A.A., DAMAG, A. and NOMAN, T., 2013. Incidence and outcome of pulmonary complications after open cardiac surgery, Thowra Hospital, Cardiac center, Sana'a, Yemen. Egyptian *Journal of Chest Diseases and Tuberculosis*, 62(4), pp. 775–780.

ALSADDIQUE, A. et al., 2016. Repeated Monitoring With Transthoracic Echocardiography and Lung Ultrasound After Cardiac Surgery: Feasibility and Impact on Diagnosis. *Journal of Cardiothoracic and Vascular Anesthesia*, 30(2), pp. 406–412.

AMERICAN ASSOCIATION FOR RESPIRATORY CARE (AARC), 2003. AARC Clinical Practice Guideline: Intermittent Positive Pressure Breathing – 2003 Revision & Update. *Respiratory Care Journal,* 43(5), pp. 540-546.

ANTONELLA, V. et al., 2016. Therapeutic Efficacy of Chest Ultrasound and Chest X-Ray After Cardiac Surgery. *Journal of Cardiothoracic and Vascular Anesthesia*, 30(3), pp. e23–e24.

ARKSEY, H. and O'MALLEY, L., 2005. Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, 8(1), pp. 19–32.

AROMATARIS, E. and MUNN, Z., eds., 2020. *Introduction to JBI Systematic reviews. In: JBI Manual for Evidence Synthesis*. [online]. JBI. Available from: https://jbi-global-wiki.refined.site/space/MANUAL/4687241/1.1+Introduction+to+JBI+Systematic+reviews [Accessed 1 Jul 2023].

AZEREDO TERRA, M., 2020. Lung ultrasound as an assessment tool for the indication of noninvasive mechanical ventilation after cardiac surgery. *Revista NovaFisio*, 24(102), 04.

BAHNER, D.P., HUGHES, D. and ROYALL, N.A., 2012. I-AIM: A Novel Model for Teaching and Performing Focused Sonography. *Journal of Ultrasound in Medicine*, 31, pp. 295–300.

BAJRACHARYA, S.M., SHRESTHA, P. and SHARMA, A., 2020. Comparison of Lung Ultrasound to X-ray for Diagnosis of Pulmonary Complications after Cardiac Surgery in Children. *Journal of Nepal Health Research Council*, 18(1), pp. 47–51.

BATTAGLINI, D. et al., 2021. An Experimental Pre-Post Study on the Efficacy of Respiratory Physiotherapy in Severe Critically Ill COVID-19 Patients. *Journal of Clinical Medicine*, 10(10), p. 2139.

BARMAN, B. et al., 2020. Impact of Bedside Combined Cardiopulmonary Ultrasound on Etiological Diagnosis and Treatment of Acute Respiratory Failure in Critically Ill Patients. *Indian Journal of Critical Care Medicine,* 24(11), pp. 1062-1070.

BEEREPOOT M. et al., 2016. Lung ultrasound detects more pulmonary complications than chest X-ray in patients after cardiac surgery: A prospective observational study. *Intensive Care Medicine Experimental*, 4(Supplement 1).

BERGER, P. and LUCKMANN, T., 1967. *The Social Construction of Reality: A Treatise in the Sociology of Knowledge.* Garden City, NY: Doubleday.

BERTOLONE, D.T. et al., 2022. Lung ultrasound: a narrative review and proposed protocol for patients admitted to Cardiac Rehabilitation Unit. *Monaldi Archives for Chest Disease*, 92(1). [online]. Available from: https://monaldi-archives.org/index.php/macd/article/view/1753 [Accessed 3 Aug 2022].

BESTER, J., COLE, C.M. and KODISH, E., 2016. The Limits of Informed Consent for an Overwhelmed Patient: Clinicians' Role in Protecting Patients and Preventing Overwhelm. *AMA Journal of Ethics*, 18(9), pp. 869–886.

BETTS, J.G. et al., 2013. *Anatomy and Physiology*. Houston, TX: OpenStax. [online]. Available from: https://openstax.org/books/anatomy-and-physiology/pages/1-introduction [Accessed 4 August 2023].

BETTS, J.G. et al., 2022. *Anatomy and Physiology 2e.* Houston, TX: OpenStax. [online]. Available from: https://openstax.org/details/books/anatomy-and-physiology-2e [Accessed 1 April 2024].

BIANCO, F. et al., 2015. Acute heart failure in post-cardiac surgery: Predictive role of lung ultrasonography. *European Heart Journal: Acute Cardiovascular Care*, 4(Supplement 1), pp. 269–270.

BIASUCCI, D.G. et al., 2014. Sonographic dynamic assessment of lung injury in a child with hypoplastic left heart syndrome undergoing extracorporeal membrane oxygenation. *Pediatric Pulmonology*, 49(12), pp. E147–E150.

BITHELL, C., 2000. Evidence-based Physiotherapy: Some thoughts on 'best evidence'. *Physiotherapy*, 86(2), pp. 58–59.

BITTL, J.A. and HE, Y., 2017. Bayesian Analysis: A Practical Approach to Interpret Clinical Trials and Create Clinical Practice Guidelines. *Circulation: Cardiovascular Quality and Outcomes,* 10(8), p. e003563

BOUHEMAD, B. et al., 2015. Ultrasound for "Lung Monitoring" of Ventilated Patients. *Anesthesiology*, 122(2), pp. 437–447.

BOWLING, A., 2014. *Research methods in health: investigating health and health services*. 4th ed. Maidenhead New York, NY: Open University Press.

BRAUN, V. and CLARKE, V., 2012. Thematic analysis. In: H. COOPER et al., eds. *APA Handbook of Research Methods in Psychology, Vol 2: Research Designs: Quantitative, Qualitative,* *Neuropsychological, and Biological.* Washington: American Psychological Association. pp. 57–71. Available from: http://content.apa.org/books/13620-004

BRENNER, D.S. et al., 2021. Diagnostic accuracy of lung ultrasound for SARS-CoV-2: a retrospective cohort study. *The Ultrasound Journal*, 13(1), pp. 12.

BROOKS, D. and THOMAS, J., 1995. Interrater Reliability of Auscultation of Breath Sounds Among Physical Therapists. *Physical Therapy*, 75(12), pp. 50–56.

BRYMAN, A., 2006. Integrating quantitative and qualitative research: how is it done? *Qualitative Research*, 6(1), pp. 97–113.

BRYMAN, A., 2007. Barriers to Integrating Quantitative and Qualitative Research. *Journal of Mixed Methods Research,* 1(1), pp. 8-22.

BUCCIARELLI, V. et al., 2016. Acute heart failure in post-cardiac surgery: Diagnostic performance of novel systemic inflammation markers and transthoracic cardiopulmonary ultrasound. *European Heart Journal: Acute Cardiovascular Care*, 5(Supplement 1), pp. 45–46.

BUCHOLTZ, M., 2000. The politics of transcription. *Journal of Pragmatics*, 32(10), pp. 1439–1465.

BUDA, N. et al., 2020. Recommendations for Lung Ultrasound in Internal Medicine. *Diagnostics*, 10(8). [online]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7460159/ [Accessed 5 May 2021].

BURRI, S.D. et al., 2022. Risk factors associated with physical therapist burnout: a systematic review. *Physiotherapy*, 116, pp. 9–24.

CANET, J. and MAZO, V., 2010. Postoperative pulmonary complications. *Minerva Anestesiologica*, 76(2), pp. 138–143.

CANTINOTTI, M. et al., 2015. Lung ultrasound: A new toll for the diagnosis of retro-sternal clots in children undergoing cardiac surgery. *Cardiology in the Young*, 25(Supplement 1), pp. S168–S169.

CANTINOTTI, M. et al., 2016. Feasibility of lung ultrasound in pediatric cardiac surgery: A new basic tool for pediatric cardiologist. Preliminary experience. *Cardiology in the Young*, 26(Supplement 1), pp. S60.

CANTINOTTI, M. et al., 2016. Lung ultrasound in adult and paediatric cardiac surgery: is it time for routine use? *Interactive CardioVascular and Thoracic Surgery*, 22(2), pp. 208–215.

CANTINOTTI, M. et al., 2018. Lung ultrasound reclassification of chest X-ray data after pediatric cardiac surgery. *Pediatric Anesthesia*, 28(5), pp. 421–427.

CANTINOTTI, M. et al., 2020a. Could judicious use of lung ultrasound reduce radiographic examinations in pediatric cardiac surgery patients? *Journal of Clinical Anesthesia*, 61.

CANTINOTTI, M. et al., 2020b. Prognostic Value of a New Lung Ultrasound Score to Predict Intensive Care Unit Stay in Pediatric Cardiac Surgery. *Annals of Thoracic Surgery*, 109(1), pp. 178–184.

CANTINOTTI, M. et al., 2022. Overview of Lung Ultrasound in Pediatric Cardiology. *Diagnostics*, 12(3), pp. 763.

CANTINOTTI, M., 2018. The importance and ways of exploring the entire chest before and after cardiac surgery: Chest radiography, lung ultrasonography, and computed tomography. *The Journal of Thoracic and Cardiovascular Surgery*, 155(5), pp. 2041–2042.

CANTINOTTI, M., GIORDANO, R. and KUTTY, S., 2020. Lung Ultrasonography in Pediatric Cardiac Surgery: A Complementary Diagnostic Tool Reply. *Annals of Thoracic Surgery*, 109(6), pp. 1946–1947.

CANTINOTTI, M., GIORDANO, R. and VALVERDE, I., 2017. Lung ultrasound: a new basic, easy, multifunction imaging diagnostic tool in children undergoing pediatric cardiac surgery. *Journal of Thoracic Disease*, 9(6), pp. 1396–1399.

CANTINOTTI, M., PAOLO DEL, S. and LAMIA AIT, A., 2017. Echo-Guided Recruitment of Lung Atelectasis after Pediatric Cardiac Surgery. *Journal of Cardiothoracic Surgery and Therapeutics*, 1(1).

CARCARY, M., 2020. The Research Audit Trail: Methodological Guidance for Application in Practice. *Electronic Journal of Business Research Methods,* 18(2), pp. 166-177.

CASE, K., HARRISON, K. and ROSKELL, C., 2000. Differences in the Clinical Reasoning Process of Expert and Novice Cardiorespiratory Physiotherapists. *Physiotherapy,* 86(1), pp. 14-21.

CATTAROSSI, L., 2013. Lung ultrasound: its role in neonatology and pediatrics. *Early Human Development*, 89, pp. S17–S19.

CHAN, K.K. et al., 2020. Chest ultrasonography versus supine chest radiography for diagnosis of pneumothorax in trauma patients in the emergency department. *Cochrane Database of Systematic Reviews*, (7). [online]. Available from: https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD013031.pub2/full?highlightAbstract=ultrasonography%7Cultrasonographi%7Cthoracic%7Cthorac [Accessed 24 Feb 2021].

CHATZIVASILOGLOU, F. et al., 2020. The use of lung ultrasound in the postoperative period following cardiac surgery. *European Respiratory Journal*, 56(suppl 64). [online]. Available from: https://erj.ersjournals.com/content/56/suppl_64/2779 [Accessed 3 Aug 2022].

CHERRYHOLMES, C.H., 1992. Notes on Pragmatism and Scientific Realism. *Educational Researcher*, 21(6), pp. 13–17.

CHUMILLAS, S. et al., 1998. Prevention of postoperative pulmonary complications through respiratory rehabilitation: A controlled clinical study. *Archives of Physical Medicine and Rehabilitation*, 79(1), pp. 5–9.

CHURCHILL, L.J. et al., 2023. The role of lung ultrasound for detecting atelectasis, consolidation, and/or pneumonia in the adult cardiac surgery population: A scoping review of the literature. *Australian Critical Care.* [Online]. Available from: https://doi.org/10.1016/j.aucc.2023.08.002 [Accessed 15 September 2023].

COIRO, S. et al., 2015. Prognostic value of residual pulmonary congestion at discharge assessed by lung ultrasound imaging in heart failure. *European Journal of Heart Failure*, 17(11), pp. 1172–1181.

COMPTON G., BHAMARE T., and SEED M., 2014. Sonographic: Pathologic correlation of pulmonary lymphangectasia. *Pediatric Radiology*, 44(Supplement 1), pp. S150–S151.

CORRADI, F. et al., 2016. Computer-Aided Quantitative Ultrasonography for Detection of Pulmonary Edema in Mechanically Ventilated Cardiac Surgery Patients. *Chest*, 150(3), pp. 640–651.

COX, E.G.M. et al., 2020. Should the ultrasound probe replace your stethoscope? A SICS-I sub-study comparing lung ultrasound and pulmonary auscultation in the critically ill. *Critical Care*, 24(1), p. 14.

CRESWELL, J.W. and CRESWELL, J.D., 2018. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 5th ed. Los Angeles, CA: SAGE Publications, Inc.

CRESWELL, J. and PLANO CLARK, V., 2007. Chapter 4: Choosing a Mixed Methods Design. In: *Designing and Conducting Mixed Methods Research*. SAGE Publications, Inc.

CRESWELL, J.W. and PLANO CLARK, V., 2017. *Designing and Conducting Mixed Methods Research*. 3rd ed. SAGE Publications, Inc.

CROTTY, M., 1998. *The foundations of social research: meaning and perspective in the research process*. NSW, Australia: Allen & Unwin.

CUMBERLAND, P.M. et al., 2014. Ophthalmic statistics note: the perils of dichotomising continuous variables. *British Journal of Ophthalmology,* 98 (6), pp. 841-843.

CYLWIK, J. and BUDA, N., 2021. Lung Ultrasonography in the Monitoring of Intraoperative Recruitment Maneuvers. *Diagnostics*, 11(2), p. 276.

DAWES, L. et al., 2022. *Hemithorax white-out (differential).* [online]. Radiopaedia.org. Available from: https://doi.org/10.53347/rID-1439 [Accessed 25 October 2023].

DE ALENCAR, J.C. et al., 2021. Lung ultrasound score predicts outcomes in COVID-19 patients admitted to the emergency department. *Annals of Intensive Care,* 11(1), p. 6.

DE SOUZA, L.A.M. et al., 2022. Implementation and Assessment of Lung Ultrasound Training Curriculum for Physiotherapists with a Focus on Image Acquisition and Calculation of an Aeration Score. *Ultrasound in Medicine & Biology*, 48(10), pp. 2119-2127.

DE SOUZA, T., GIATTI, M. and BRANDÃO, M., 2016. Lung ultrasound for diagnosis of pneumothorax in an infant. *Journal of Pediatric Critical Care*, 3(4), p. 101.

DELLINGER, A.B. and LEECH, N.L., 2007. Toward a Unified Validation Framework in Mixed Methods Research. *Journal of Mixed Methods Research*, 1(4), pp. 309–332.

DEMI, L. et al., 2023. New International Guidelines and Consensus on the Use of Lung Ultrasound. *Journal of Ultrasound in Medicine*, 42(2), pp. 309–344.

DENZIN, N.K. and LINCOLN, Y.S., 2018. *The SAGE Handbook of Qualitative Research*. 5th ed. SAGE Publications, Inc.

DUREAU P. et al., 2017. Lung ultrasound for early diagnosis of pneumonia after cardiac surgery. *Annals of Intensive Care*, 7(1 Supplement 1), p. 101.

EBRAHIMI, A. et al., 2014. Diagnostic Accuracy of Chest Ultrasonography versus Chest Radiography for Identification of Pneumothorax: A Systematic Review and Meta-Analysis. *Tanaffos*.

ECKHARDT, A.L. and DEVON, H.A., 2017. The MIXED framework: A novel approach to evaluating mixed-methods rigor. *Nursing Inquiry,* 24(4), p. e12189.

EDRICH, T. et al., 2015. CASE 11--2015: Intraoperative Transthoracic Cardiac and Pulmonary Ultrasonography. *Journal of Cardiothoracic and Vascular Anesthesia*, 29(6), pp. 1702–1711.

EFREMOV, S.M. et al., 2020. Lung Ultrasonography and Cardiac Surgery: A Narrative Review. *Journal of Cardiothoracic and Vascular Anesthesia*, 34(11), pp. 3113–3124.

ELAYASHY, M. et al., 2019. Effect of ultrafiltration on extravascular lung water assessed by lung ultrasound in children undergoing cardiac surgery: a randomized prospective study. *BMC Anesthesiology*, 19(93).

ELLIS, R. et al., 2018. Exploring the clinical use of ultrasound imaging: A survey of physiotherapists in New Zealand. *Musculoskeletal Science and Practice,* 34, pp. 27-37.

ELLIS, R. et al., 2020. Exploring the use of ultrasound imaging by physiotherapists: An international survey. *Musculoskeletal Science and Practice,* 49, p.102213.

ELWAKEEL M.M. et al., 2019. Prediction of postoperative pulmonary complications by ultrasonic assessment of extravascular lung water in pediatric patients with left to right shunt lesions. *Indian Journal of Public Health Research and Development*, 10(11), pp. 3435–3440.

EMPERADOR, F. et al., 2020. Extravascular Lung Water and Effect on Oxygenation Assessed by Lung Ultrasound in Adult Cardiac Surgery. *CUREUS*, 12(8).

FARRELL, C. et al., 2022. *Exploring the use of lung ultrasound in the cardiac surgery population: a scoping review protocol.* [online]. Available from: https://osf.io/cjvtp/ [Accessed 1 Apr 2023].

FARRELL, C. et al., 2023. Exploring the Use of Lung Ultrasonography to Assess Cardiac Surgery Patients: A Scoping Review. *Journal of Diagnostic Medical Sonography.* [Online]. Available from: https://doi.org/10.1177/87564793231198521 [Accessed 22 September 2023].

FERNANDEZ-BUSTAMANTE, A. et al., 2017. Postoperative Pulmonary Complications, Early Mortality, and Hospital Stay Following Noncardiothoracic Surgery: A Multicenter Study by the Perioperative Research Network Investigators. JAMA Surgery, 152(2), pp. 157–166.

FETTERS, M.D., CURRY, L.A. and CRESWELL, J.W., 2013. Achieving Integration in Mixed Methods Designs—Principles and Practices. *Health Services Research*, 48(6 Pt 2), pp. 2134–2156.

FISCHER, M.O. et al., 2022. Postoperative Pulmonary Complications After Cardiac Surgery: The VENICE International Cohort Study. *Journal of Cardiothoracic and Vascular Anesthesia*, 36(8, Part A), pp. 2344–2351.

FOT, E.V. et al., 2019. Prognostic value of lung ultrasonography after on-pump cardiac surgery. *Almanac of Clinical Medicine*, 47(7), pp. 654–661.

GALE, N.K. et al., 2013. Using the framework method for the analysis of qualitative data in multi-disciplinary health research. *BMC Medical Research Methodology*, 13(1), p. 117.

GARDUNO-LOPEZ, J., GARCIA-CRUZ, E. and BARANDA-TOVAR, F., 2019. Cardiac, cerebral, renal, optic nerve, and lung ultrasound study (CCROSS) protocol. *Archivos de Cardiologia de Mexico*, 89(2), pp. 126–137.

GAUDREAULT, N. et al., 2021. Using ultrasound imaging to assess novice physiotherapy students' ability to locate musculoskeletal structures with palpation. *Physiotherapy*, 113, pp. 53–60.

GHOTRA, G.S. et al., 2021. Role of Lung Ultrasound in the Detection of Postoperative Pulmonary Complications in Pediatric Patients: A Prospective Observational Study. *Journal of Cardiothoracic and Vascular Anesthesia*, 35(5), pp. 1360–1368.

GIL-RODRIGUEZ, J. et al., 2022. Ultrasound findings of lung ultrasonography in COVID-19: A systematic review. *European Journal of Radiology*, 148, p. 110156.

GIRALDO-RESTREPO, J.A. and SERNA-JIMÉNEZ, T.J., 2015. The FAST and extended FAST examinations. *Colombian Journal of Anesthesiology.*

GIRONA-ALARCÓN, M. et al., 2022. LUCAS (lung ultrasonography in cardiac surgery) score to monitor pulmonary edema after congenital cardiac surgery in children. *The Journal of Maternal-Fetal & Neonatal Medicine*, 35(6), pp. 1213–1218.

GOODWIN, R. et al., 2021. Evaluation of the First Contact Physiotherapy (FCP) model of primary care: a qualitative insight. *Physiotherapy*, 113, pp. 209–216.

GRANT, M.J. and BOOTH, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, 26(2), pp. 91–108.

GRANT, S.W. et al., 2021. Trends and outcomes for cardiac surgery in the United Kingdom from 2002 to 2016. *JTCVS Open*, 7, pp. 259-269.

GRAVEN, T. et al., 2015. Focused ultrasound of the pleural cavities and the pericardium by nurses after cardiac surgery. *Scandinavian Cardiovascular Journal*, 49(1), pp. 56–63.

GRAY, H., 1918. *Anatomy of the Human Body.* 20th ed. Philadelphia/New York City: Bartleby.

GRILLO, L. et al. 2023. Physiotherapy assessment of breathing pattern disorder: a qualitative evaluation. *BMJ Open Respiratory Research,* 10(1), e001395.

GUBA, E., 1990. *The Paradigm Dialog*. London: SAGE Publications, Inc.

GUETTERMAN, T.C., FETTERS, M.D. and CRESWELL, J.W., 2015. Integrating Quantitative and Qualitative Results in Health Science Mixed Methods Research Through Joint Displays. *The Annals of Family Medicine*, 13(6), pp. 554–561.

HAMADAH, H. and KABBANI, M., 2017. Bedside Ultrasound in the Diagnosis and Treatment of Children with Respiratory Difficulty Following Cardiac Surgery. *Journal of Clinical Imaging Science*, 7, pp. 1–12.

HANEKOM, S.D., FAURE, M. and COETZEE, A., 2007. Outcomes research in the ICU: An aid in defining the role of physiotherapy. *Physiotherapy Theory and Practice*, 23(3), pp. 125–135.

HANSELL, L. et al., 2021. Lung ultrasound has greater accuracy than conventional respiratory assessment tools for the diagnosis of pleural effusion, lung consolidation and collapse: a systematic review. *Journal of Physiotherapy*, 67(1), pp. 41–48.

HANSELL, L. et al., 2023a. Barriers and facilitators to achieving competence in lung ultrasound: A survey of physiotherapists following a lung ultrasound training course. *Australian Critical Care*, 36(4), pp. 573–578.

HANSELL, L. et al., 2023b. Interrater reliability in assigning a lung ultrasound score. *Australian Critical Care,* 36(5), pp. 732-736.

HANSELL, L. et al., 2023c. Quantification of changes in lung aeration associated with physiotherapy using lung ultrasound in mechanically ventilated patients: a prospective cohort study. *Physiotherapy,* 119, pp. 26-33.

HASAN, T. et al., 2021. Lung ultrasound compared with bedside chest radiography in a paediatric cardiac intensive care unit. *Acta Paediatrica*, 110(4), pp. 1335–1340.

HAYWARD, S., 2021. *Another 2 physiotherapists gained their @FUSICuk Lung Ultrasound accreditation this month from @ICS_updates.* [Twitter] 31 January 2021. Available from: https://x.com/sonophysio/status/1355794395228991490 [Accessed 4 March 2024].

HAYWARD, S. and HAYWARD, L., 2019. Thoracic ultrasound can optimise the sequence of medical and physiotherapy treatments during an opaque hemithorax (whiteout): A case report. *Physiotherapy Practice and Research*, 40(1), pp. 45–50.

HAYWARD, S. and HAYWARD, L., 2019a. Opaque hemithorax (whiteout): a literature review exploring its causes, potential use of thoracic ultrasound and the role of physiotherapy. *Physiotherapy*, 105, pp. e134–e135.

HAYWARD, S. and KELLY, D., 2017. Respiratory physiotherapy and lung ultrasound: A service evaluation of a competency based training programme. *Journal of Association of Chartered Physiotherapists in Respiratory Care*, 50.

HAYWARD, S., INNES, S. and SMITH, M., 2022. Challenges and opportunities in point-of-care ultrasound: A qualitative exploration of respiratory physiotherapists' experiences of lung ultrasound training and its adoption in critical care. *Ultrasound*, 30(2), pp. 126–133.

HAYWARD, S., SMITH, M. and INNES, S., 2020. Diagnostic thoracic ultrasound imaging – An exploration of respiratory physiotherapists' interest and use in clinical practice: A national survey. Ultrasound, 28(1), pp. 14–22.

HAYWARD, S.A. and JANSSEN, J., 2018. Use of thoracic ultrasound by physiotherapists: a scoping review of the literature. *Physiotherapy*, 104(4), pp. 367–375.

HE, P. et al., 2021a. Effect of positive end-expiratory pressure on the incidence of atelectasis in children with congenital heart disease undergoing lateral thoracotomy under cardiopulmonary bypass. *Journal of Shanghai Jiaotong University (Medical Science)*, 41(6), pp. 781–785.

HE, P. et al., 2021b. Effectiveness of postural lung recruitment on postoperative atelectasis assessed by lung ultrasound in children undergoing lateral thoracotomy cardiac surgery with cardiopulmonary bypass. *Pediatric Pulmonology*, 56(6), pp. 1724–1732.

HELDEWEG, M.L.A. et al., 2022. The impact of lung ultrasound on clinical-decision making across departments: a systematic review. *The Ultrasound Journal*, 14(1), p. 5.

HERON, J. and REASON, P., 1997. A Participatory Inquiry Paradigm. *Qualitative Inquiry*, 3(3), pp. 274–294.

HEW, M. and TAY, T.R., 2016. The efficacy of bedside chest ultrasound: from accuracy to outcomes. *European Respiratory Review*, 25(141), pp. 230–246.

HIGGS, J. et al., eds., 2019. Clinical reasoning in the health professions. 4th ed. Edinburgh London New York: Elsevier.

HOUGH, A., 2018. Hough's Cardiorespiratory Care: an evidence-based, problem-solving approach. 5th ed. Edinburgh: Elsevier.

HOUSE OF COMMONS HEALTH AND SOCIAL CARE COMMITTEE, 2022. *Workforce: recruitment, training and retention in health and social care*. UK Parliament.

HUI K. et al., 2019. Correlation between lung ultrasound score and postoperative pulmonary complications after cardiac surgery. *Chinese Journal of Clinical Thoracic and Cardiovascular Surgery*, (12), pp. 688–692.

IBRAHIM, I. et al., 2021. Efficacy of transalveolar pressure measurement as a monitoring parameter for lung recruitment in postcardiac surgery hypoxic patients. *Egyptian Journal of Anaesthesia*, 37(1), pp. 145–151.

INNES, S. and JACKSON, J., 2019. Musculoskeletal ultrasound imaging - An exploration of physiotherapists' interests and use in practice. *Musculoskeletal Science and Practice*, 44, p. 102068.

JI, Q. et al., 2013. Risk Factors for Pulmonary Complications Following Cardiac Surgery with Cardiopulmonary Bypass. *International Journal of Medical Sciences*, 10(11), pp. 1578–1583.

KARTHIKA, M. et al., 2019. Lung Ultrasound: The Emerging Role of Respiratory Therapists. *Respiratory Care*, 64(2), pp. 217–229.

KASKINEN, A.K. et al., 2017. Assessment of extravascular lung water by ultrasound after congenital cardiac surgery. *Pediatric Pulmonology*, 52(3), pp. 345–352.

KENDRICK, C., HOGARTH, S. and HAYWARD, S., 2022. The novel use of lung ultrasound to reduce anxiety during weaning from mechanical ventilation: A case report. *Physiotherapy*, 114, pp. e158–e159.

KHALIL, H. et al., 2020. Evaluation of the JBI scoping reviews methodology by current users. *JBI Evidence Implementation*, 18(1), p. 95.

KRUISSELBRINK, R. et al., 2017. I-AIM (Indication, Acquisition, Interpretation, Medical Decision-making) Framework for Point of Care Lung Ultrasound. *Anesthesiology,* 127(3), pp. 568–582.

LARSON, I., 2016. *The use of lung ultrasound to assess the prevalence of lung interstitial syndrome in paediatric cardiac surgery patients and the measurement of postoperative length of hospital stay.* [online]. Available from: http://scholar.ufs.ac.za/xmlui/handle/11660/6427 [Accessed 3 Aug 2022].

LAU, Y.H., HAYWARD, S. and NTOUMENOPOULOS, G., 2023. An international survey exploring the adoption and utility of diagnostic lung ultrasound by physiotherapists and respiratory therapists in intensive care. *Journal of the Intensive Care Society*, 24(4), pp. 364–371.

LEBLANC, D. et al., 2014. Early lung ultrasonography predicts the occurrence of acute respiratory distress syndrome in the blunt trauma patients. *Intensive Care Medicine,* 40(10), pp. 1468-1474.

LE NEINDRE, A. et al., 2016. Thoracic ultrasound: Potential new tool for physiotherapists in respiratory management. A narrative review. *Journal of Critical Care*, 31(1), pp. 101–109.

LE NEINDRE, A. et al., 2021. Diagnostic accuracy of diaphragm ultrasound to predict weaning outcome: A systematic review and meta-analysis. *International Journal of Nursing Studies*, 117, p. 103890.

LE NEINDRE, A. et al., 2023. Thoracic ultrasound influences physiotherapist's clinical decision-making in respiratory management of critical care patients: a multicentre cohort study. *Thorax*, 78(2), pp. 169–175.

LEECH, M. et al., 2015. Lung Ultrasound for Critical Care Physiotherapists: A Narrative Review. *Physiotherapy Research International,* 20(2), pp. 69–76.

LEECH, M. et al., 2015a. Physiotherapist-initiated lung ultrasound to improve intensive care management of a deteriorating patient and prevent intubation: a case report. *Physiotherapy Theory and Practice*, 31(5), pp. 372–376.

LEECH, M. et al., 2015b. Lung Ultrasound for Critical Care Physiotherapists: A Narrative Review. *Physiotherapy Research International*, 20(2), pp. 69–76.

LICHTENSTEIN, D.A. et al., 2004. Comparative Diagnostic Performances of Auscultation, Chest Radiography, and Lung Ultrasonography in Acute Respiratory Distress Syndrome. *Anesthesiology*, 100(1), pp. 9–15.

LICHTENSTEIN, D.A., 2009. Lung Ultrasound in the Critically Ill. *Journal of Medical Ultrasound,* 17(3), pp. 125-142.

LICHTENSTEIN, D.A. and MAURIAT, P., 2012. Lung Ultrasound in the Critically Ill Neonate. *Current Pediatric Reviews*, 8(3), pp. 217-223

LICHTENSTEIN, D.A. and MEZIÈRE, G.A., 2008. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest*, 134(1), pp. 117–125.

LICHTENSTEIN, D.A. and MEZIÈRE, G.A., 2011. The BLUE-points: three standardized points used in the BLUE-protocol for ultrasound assessment of the lung in acute respiratory failure. *Critical Ultrasound Journal,* 3, pp. 109-110.

LICHTENSTEIN, D.A., 2014. Lung ultrasound in the critically ill, *Annals of Intensive Care*, 4, p. 12.

LINCOLN, Y.S. and GUBA, E.G., 1985. *Naturalistic Inquiry*. Beverly Hills, CA: SAGE Publications, Inc.

LUMSDEN, G. et al., 2017. Physiotherapists utilizing diagnostic ultrasound in shoulder clinics. How useful do patients find immediate feedback from the scan as part of the management of their problem? *Musculoskeletal Care,* 16(1), pp. 209-213.

MANSKE, R. et al., 2023. Physical Therapists Use of Diagnostic Ultrasound Imaging in Clinical Practice: A Review of Case Reports. *International Journal of Sports Physical Therapy*, 18(1), pp. 215-227.

MARINI, T.J. et al., 2021. Lung ultrasound: the essentials. *Radiology Cardiothoracic Imaging*, 3(2), p. e200564.

MCMULLIN, C., 2023. Transcription and Qualitative Methods: Implications for Third Sector Research. *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations*, 34(1), pp. 140–153.

MENZEL, C. et al., 2014. Chest ultrasound vs. Chest X-ray in pediatric patients after congenital cardiac surgery-a comparative study. *Cardiology in the Young. Conference: 48th Annual Meeting of the Association for European Paediatric and Congenital Cardiology, AEPC with Joint Sessions with the Japanese Society of Pediatric Cardiology and Cardiac Surgery and Asia-Pacific Pediatric Cardiac Society. Finland. Conference Start: 20140521. Conference End: 20140524*, 24, p. S148-S149.

MIKKOLA, P. et al., 2021. Prior knowledge elicitation: The past, present, and future. *arXiv.* [Online]. Available from: https://doi.org/10.48550/arXiv.2112.01380 [Accessed 1 October 2023].

MISKOVIC, A. and LUMB, A.B., 2017. Postoperative pulmonary complications. *British Journal of Anaesthesia*, 118(3), pp. 317–334.

MOHAMED, M.A., CHENG, C. and WEI, X., 2021. Incidence of postoperative pulmonary complications in patients undergoing minimally invasive versus median sternotomy valve surgery: propensity score matching. *Journal of Cardiothoracic Surgery,* 16, p. 287.

MOHAMMED, A.K., MADKOUR, M.A. and HASSANIEN, H.M., 2019. Furosemide: Would it help to improve the lungs as evaluated by sonography and compliance during aortic coarctation surgery. *Annals of Cardiac Anaesthesia*, 22(3), pp. 254–259.

MOJOLI, F. et al., 2019. Lung Ultrasound for Critically Ill Patients. *American Journal of Respiratory and Critical Care Medicine*, 199(6), pp. 701-714.

MONAGHAN, T.F. et al., 2021. Foundational Statistical Principles in Medical Research: Sensitivity, Specificity, Positive Predictive Value, and Negative Predictive Value. *Medicina*, 57(5), p. 503.

MONASTESSE, A. et al., 2017. Lung Ultrasonography for the Assessment of Perioperative Atelectasis: A Pilot Feasibility Study. *Anesthesia & Analgesia*, 124(2), pp. 494–504.

MORGAN, D.L., 2007. Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods. *Journal of Mixed Methods Research*, 1(1), pp. 48–76.

MORRIS, D.E., OAKLEY, J.E. and CROWE, J.A., 2014. A web-based tool for eliciting probability distributions from experts. *Environmental Modelling & Software*, 52, pp. 1–4.

MOSHAVEGH, R. et al., 2019. Automatic Detection of B-Lines in $In Vivo$ Lung Ultrasound. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 66(2), pp. 309–317.

MUMOLI, N. et al., 2016. Accuracy of Nurse-Performed Lung Ultrasound in Patients With Acute Dyspnea: A Prospective Observational Study. *Medicine*, 95(9), p. e2925.

MUNN, Z. et al., 2018. What kind of systematic review should I conduct? A proposed typology and guidance for systematic reviewers in the medical and health sciences. *BMC Medical Research Methodology*, 18(1), p. 5.

MURALI, A. et al., 2022. Lung ultrasound for the evaluation of dyspnea: a pictorial review. *Acute and Critical Care,* 37(4), pp. 502-515.

MUSOLINO, A.M. et al., 2022. Ten Years of Pediatric Lung Ultrasound: A Narrative Review. *Frontiers in Physiology*, 12, p. 721951.

MYSZKOWSKI, M., 2019. The usefulness of respiratory ultrasound assessment for modifying the physiotherapeutic algorithm in children after congenital heart defect surgeries. *Journal of Ultrasonography*, 19(76), pp. 17–22.

NASA, P., JAIN, R. and JUNEJA, D., 2021. Delphi methodology in healthcare research: How to decide its appropriateness. *World Journal of Methodology,* 11(4), pp. 116-129.

NATIONAL INSTITUTE FOR CARDIOVASCULAR OUTCOMES RESEARCH [NICOR], 2023. *National Adult Cardiac Surgery Audit (NACSA) 2023 Summary report (2019/20-2021/22 data).* [Online]. Leicester: NICOR. Available from: https://www.nicor.org.uk/wp-content/uploads/2023/06/10633_NICOR-Annual-Summary_NACSA_v4.pdf [Accessed 11 October 2023].

NAVEED, A. et al., 2017. Incidence and risk factors of Pulmonary Complications after Cardiopulmonary bypass. *Pakistan Journal of Medical Sciences*, 33(4), pp. 993–996.

NGUYEN, H.B. et al., 2020. Cardiogenic Shock Secondary to Dynamic Left Ventricular Outflow Tract Obstruction and Apical Ballooning after Nonmitral Cardiovascular Surgery. *Case Reports in Critical Care*, 2020, p. 8826187.

NIYOGI, S.G. et al., 2022. Utility of Lung Ultrasound in the Estimation of Extravascular Lung Water in a Pediatric Population—A Prospective Observational Study. *Journal of Cardiothoracic and Vascular Anesthesia*, 36(8, Part A), pp. 2385–2392.

NOWELL, L.S. et al., 2017. Thematic Analysis: Striving to Meet the Trustworthiness Criteria. *International Journal of Qualitative Methods*, 16(1), p. 1609406917733847.

NTOUMENOPOULOS, G. et al., 2017. Evaluation of a pilot programme on diagnostic thoracic ultrasound curriculum for acute care physiotherapists. *Australasian Journal of Ultrasound in Medicine*, 20(4), pp. 147–154.

NTOUMENOPOULOS, G., PARRY, S.M. and NEINDRE, A.L., 2018. Impact of an intensive education programme of diagnostic lung and lower limb ultrasound on physiotherapist knowledge: A pilot study. *Australasian Journal of Ultrasound in Medicine*, 21(2), pp. 104–114.

OLIVEIRA, C. et al. 2022. Prevalence of Burnout in Physiotherapists During COVID-19: A Systematic Review. In: P. AREZES et al. *Occupational and Environmental Safety and Health IV. Studies in Systems, Decision and Control*, vol 449. Springer, Cham. https://doi-org.ezproxy.rgu.ac.uk/10.1007/978-3-031-12547-8_29

OMAR, H.R. et al., 2010. Occult pneumothorax, revisited. *Journal of Trauma Management & Outcomes*, 4, p. 12.

O'NEAL, J.B., SHAW, A.D. and BILLINGS, F.T., 2016. Acute kidney injury following cardiac surgery: current understanding and future directions. *Critical Care*, 20, p.187.

ONWUEGBUZIE, A.J. and JOHNSON, R.B., 2006. The Validity Issue in Mixed Research. *Research in the Schools,* 13, pp. 48-63

OZTURK, E. et al., 2017. The Efficacy of Thoracic Ultrasonography in Postoperative Newborn Patients after Cardiac Surgery. *Brazilian Journal of Cardiovascular Surgery*, 32(4), pp. 283–287.

PACZKOWSKI K. et al., 2010. Is transthoracic ultrasound a useful tool for bedside differential diagnosis of respiratory failure in children after cardiac surgery with extracorporeal circulation? *Eur. J. Med. Res.*, 15(Supplement 1), p. 166.

PACZKOWSKI, K. et al., 2012. Transthoracic lung ultrasound during postoperative intensive care in children with congenital heart disease. *Polish Journal of Thoracic and Cardiovascular Surgery*, 9(1), pp. 114–120.

PALAMATTAM, Dr.D.Ja. et al., 2022. Bedside chest ultrasound in post operative pediatric cardiac surgery patients: Comparison with bedside chest radiography. *Journal of Cardiothoracic and Vascular Anesthesia*. [online]. Available from: https://www.sciencedirect.com/science/article/pii/S1053077022004773 [Accessed 3 Aug 2022].

PARLEVLIET, K. et al., 2016. Lung ultrasound detects pulmonary complications earlier than chest x-ray in patients after cardiac surgery: a prospective single centre observational study. *Intensive Care Medicine Experimental. Conference: 29th Annual Congress of the European Society of Intensive Care Medicine, ESICM 2016. Italy*, 4, [online]. Available from: https://www.cochranelibrary.com/central/doi/10.1002/central/CN-01407533/full.

PARRY, A., 1997. New Paradigms for Old: Musings on the shape of clouds. *Physiotherapy*, 83(8), pp. 423–433.

PETERS, M.D.J. et al., 2015. Guidance for conducting systematic scoping reviews. *International Journal of Evidence-Based Healthcare*, 13(3), pp. 141–146.

PETERS, M.D.J. et al., 2020. Chapter 11: Scoping Reviews (2020 version). In: E. AROMATARIS and Z. MUNN, eds. *JBI Manual for Evidence Synthesis*. JBI. Available from: https://synthesismanual.jbi.global/.

PETERS, M.D.J. et al., 2021. Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Implementation*, 19(1), pp. 3–10.

PHILLIPS, C.T. and MANNING, W.J., 2017. A Woman in Her 90s With Respiratory Distress After Transcatheter Aortic Valve Replacement and Pacemaker Implantation. *Chest*, 151(4), pp. e77–e79.

PICANO, E. et al., 2006. Ultrasound Lung Comets: A Clinically Useful Sign of Extravascular Lung Water. *Journal of the American Society of Echocardiography*, 19(3), pp. 356–363.

PICANO, E., et al., 2014. The appropriate and justified use of medical radiation in cardiovascular imaging: a position document of the ESC Associations of Cardiovascular Imaging, Percutaneous Cardiovascular Interventions and Electrophysiology. *European Heart Journal,* 35, pp. 665-672.

PICCOLI, M. et al., 2005. Bedside Diagnosis and Follow-up of Patients With Pleural Effusion by a Hand-Carried Ultrasound Device Early After Cardiac Surgery. *Chest*, 128(5), pp. 3413–3420.

PLATZ, T., 2021. Methods for the Development of Healthcare Practice Recommendations Using Systematic Reviews and Meta-Analyses. *Frontiers in Neurology,* 12, p. 699968.

POLITO, A., BIASUCCI, D.G. and COGO, P., 2016. Point-of-care pleural and lung ultrasound in a newborn suffering from cardiac arrest due to tension pneumothorax after cardiac surgery. *Cardiology in the Young*, 26(2), pp. 400–402.

PRIEST, S., 2020. The implementation of a 'One Stop Shop' shoulder clinic within a musculoskeletal triage service: assessment, diagnostic ultrasound & guided injections. *Physiotherapy,* 107, pp. e197–e198.

RAMELLI A. et al., 2016. Evaluation of changes in lung ultrasound patterns after chest physiotherapy in patients undergoing cardiac surgery. *Intensive Care Medicine Experimental*, 4(Supplement 1).

REGNAULT, A., WILLGOSS, T. and BARBIC, S., 2018. Towards the use of mixed methods inquiry as best practice in health outcomes research. *Journal of Patient-Reported Outcomes,* 2, p.19.

RICCI F. et al., 2014. Utility of ultrasound lung comets in the early diagnosis of acute heart failure in post-cardiac surgery: The LUCE study. *European Heart Journal Cardiovascular Imaging*, 15(Supplement 2).

RICCI F. et al., 2015. Prognostic value of transthoracic cardiopulmonary ultrasound in cardiac surgery intensive care unit. *European Heart Journal Cardiovascular Imaging*, 16(Supplement 2).

RICCI F. et al., 2016. Diagnostic performance and prognostic value of cardiopulmonary ultrasound for the early diagnosis of postoperative heart failure after cardiac surgery. *European Heart Journal Cardiovascular Imaging*, 17(Supplement 2).

RICCI Z. et al., 2014. Lung sonography to assess pulmonary overflow in neonates and children undergoing cardiac surgery. *Pediatr. Crit. Care Med.*, 15(4 Supplement 1), p. 91.

RICHARD, R. et al., 2021. The Significance of B-Lines on Lung Ultrasonography in the Preoperative Assessment of Patients Undergoing Cardiac Surgery. *American Journal of Respiratory and Critical Care Medicine*, 203(9).

RITCHIE, J. et al., eds., 2013. *Qualitative research practice: a guide for social science students and researchers*. 2nd ed. SAGE Publications Ltd.

SACKETT, D.L. and STRAUS, S., 1998. On some clinically useful measures of the accuracy of diagnostic tests. *American College of Physicians Journal Club,* 129(2), pp. A17-9.

SÁNCHEZ, I.T., et al., 2019. Influence of Cardiorespiratory Clinical Placements on the Specialty Interest of Physiotherapy Students. *Healthcare,* 7(4), p. 148.

SANTOS-MARTÍNEZ, L.E. et al., 2020. Pulmonary ultrasound imaging in the hemodynamic evaluation in the early postoperative period of cardiac surgery. *Archivos de Cardiologia de Mexico*, 90(2), pp. 242–245.

SAPORITO, A. et al., 2013. Thoracic ultrasound confirmation of correct lung exclusion before one-lung ventilation during thoracic surgery. *Journal of Ultrasound*, 16(4), pp. 195–199.

SARANTEAS, T. et al., 2011. Lung Ultrasound and Transthoracic Echocardiography in the Differentiation Between Pericardial and Left Pleural Effusion in a Cardiac Surgery Patient. *Journal of Cardiothoracic and Vascular Anesthesia*, 25(3), pp. 603–605.

SARANTEAS, T., 2011. Ultrasound examination for the diagnosis of pneumonia associated with Acinetobacter baumannii in a cardiac surgery patient. *Journal of Cardiothoracic and Vascular Anesthesia*, 25(5), pp. e38–e39.

SARKAR, M. et al. 2015. Auscultation of the respiratory system. *Annals of Thoracic Medicine,* 10(3), pp. 158-168.

SAUSSE M. et al., 2021. Transesophageal Lung Ultrasound (TELUS) in Adult Cardiac Surgery: Clinical Significance and Predictive Performance for Postoperative Respiratory Events (PORE). *Intensive Care Medicine Experimental*, 9(Supplement 1).

SCHIEFENHÖVEL, F. et al., 2022. Pleural effusions are associated with adverse outcomes after cardiac surgery: a propensity-matched analysis. *Journal of Cardiothoracic Surgery,* 17, p. 298.

SCHRIFT, D. et al., 2017. A case report of lung ultrasound missing a pneumothorax due to patient positioning. *Ultrasound*, 25(4), pp. 248-250.

SCURLOCK-EVANS, L., UPTON, P. and UPTON, D., 2014. Evidence-Based Practice in physiotherapy: a systematic review of barriers, enablers and interventions. *Physiotherapy*, 100(3), pp. 208–219.

SENGEL, A. et al., 2018. Interstitial oedema in patients undergoing cardiac surgery: Evaluation through lung ultrasonography. *Journal of Cardiothoracic and Vascular Anesthesia*, 32, pp. S49–S50.

SENNIAPPAN, K. et al., 2019. Bedside Lung Ultrasound for Postoperative Lung Conditions in Cardiothoracic Intensive Care Unit: Diagnostic Value and Comparison with Bedside Chest Roentgenogram. *Anesthesia, Essays and Researches*, 13(4), pp. 649–653.

SENST, B., KUMAR, A. and DIAZ, R.R., 2022. *Cardiac Surgery*. [Online]. Treasure Island, FL: StatsPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK532935/ [Accessed 11 October 2023].

SHAW, J., CONNELLY, D. and ZECEVIC, A., 2010. Pragmatism in practice: Mixed methods research for physiotherapy. *Physiotherapy Theory & Practice*, 26(8), pp. 510–518.

SHIER, D., BUTLER, J. and LEWIS, R., 2018. *Hole's essentials of human anatomy & physiology.* 13th ed. New York, NY: McGraw-Hill Education.

SHOKOOHI, H. et al., 2020. Point-of-care ultrasound stewardship. *Journal of the American College of Emergency Physicians Open*, 1(6), pp. 1326–1331.

SINGH, A. et al., 2020. *Role of ultrasound in predicting weaning failure in children undergoing cardiac surgery: Prospective observational study*. Preprints. Available from: https://www.authorea.com/users/367836/articles/487099-role-of-ultrasound-in-predicting-weaning-failure-in-children-undergoing-cardiac-surgery-prospective-observational-study?commit=842bf4e5ceb33754f1f78c9c995e3671a5d7f4d5 [Accessed 3 Aug 2022].

SKAMAGKI, G. et al., 2022. The concept of integration in mixed methods research: a step-by-step guide using an example study in physiotherapy. *Physiotherapy Theory and Practice.* [online]. Available from: https://doi.org/10.1080/09593985.2022.2120375 [Accessed 19 August 2023].

SMITH, M. et al., 2022. Point of care ultrasound in pelvic health: scope of practice, education and governance for physiotherapists. *International Urogynecology Journal*, 33(10), pp. 2669–2680.

SMITH, M. et al., 2023. A proposed framework for point of care musculoskeletal ultrasound and ultrasound image-guided interventions by physiotherapists: scope of practice, education and governance. *The Ultrasound Journal*, 15(1), p. 15.

SMITH, M., HAYWARD, S. and INNES, S., 2022. A proposed framework for point of care lung ultrasound by respiratory physiotherapists: scope of practice, education and governance. *The Ultrasound Journal*, 14(1), p. 24.

SMITH, M., HIGGS, J. and ELLIS, E., 2007. Physiotherapy decision making in acute cardiorespiratory care is influenced by factors related to the physiotherapist and the nature and context of the decision: a qualitative study. *Australian Journal of Physiotherapy,* 57, pp. 261-267.

SMITH, M.J. et al., 2020. Point-of-care lung ultrasound in patients with COVID-19 – a narrative review. *Anaesthesia*, 75(8), pp. 1096–1104.

SONG, I.-K. et al., 2018. Utility of Perioperative Lung Ultrasound in Pediatric Cardiac Surgery: A Randomized Controlled Trial. *Anesthesiology*, 128(4), pp. 718–727.

SPERANDEO, M., MIRIJELLO, A. and DE COSMO, S., 2020. Lung Ultrasonography in Pediatric Cardiac Surgery: A Complementary Diagnostic Tool. *Annals of Thoracic Surgery*, 109(6), pp. 1946–1946.

STEENVOORDEN, T.S. et al., 2018. Lung point in the absence of pneumothorax. *Intensive Care Medicine*, 44(8), pp. 1329–1330.

STEPPAN, D., DIGIUSTO, M. and STEPPAN, J., 2020. Perioperative Lung Ultrasound in the Pediatric Intensive Care Unit—Beyond the Vasculature and Parenchyma. *Journal of Cardiothoracic and Vascular Anesthesia*, 34(4), pp. 956–958.

SUN, L. et al., 2020. Lung ultrasound evaluation of incremental PEEP recruitment maneuver in children undergoing cardiac surgery. *Pediatric Pulmonology*, 55(5), pp. 1273–1281.

SUTTON, A. et al., 2019. Meeting the review family: exploring review types and associated information retrieval requirements. *Health Information & Libraries Journal*, 36(3), pp. 202–222.

SWINTON, P.A. et al., 2022. Interpreting magnitude of change in strength and conditioning: Effect size selection, threshold values and Bayesian updating. *Journal of Sports Sciences,* 40(18), pp. 2047-2054.

TAGLIAFERRI, S.D. et al., 2023. How to Interpret Effect Sizes for Biopsychosocial Outcomes and Implications for Current Research. *The Journal of Pain,* 25(4), pp. 857-861.

TANNER, T.G. and COLVIN, M.O., 2020. Pulmonary Complications of Cardiac Surgery. *Lung,* 198(6), pp. 889–896.

TARGHETTA, R. et al., 1994. Sonographic lung surface evaluation in pulmonary sarcoidosis: preliminary results. *Journal of Ultrasound in Medicine*, 13(5), pp. 381–388.

TEDDLIE, C. and TASHAKKORI, A., 2009. Chapter 12: The inference process in mixed methods research. In: *Foundations of Mixed Methods Research: Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences*. USA: SAGE Publications, Inc. pp. 285–314.

THE ASSOCIATION OF CHARTERED PHYSIOTHERAPISTS IN CARDIAC REHABILITATION (ACPICR), 2016. *Early Activity After Cardiac Surgery*. [Online]. London: ACPICR. Available from: https://www.acpicr.com/data/Page_Downloads/EarlyActivityAfterCardiacSurgery2016-Booklet-A4_0.pdf [Accessed 1 October 2023].

THE CHARTERED SOCIETY OF PHYSIOTHERAPY (CSP), 2022. *Context of Physiotherapists using Point of Care Ultrasound (POCUS) in physiotherapy practice.* [Online]. London: CSP. Available from: https://www.csp.org.uk/publications/context-physiotherapists-using-point-care-ultrasound-pocus-physiotherapy-practice [Accessed 1 October 2023].

THE CHARTERED SOCIETY OF PHYSIOTHERAPY (CSP), 2023. *Boost physio numbers to tackle public dissatisfaction with the NHS, says CSP.* [online]. London: CSP. Available from: https://www.csp.org.uk/news/2023-03-29-boost-physio-numbers-tackle-public-dissatisfaction-nhs-says-csp [Accessed 1 April 2024].

THE INTENSIVE CARE SOCIETY, 2024. *FUSIC Lung.* [online]. London: The Intensive Care Society. Available from: https://www.ics.ac.uk/product/fusic-lung.html [Accessed 4 March 2024].

THOMAS, P. et al., 2020. Physiotherapy management for COVID-19 in the acute hospital setting: clinical practice recommendations. *Journal of Physiotherapy,* 66(2), pp. 73-82.

THOMAS, P. et al., 2022. Physiotherapy management for COVID-19 in the acute hospital setting and beyond: an update to clinical practice recommendations. *Journal of Physiotherapy*, 68, pp. 8-25.

THURAISINGAM A. et al., 2015. Accuracy of clinical examination and chest xray compared to lung ultrasound in postoperative cardiac surgery patients. *Heart Lung and Circulation*, 24(Supplement 1), pp. e72–e73.

TOUW, H.R. et al., 2018. Lung ultrasound compared with chest X-ray in diagnosing postoperative pulmonary complications following cardiothoracic surgery: a prospective observational study. *Anaesthesia*, 73(8), pp. 946–954.

TOWNSLEY, M.M., 2021. Lung Ultrasound in Pediatric Cardiac Surgery: A Complementary Tool for Predicting and Identifying Postoperative Pulmonary Complications. *Journal of Cardiothoracic and Vascular Anesthesia*, 35(5), pp. 1369–1370.

TRICCO, A.C. et al., 2016. A scoping review on the conduct and reporting of scoping reviews. *BMC Medical Research Methodology*, 16(1), p. 15.

TRICCO, A.C. et al., 2018. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine*, 169(7), pp. 467–473.

TRIGGLE, N. and BAILEY, E., 2023. *Physiotherapists join NHS strike in one-day walkout.* [online]. BBC: BBC. Available from: https://www.bbc.com/news/health-64404684 [Accessed 1 April 2024].

TUNG-CHEN, Y. et al., 2021. The Impact of Different Lung Ultrasound Protocols in the Assessment of Lung Lesions in COVID-19 Patients: Is There an Ideal Lung Ultrasound Protocol? *Journal of Ultrasound*, 25(3), pp. 483–491.

TUSMAN, G., ACOSTA, C.M. and COSTANTINI, M., 2016. Ultrasonography for the assessment of lung recruitment maneuvers. *Critical Ultrasound Journal*, 8(1), p. 8.

UEDA K et al., 2011. Intraoperative pneumothorax identified with transthoracic ultrasound. *Anesthesiology*, 115(3), pp. 653–655.

USTA, E., MUSTAFI, M. and ZIEMER, G., 2010. Ultrasound estimation of volume of postoperative pleural effusion in cardiac surgery patients. *Interactive CardioVascular and Thoracic Surgery*, 10(2), pp. 204–207.

VARGAS, F. et al., 1994. Relationship between pleural effusion and pericardial involvement after myocardial revascularization. *Chest*, 105(6), pp. 1748–1752.

VERGARA SANCHEZ A. et al., 2019. Evaluation of lung B-lines in critical care patients as a readmission or mortality predictor. *European Heart Journal: Acute Cardiovascular Care*, 8(Supplement 1), p. 143.

VEZZANI, A. et al., 2014. Diagnostic Value of Chest Ultrasound After Cardiac Surgery: A Comparison With Chest X-ray and Auscultation. *Journal of Cardiothoracic and Vascular Anesthesia*, 28(6), pp. 1527–1532.

VITALE, V. et al., 2017. Lung ultrasound profile after cardiopulmonary bypass in paediatric cardiac surgery: first experience in a simple cohort. *Interactive CardioVascular and Thoracic Surgery*, 24(4), pp. 598–602.

VITALE, V., RICCI, Z. and COGO, P., 2014. Lung Ultrasonography and Pediatric Cardiac Surgery: First Experience With a New Tool for Postoperative Lung Complications. *Annals of Thoracic Surgery*, 97(4), pp. E121–E124.

VITOMSKYI, V., 2020. The impact of mobilization and other factors on pleural effusion in patients undergoing cardiac surgical procedures. *Journal of Physical Education and Sport*, 20, pp. 2167–2173.

VOHRA, H.A. et al., 2023. Consensus statement on aortic valve replacement via an anterior right minithoracotomy in the UK healthcare setting. *Open Heart*, 10, p. e002194.

VOLPICELLI, G. et al., 2006. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. *The American Journal of Emergency Medicine*, 24(6), pp. 689–696.

VOLPICELLI, G. et al., 2012. International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Medicine*, 38(4), pp. 577–591.

WAINWRIGHT, S.F. et al., 2011. Factors That Influence the Clinical Decision Making of Novice and Experienced Physical Therapists. *Physical Therapy,* 91(1), pp. 87-101.

WANG, J. et al., 2020. Diagnosis and treatment value of bedside pulmonary ultrasound for atelectasis in patients after cardiac surgery. *Zhonghua Yi Xue Za Zhi*, 100(3), pp. 220–224.

WASTI, S.P. et al., 2022. The Growing Importance of Mixed-Methods Research in Health. *Nepal Journal of Epistemology,* 12(1), pp. 1175-1178.

WEISSMAN, C., 2004. Pulmonary Complications After Cardiac Surgery. *Seminars in Cardiothoracic and Vascular Anesthesia*, 8(3), pp. 185–211.

WHITTAKER, J.L. et al., 2019. Imaging with ultrasound in physical therapy: What is the PT's scope of practice? A competency-based educational model and training recommendations. *British Journal of Sports Medicine,* 53, pp. 1447-1453.

WILLIAMS, M.C., et al., 2019. Using radiation safely in cardiology: what imagers need to know. *Heart,* 105, pp. 798-806.

WINKLER, M.H. et al., 2018. Diagnostic Accuracy of Chest Radiograph, and When Concomitantly Studied Lung Ultrasound, in Critically Ill Patients with Respiratory Symptoms: A Systematic Review and Meta-Analysis. *Critical Care Medicine*, 46(7), pp. e707–e714.

WU, L. et al., 2018. Feasibility of lung ultrasound to assess pulmonary overflow in congenital heart disease children. *Pediatric Pulmonology*, 53(11), pp. 1525–1532.

WU, L. et al., 2019. Modified Lung Ultrasound Examinations in Assessment and Monitoring of Positive End-Expiratory Pressure-Induced Lung Reaeration in Young Children with Congenital Heart Disease Under General Anesthesia. *Pediatric Critical Care Medicine*, 20(5), pp. 442–449.

XIE, C. et al., 2020. Feasibility and efficacy of lung ultrasound to investigate pulmonary complications in patients who developed postoperative Hypoxaemia-a prospective study. *BMC Anesthesiology*, 20(1), p. 220.

XIROUCHAKI, N. et al., 2014. Impact of lung ultrasound on clinical decision making in critically ill patients. *Intensive Care Medicine*, 40(1), pp. 57–65.

YOUNG D. and MOHANRAJ E.M., 2014. Ablation inflammation: An unusual presentation of pleural effusion. *American Journal of Respiratory and Critical Care Medicine*, 189. [online]. Available from: http://www.atsjournals.org/doi/pdf/10.1164/ajrccm-conference.2014.189.1_MeetingAbstracts.A2917.

YU, X. et al., 2016. Performance of Lung Ultrasound in Detecting Peri-Operative Atelectasis after General Anesthesia*. Ultrasound in Medicine & Biology*, 42(12), pp. 2775–2784.

APPENDIX

APPENDIX 1 – Search Strategies

Medline (via EBSCOhost)

Search conducted 6 April 2022

Search	Query
#1	(MH "Lung") OR (TX "lung") OR (MH "Lung Diseases") OR (TX "lung diseas*")
#2	(MH "Ultrasonography") OR (TX "ultraso*")
#3	#1 AND #2
#4	(TX "lung ultraso*") OR (TX "chest ultraso*") OR (TX "pulmonary ultraso*")
#5	#3 OR #4
#6	(MH "Thoracic Surgery") OR (TX "thoracic surgery") OR (TX "cardi* surgery") OR (TX "heart surgery") OR (TX "Coronary artery bypass *") OR (TX "CABG") OR (TX "Heart valve repair") OR (TX "Heart valve replacement") OR (TX "Coronary angioplasty") OR (TX "Coronary stenting") OR (TX "Atherectomy") OR (TX "Cardiomyoplasty") OR (TX "Heart transplant") OR (TX "Catheter ablation")
#7	#5 AND #6
Records Retrieved: 3,007	

CINAHL (via EBSCOhost)

Search conducted 6 April 2022

Search	Query
#1	(MH "Lung+") OR (TX "lung") OR (MH "Lung Diseases+") OR (TX "lung diseas*")
#2	(MH "Ultrasonography+") OR (TX "ultraso*")
#3	S1 AND S2
#4	(TX "lung ultraso*") OR (TX "chest ultraso*") OR (TX "pulmonary ultraso*")

#5	S3 OR S4
#6	(MH “Surgery, Cardiovascular+”) OR (TX “cardi* surgery”) OR (MH “Heart Surgery+”) OR (TX “heart surgery”) OR (TX "thoracic surgery") OR (TX “Coronary artery bypass *”) OR (TX "CABG") OR (TX “Heart valve repair”) OR (TX “Heart valve replacement”) OR (TX “Coronary angioplasty”) OR (TX “Coronary stenting”) OR (TX “Atherectomy”) OR (TX “Cardiomyoplasty”) OR (TX “Heart transplant”) OR (TX “Catheter ablation”)
#7	S5 AND S6
Records Retrieved: 2,914	

Web of Science

Search conducted 6 April 2022

Search	Query
#1	ALL=Lung OR ALL="Lung Diseases" OR (TI="Lung disease*" OR AB="Lung diseas*") OR (TI=Lung OR AB=Lung)
#2	ALL=Ultrasonography OR (TI=ultraso* OR AB=ultraso*)
#3	#1 AND #2
#4	(TI="lung ultraso*" OR AB="lung ultraso*") OR (TI="chest ultraso*" OR AB="chest ultraso*") OR (TI="pulmonary ultraso*" OR AB="pulmonary ultraso*")
#5	#3 OR #4
#6	(TI="thoracic surgery" OR AB="thoracic surgery") OR (TI="cardi* surgery" OR AB="cardi* surgery") OR (TI="heart surgery" OR AB="heart surgery") OR (TI="coronary artery bypass *" OR AB="coronary artery bypass *") OR (TI=cabg OR AB=cabg) OR (TI="heart valve repair" OR AB="heart valve repair") OR (TI="heart valve replacement" OR AB="heart valve replacement") OR (TI="coronary angioplasty" OR AB="coronary angioplasty") OR (TI="coronary stenting" OR AB="coronary stenting") OR (TI=atherectomy OR AB=atherectomy) OR (TI=cardiomyoplasty OR AB=cardiomyoplasty) OR (TI="heart transplant" OR AB="heart transplant") OR (TI="catheter ablation" OR AB="catheter ablation")

#7	#5 AND #6
Records Retrieved: 484	

Scopus

Search conducted 6 April 2022

Search	Query
#1	INDEXTERMS(Lung) OR INDEXTERMS("Lung Diseases") OR TITLE-ABS("Lung diseas*") OR TITLE-ABS(Lung)
#2	INDEXTERMS(Ultrasonography) OR TITLE-ABS(ultraso*)
#3	#1 AND #2
#4	TITLE-ABS("lung ultraso*") OR TITLE-ABS("chest ultraso*") OR TITLE-ABS("pulmonary ultraso*")
#5	#3 OR #4
#6	TITLE-ABS("thoracic surgery") OR TITLE-ABS("cardi* surgery") OR TITLE-ABS("heart surgery") OR TITLE-ABS("coronary artery bypass *") OR TITLE-ABS(cabg) OR TITLE-ABS("heart valve repair") OR TITLE-ABS("heart valve replacement") OR TITLE-ABS("coronary angioplasty") OR TITLE-ABS("coronary stenting") OR TITLE-ABS(atherectomy) OR TITLE-ABS(cardiomyoplasty) OR TITLE-ABS("heart transplant") OR TITLE-ABS("catheter ablation")
#7	#5 AND #6
Records Retrieved: 693	

Cochrane Trials and Reviews

Search conducted 6 April 2022

Search	Query
#1	[mh Lung] OR [mh "Lung Diseases"] OR ("Lung" NEXT diseas*):ti,ab OR Lung:ti,ab
#2	[mh Ultrasonography] OR ultraso*:ti,ab

#3	#1 AND #2
#4	("lung" NEXT ultraso*):ti,ab OR ("chest" NEXT ultraso*):ti,ab OR ("pulmonary" NEXT ultraso*):ti,ab
#5	#3 OR #4
#6	"thoracic surgery":ti,ab OR (cardi* NEXT "surgery"):ti,ab OR "heart surgery":ti,ab OR ("coronary artery bypass" NEXT *):ti,ab OR cabg:ti,ab OR "heart valve repair":ti,ab OR "heart valve replacement":ti,ab OR "coronary angioplasty":ti,ab OR "coronary stenting":ti,ab OR atherectomy:ti,ab OR cardiomyoplasty:ti,ab OR "heart transplant":ti,ab OR "catheter ablation":ti,ab
#7	#5 AND #6
Records Retrieved: 114	

EMBASE (via OVID)

Search conducted 6 April 2022

Search	Query
#1	exp Lung/ OR exp Lung Diseases/ OR Lung diseas*.tw. OR Lung.tw.
#2	exp Ultrasonography/ OR ultraso*.tw.
#3	1 AND 2
#4	lung ultraso*.tw. OR chest ultraso*.tw. OR pulmonary ultraso*.tw.
#5	3 OR 4
#6	thoracic surgery.tw. OR cardi* surgery.tw. OR heart surgery.tw. OR coronary artery bypass *.tw. OR cabg.tw. OR heart valve repair.tw. OR heart valve replacement.tw. OR coronary angioplasty.tw. OR coronary stenting.tw. OR atherectomy.tw. OR cardiomyoplasty.tw. OR heart transplant.tw. OR catheter ablation.tw.
#7	5 AND 6
Records Retrieved: 4,287	

EBSCO Open Dissertation

Searched 3 August 2022

Search	Query	Records Retrieved
#1	"lung ultrasound" AND "cardiac surgery"	0
#2	"lung ultrasound" AND "heart surgery"	0
#3	"thoracic ultrasound" AND "cardiac surgery"	0
#4	"thoracic ultrasound" AND "heart surgery"	0
#5	"chest ultrasound" AND "cardiac surgery"	0
#6	"chest ultrasound" AND "heart surgery"	0

Networked Digital Library of Theses and Dissertations – Global ETD Search

Search conducted 3 August 2022

Search	Query	Records Retrieved
#1	"lung ultrasound" AND "cardiac surgery"	0
#2	"lung ultrasound" AND "heart surgery"	0
#3	"thoracic ultrasound" AND "cardiac surgery"	0
#4	"thoracic ultrasound" AND "heart surgery"	0
#5	"chest ultrasound" AND "cardiac surgery"	0
#6	"chest ultrasound" AND "heart surgery"	0
#7	“lung ultrasound” AND “surgery”	0
#8	"thoracic ultrasound" AND "surgery"	0
#9	"chest ultrasound" AND "surgery"	0

Google Scholar

Search conducted 3 August 2022

Search	Query	Records Retrieved
#1	"lung ultrasound" AND "cardiac surgery"	85
#2	"lung ultrasound" AND "heart surgery"	29
#3	"thoracic ultrasound" AND "cardiac surgery"	18

Google Scholar

Search conducted 4 August 2022

Search	Query	Records Retrieved
#1	"thoracic ultrasound" AND "heart surgery"	8
#2	"chest ultrasound" AND "cardiac surgery"	25
#3	"chest ultrasound" AND "heart surgery"	7

APPENDIX 2 – Characteristics of Included Reports

Empirical Research Studies						
Lead Author, Year, and Country	**Aim**	**Study Type**	**Setting**	**Participant Description**	**Type of Surgery**	**Author's Description of Key Findings**
Alsaddique 2016 Australia	To determine whether both repeated postoperative transthoracic echocardiography and lung ultrasound revealed or excluded clinically important cardiac and respiratory disorders compared to conventional monitoring and CXR.	Observational - cohort	General ICU/ITU, General Ward	Patients older than 18 receiving cardiac surgery; Mean (SD): 57.3 yrs (13.1); Majority male; n=91	CABG, Valve repair/replacement, Thoracic aorta, LV aneurysmectomy	Routine repeated monitoring with cardiac and lung ultrasound after cardiac surgery is feasible and frequently alters diagnosis of clinically important cardiac and respiratory pathology.
Bajracharya 2020 Nepal	To compare diagnostic performance of LUS in comparison to CXR to detect pulmonary complication after cardiac surgery in children	Observational - cohort	CICU/CITU	All consecutive paediatric patients aged less than 14 years scheduled for cardiac surgery; Mean: 6.3 ± 4.7 yrs; Majority male; n=141	Congenital cardiac surgery, Valve repair/replacement	Lung ultrasound done routinely is an alternative non-invasive, reliable and accurate tool for diagnosing common pulmonary complications in paediatric patient post-cardiac surgery as compared to CXR with acceptable diagnostic accuracy thereby decreasing exposure to ionizing radiation, time and costs.
Beerepoot 2016 Netherlands	To compare the rates of PPCs detected by LUS and CXR in patients after cardiac surgery admitted to ICU	Observational - cohort	General ICU/ITU	Cardiac surgery patients; Mean: 68 ± 9.5 yrs; Majority male; n=134	NR	LUS detects more PPCs than CXR in patients after cardiac surgery and with good inter-observer agreement. In addition, time to perform LUS is significantly shorter. However, most PPCs detected by LUS come with little clinical consequence. Therefore, we suggest in further studies to quantify the extent of the PPC

						detected by LUS to improve its value in clinical decision making.
Bianco 2015 Italy	To assess the diagnostic performance and the predictive value of ultrasound lung comets compared with CXR and NT-proBNP, for the early diagnosis of postoperative acute heart failure (AHF) in a cohort of patients admitted to the cardiac surgery intensive care unit of our hospital.	Observational - cohort	CICU/CITU	Cardiac surgery patients; Mean: 69.7 ± 10.1 yrs; n=55	NR	LUS allows a prompt and reliable ruling-out of AHF, but with lower specificity compared to supine CXR and NT-proBNP assay.
Biasucci 2014 Italy	To report a case in which LUS was used as an effective lung monitoring tool during treatment of a child suffering from severe and complex lung injury after heart surgery.	Observational - case study/report	NR	A 1-year-old male with hypoplastic left heart syndrome underwent bidirectional Glenn procedure and systemic to-left pulmonary artery shunt for heart palliation due to severe hypoplasia of left pulmonary artery.	Bidirectional Glenn procedure and systemic-to-left pulmonary artery shunt	The decision for extracorporeal membrane oxygenation weaning was also supported by the documentation of the bilateral sonographic improvement of the perfused lobes.
Bucciarelli 2016 Italy	To assess the additional diagnostic performance of neutrophil-to-lymphocyte ratio (NLR) and platelet-to-lymphocyte ratio (PLR) along with cardiopulmonary ultrasound for early rule-in and rule-out diagnosis of postoperative heart failure (PHF).	Observational - cohort	CICU/CITU	Admitted to the cardiac surgery ICU after elective cardiac surgery with a cardiopulmonary ultrasound available before and after surgery; Mean: 68.9±9.8 yrs; Majority male, n=81	CABG, NR	Elevated preoperative NLR and PLR well correlate with elevated B-lines, reduced echocardiographic myocardial performance indexes and pulmonary arterial pressure in early diagnosis of PHF in elective patients after cardiac surgery.
Cantinotti 2018 Italy	To test the feasibility of LUS following paediatric cardiac surgery and to compare LUS	Observational - cohort	General ICU/ITU	All children and adolescent (<20 years old) undergoing corrective or	Congenital cardiac surgery	In 81 cases, LUS allowed reclassification of CXR findings, including 40 new diagnoses

	and CXR findings, assessing whether LUS may provide additional information.			palliative congenital heart disease surgery; Median: 9.3 mo.; IQR: 1 mo. - 6 yrs; Majority male; n=79		(diagnosis of effusion/atelectasis with negative CXR reports) and 41 changes in diagnosis (effusions reclassified as atelectasis/severe congestion or vice versa)
Cantinotti 2015 Italy	To assess LUS ability to evaluate common pulmonary complications after cardiac surgery	Observational - cohort	NR	Paediatric cardiac surgery patients; Mean: 24.8 ± 73 mo.; n=85	Congenital cardiac surgery	LUS may lead to a new diagnosis of unknown retro-sternal clots as well as a better definition of those incidentally detached at echocardiography, potentially leading to less need for more complex, ionizing and expensive examinations.
Cantinotti 2016 Italy	To test the feasibility of LUS in paediatric cardiac surgery.	Observational - cohort	NR	Paediatric cardiac surgery patients; Median: 6 mo.; Range: 1 day - 16.7 yrs; n=62	NR	LUS allows differential diagnosis and severity estimation of effusion/atelectasis, and the posterior approach is much more accurate than anterior/lateral for this setting.
Cantinotti 2020 Italy	To investigate the prognostic potential of a new LUS score in children undergoing surgery for congenital heart disease (CHD), and (2) to compare LUS score with traditional markers of outcome including age, body surface area, The Society of Thoracic Surgeons/European Association of Cardio-Thoracic Surgery (STAT) score, Aristotle score, and cardiopulmonary bypass (CPB) time and established	Observational - cohort	General ICU/ITU	All children and adolescents (<18 years old) undergoing corrective or palliative CHD surgery between June 2015 and May 2018 at the Department of Paediatric Cardiac Surgery of Fondazione CNR–Regione Toscana G. Monasterio; Median age: 0.55 years; IQR: 0.09-4.15 yrs; n=237	Congenital cardiac surgery	The LUS score, when added as continuous predictor to a conventional risk model (age, STAT score, and cardiopulmonary bypass time) emerged significant both for intensive care unit length of stay (beta 0.145, P [.047) and extubation time (beta 1.644; P[.024).

	prognostic biomarkers such as brain natriuretic peptide (BNP) and cystatin-C.					
Chatzivasiloglou 2020 Greece	To report the respiratory complications in the immediate postoperative period following cardiac surgery and to highlight the importance of lung ultrasound in the cardiac surgery ICU.	Observational - cohort	CICU/CITU	Cardiac surgery patients; n=170	NR	Atelectasis was detected in 71% of the patients, pleural effusion in 94%, alveolar-interstitial syndrome in 26% and consolidation in 14%. Prompt diagnosis of postoperative complications following cardiac surgery is of paramount importance and it may be made reliably, quickly and safely with LUS.
Compton 2014 Canada	To report the use of ultrasound to diagnose pulmonary lymphangectasia (PL) in newborn.	Observational - case study/report	NR	Newborn male with suspected pulmonary lymphangectasia	NR	This report represents the first description of the use of ultrasound to diagnose PL. The abnormal ultrasound appearances are easily detectable using a high frequency linear probe in an intercostal scanning approach.
Corradi 2016 Italy	To investigate whether quantitative LUS (Q-LUS) can provide estimates of pulmonary oedema that are better correlated with pulmonary capillary wedge pressure (PCWP) and EVLW than visual LUS (V-LUS).	Observational - cohort	General ICU/ITU	Patients requiring invasive hemodynamic monitoring after cardiac surgery; EVLW: 69 ± 8 yrs; PCWP: 70 ± 8 yrs; Majority male, n=48	CABG, Valve repair/replacement, Aortic surgery	Both V-LUS and Q-LUS are acceptable indicators of pulmonary oedema in mechanically ventilated patients. However, at high PEEP only Q-LUS provides data that are significantly correlated with PCWP and EVLW. Computer-aided Q-LUS has the advantages of being not only independent of operator perception but also of PEEP.
de Souza 2016 Brazil	To describe the presence of a pneumothorax, identified by point-of-care ultrasound in a 4-month-old infant in postoperative care after cardiac surgery.	Observational - case study/report	PICU	A 4-month-old infant (weighing 5 kg) diagnosed with endocarditis	Removal of a right atrial vegetative lesion	This case report describes the successful use of chest ultrasound to diagnosis a pneumothorax in an infant.

Dureau 2017 France	To investigate the clinical relevance of LUS diagnosis of pneumonia in cardiac postoperative patients with acute respiratory failure (ARF).	Observational - cohort	CICU/CITU	Adult patients with acute respiratory failure (ARF) less than 3 days after a cardiac surgery with CPB; Mean: 65 ± 12 yrs; Majority male; n=51	NR	LUS combined with a clinical score can be a reliable tool for early diagnosis of pneumonia in a cardiac ICU population after cardiac surgery with cardiopulmonary bypass.
Edrich 2015 Austria	To describe a case where intraoperative transthoracic cardiac and pulmonary ultrasound played a key role in the timely management of sudden cardiopulmonary decompensation.	Observational - case study/report	OR	An 81-year-old male brought via ambulance to the emergency room with the complaint of sudden onset of pain, pallor, and weakness in the right leg.	AAA Repair	The present report demonstrates the value that anaesthesiologists can bring to an operative team when they have basic competency in cardiac and pulmonary ultrasonography.
Elayashy 2019 Egypt	To study the effect of ultrafiltration during cardiopulmonary bypass on post-bypass EVLW using LUS and its effect on oxygenation.	RCT	General ICU/ITU	Congenital heart disease patients between 1 and 48 mo. with body weight >3kg; Ultrafiltration group: 15.5 ± 14 mo.; Non-filtration group: 19 ± 14.8 mo.; Majority female; n=60	Congenital cardiac surgery	Conventional ultrafiltration did not alter EVLW when assessed by LUS and the oxygenation state.
Elwakeel 2019 Egypt	To study the use of LUS to evaluate EVLW and predict PPCs.	Observational - cohort	Paediatric cardiac ICU	Paediatric patients with acyanotic CHD, scheduled for elective cardiac surgery; 6 mo. to 5 yrs; Mean: 1.48; Majority female; n=80	Congenital cardiac surgery	LUS score in patients complicated by PPC showed a significant difference from non-complicated patients; in all LUS scans
Emperador 2020 Saudi Arabia	To assess EVLW before and after cardiac surgery by scoring B-lines using LUS. The primary outcomes were to assess the relationship between B-lines and the effect on oxygenation and time of extubation.	Observational - cohort	General ICU/ITU	Patients older than 18 years who were scheduled for elective cardiac surgery using CPB; Mean(range): 56 (18 - 87) yrs; Majority male; n=73	CABG, Valve repair/replacement, Excision of tumour	We found three significant correlations that support the use of LUS in cardiac surgery: 1) the more B-lines, the lower the oxygenation; 2) the more B-lines, the longer the period of ventilation; 3) the more B-lines, the more positive the fluid balance.

Fot 2019 Russia	To evaluate the effectiveness of ultrasonic monitoring of the lungs in detecting PPCs in patients after cardiosurgical interventions under cardiopulmonary bypass.	Observational - cohort	CICU/CITU	Patients who had cardiosurgical intervention under cardiopulmonary bypass with subsequent hospitalization in a cardiac ICU; Mean(range): 63 (53-69) yrs; Majority male; n=39	Valve repair/replacement, Congenital cardiac surgery, AAA	Lung ultrasonography monitoring accelerates the diagnosis of respiratory problems after cardiac surgery and allows timely identification of the patients requiring prolonged respiratory support and ICU stay.
Azeredo Terra 2020 Brazil	To analyse whether the evaluation of pulmonary aeration by LUS for the indication of NIV in patients undergoing cardiac surgery caused an impact on the length of stay in the ICU and in the hospital.	Observational - cross-sectional	CICU/CITU	Patients undergoing elective CS from January 2016 to August 2020 and who were admitted to the Cardiac ICU; Mean: 59.9 ± 11.7 yrs; Majority male; n=111	Valve repair/replacement, Myocardial revascularization	Results of this study suggest that LUS makes it possible to early identify pulmonary complications and facilitate indication of NIV to reverse dysfunctions of the respiratory system in patients undergoing cardiac surgery.
Ghotra 2021 India	To assess whether the addition of LUS to the usual practice of clinico-radiologic examination would result in earlier or better detection of PPC in paediatric patients undergoing cardiac surgery under cardiopulmonary bypass.	Observational - cohort	General ICU/ITU	Paediatric patients aged between 1 month and 14 years with left-to-right shunt and a history of congestive heart failure and/or history of respiratory tract infection in the last 4 weeks; No PPCS: 2 (1-5.75) yrs; PPCs: 1 (0.5-1) yrs; Majority male; n=100	Congenital cardiac surgery	LUS improves identification of PPC over clinico-radiologic examination in the early postoperative period. Preoperative LUS scores have better predictive ability than CXR scores for the occurrence of PPC.
Girona-Alarcon 2022 Spain	To compare the sensitivity, specificity, and positive and negative predictive values of LUS (using a quantitative score) with respect to CXR, in order to assess pulmonary oedema in	Observational - cohort	PICU	<2 months old with CHD that required CPB; Median age: 12.5 days; IQR: 9-17.5 days; Majority male; n=17	NR	LUS detected pulmonary oedema better than CXR, with greater sensitivity and negative predictive value. LUCAS score was useful to predict more inotropic support and longer mechanical ventilation.

	children prior to cardiopulmonary bypass.					
Hasan 2021 Italy	To compare the use of bedside CXR with LUS in paediatric patients undergoing cardiac surgery, identifying the presence of pneumothorax, pulmonary effusion and pulmonary congestion and to demonstrate the non-inferiority of LUS compared to CXR in the detection of lung lesions.	Observational - cohort	Paediatric cardiac ICU	Paediatric patients affected by a congenital cardiovascular disease who underwent cardiac surgery; Median(range): 11 mo. (12 d - 15 yrs); Majority male, n=52	Congenital cardiac surgery	LUS showed a good agreement for pneumothorax and a moderate agreement for both pleural effusion and pulmonary congestion. LUS also showed a significantly superior relative sensitivity than CXR for pulmonary congestion and pleural effusion and a significantly inferior relative sensitivity for pneumothorax.
Hayward 2019 UK	To highlight the impact of thoracic ultrasound on physiotherapy practice.	Observational - case study/report	CICU/CITU	63-year-old postoperative male patient who underwent cardiac surgery for mitral and tricuspid valve repair and three coronary bypass grafts	CABG, Valve repair/replacement	When patients are referred to physiotherapy thoracic ultrasound can highlight pathologies not amenable to physiotherapy treatment.
He 2021a China	To investigate the effectiveness of postural lung recruitment manoeuvre in improving postoperative atelectasis evaluated by LUS scans in children undergoing right lateral thoracotomy cardiac surgery with cardiopulmonary bypass.	RCT	CICU/CITU	Paediatric patients aged 3 years or younger, with American Society of Anaesthesiology physical status 2 or 3, scheduled for right lateral thoracotomy cardiac surgery (ventricular septal defect or atrial septal defect closure) with CPB were included in; Group C: 1.6 years; Group P: 1.7 years; Majority female; n=84	Congenital cardiac surgery	More significant reduction of the left LUS scores and sizes of atelectatic areas were found in the postural lung recruitment group than those in the control group.

He 2021b China	To study the effect of positive-end expiratory pressure (PEEP) on perioperative atelectasis in these children evaluated by lung ultrasonography, and the rationality and effectiveness of PEEP in lateral thoracotomy with small incision surgery	RCT	OR	Children who underwent thoracotomy in lateral decubitus by the same group of surgeons under cardiopulmonary bypass (CPB); Group C: 1.8±0.5 yrs Group P: 1.7±0.6 yrs; Majority female, n=57	Congenital cardiac surgery	LUS was used to assess for atelectasis
Hui 2019 China	To investigate the correlation between lung ultrasound images and postoperative pulmonary complications in patients after cardiac surgery.	Observational - cohort	General ICU/ITU	Cardiac and major vascular surgery patients newly admitted to the ICU; Mean: 60.50±10.43 yrs; Majority male; n=52	Valve repair/replacement, Left atrium myxoma	Bedside LUS is an effective method for clinical monitoring of pulmonary complications.
Ibrahim 2021 Egypt	To evaluate the efficacy of transalveolar pressure measurement (PTA) using oesophageal manometer as a monitoring parameter during a modified stepwise staircase lung recruitment employing adaptive ventilation mode (AVM) in postcardiac surgery hypoxic patients.	Observational - case series	General ICU/ITU	Adult patients who were undergone on-pump cardiac surgeries; 20-30 yrs (n=9), 30–40 (n=18), 40–50 (n=10), 50–60 (n=15) and 60–70 (n=10); Majority male; n=62	CABG, Valve repair/replacement, Congenital cardiac surgery	Hypoxic index and ultrasound lung aeration score could be used to detect atelectatic and the effectiveness of the lung recruitment manoeuvre.
Kaskinen 2017 Finland	To investigate whether LUS could estimate EVLW after congenital cardiac surgery.	Observational - cohort	PICU	Children scheduled for surgery for different types of CHD; Median age: 4.43 months; IQR: 0.4-21; n=61	Congenital cardiac surgery	In this observational study, we found a significant positive correlation between lung ultrasound and CXR in assessing EVLW in children undergoing surgery for congenital heart disease.
Larson 2016 South Africa	To assess the prevalence of lung interstitial syndrome (LIS) due to EVLW in	Observational - cross-sectional	CICU/CITU	Paediatric cardiac surgery patients, previously diagnosed with high	Congenital cardiac surgery	This is the first study that uses LUS to assess the prevalence of LIS due to EVLW in paediatric cardiac surgical

	paediatric patients with high pulmonary-flow congenital cardiac lesions.			pulmonary flow lesions scheduled for palliative or corrective surgery; Median(range): 17.0 (6.0-108.0) mo.; Equal split; n=20		patients undergoing cardiopulmonary bypass.
Cantinotti 2017 Italy	To describe a case of manual recruitment of atelectasis under lung ultrasound guidance in a child after surgical ligation of patent ductus arteriosus	Observational - case study/report	Paediatric cardiac ICU	An 11-month-old female baby underwent a surgical ligation of a large patent ductus arteriosus.	Congenital cardiac surgery	LUS may help to follow rapid and dynamic pulmonary changes occurring post cardiac surgery and to actively monitor invasive/non-invasive manoeuvres, such as one we have described.
Menzel 2014 Germany	To find out if the number of X-ray images and thus radiation exposure to the patients may be reduced by the use of ultrasound.	Observational - case study/report	OR	A 13-year-old girl with restrictive cardiomyopathy was admitted in OR for heart transplant	Heart transplant	In emergency, CXR is not mandatory to perform the diagnosis since pneumothorax is a thoracic pathology of surface and can be detected quickly by ultrasound.
Mohammed 2019 Egypt	To evaluate furosemide on attempting lung injury and/or oedema during coarctation repair surgery and to evaluate dynamic lung compliance	RCT	General ICU/ITU	Patients with simple coarctation of the aorta aged 1-18 mo. who required coarctation repair surgery; C Group: 4.642±2.617 mo. F Group: 3.853±3.289 mo.; Majority male; n=56	Coarctation of the aorta	LUS was used as an outcome measure for the study
Moshavegh 2019 Denmark	To propose an automatic method for accurate detection and visualization of B-lines in ultrasound lung scans, which provides a quantitative measure for the number of B-lines present.	Observational - case-control	NR	Four healthy subjects and four patients with pulmonary oedema were scanned. The patients had undergone major cardiac surgery; 32, 42, 31 and 28 yrs; Majority male	CABG, Left atrium myxoma, heart implantation	The results indicated the proposed technique was able to detect the B-lines and was able to differentiate the ultrasound scans acquired from the patients after cardiac surgery and those acquired from healthy subjects.
Myszkowski 2019 Poland	To assess the effectiveness and the possible use of diagnostic transthoracic	Observational - cohort	General ICU/ITU	Patients between 1 and 12 months after a series of congenital heart	Congenital cardiac surgery	A tailored protocol for ultrasonographic assessment of the respiratory tract is an optimal tool

	ultrasound of the respiratory tract to qualify patients for therapy and to monitor the effectiveness of physiotherapy in children after cardiac surgeries.			surgeries using cardiopulmonary bypass; Median(SD): 5.24 mo. (2.94); n=103		for determining therapeutic goals, as well as for the assessment of the efficacy of pulmonary physiotherapy in paediatric patients after cardiac corrections. The diagnostic value of ultrasonographic assessment of the respiratory tract and standard radiography in the study group depends on the location of the investigated lung segment.
Nguyen 2020 Vietnam	To report a case of severe systolic anterior movement of the anterior mitral leaflet after coronary artery bypass grafting (CABG) with low left ventricular ejection fraction (LVEF), which was promptly diagnosed and successfully treated based on echocardiography and lung ultrasound.	Observational - case study/report	CICU/CITU	A 72-year-old Vietnamese woman presented to a community hospital due to chest pain for the previous three days.	CABG	All these interventions were carried out under close hemodynamic monitoring, echocardiography, and lung ultrasound.
Niyogi 2021 India	To investigate the correlation of LUS B-line scoring with EVLW index (EVLWI), thresholds indicating elevated EVLWI, and its outcome following paediatric cardiac surgery.	Observational - cohort	CICU/CITU	Children aged younger than 12 years undergoing elective cardiac surgery for complete correction of cyanotic or acyanotic congenital heart disease; Median(IQR): 28 (13-72) mo.; Majority male; n=25	Congenital cardiac surgery	LUS B-line scoring has limited utility in semiquantitative estimation of EVLWI at lower thresholds of EVLWI in paediatric cardiac surgical patients.
Ozturk 2017 Turkey	To evaluate the efficacy of thoracic ultrasonography during echocardiography in newborns.	Observational - cohort	General ICU/ITU	Sixty newborns who had undergone paediatric cardiac surgery; Median(range): 14 days (2-30 days); Majority male, n=60	Congenital cardiac surgery	Except for one of the cases determined by both methods, five of the cases were diagnosed by ultrasonography. There was a moderate correlation when all pathologies evaluated together (k=0.51)

Paczkowski 2010 Poland	To assess usefulness of transthoracic ultrasound in monitoring paediatric patients after cardiac surgery with extracorporeal circulation.	Observational - cohort	NR	Paediatric patients who were qualified to cardiac surgery with extracorporeal circulation; Average(range): 13.7 mo. (5 days - 6 yrs); n=33	NR	Our early data suggest that transthoracic ultrasound brings extra information during intensive care for paediatric patients after cardiac surgery with extracorporeal circulation.
Paczkowski 2012 Poland	To present the possibility of using Transthoracic ultrasound of the lungs during postoperative monitoring in children with congenital heart disease after cardiac surgery under extracorporeal circulation (ECC) conditions.	Observational - cohort	NR	Children who underwent cardiac surgery; Mean(range): 15.7 mo. (5 days - 11.8 yrs); Majority male; n=126	Congenital cardiac surgery	Ultrasound images of lungs were entirely correct in all cases before surgery and no abnormalities were observed, whereas on the first or the second day after surgery several ultrasound findings were observed.
Palamattam 2022 India	To study the degree of agreement between Chest Ultrasound (CUS) studies and CXR studies in postoperative paediatric cardiac surgical patients regarding diagnosis of thoracic abnormalities & also to compare the diagnostic performance of CUS in reference to CXR for the detection of thoracic abnormalities.	Observational - cohort	General ICU/ITU	Patients who were in the age group of 2 months to 18 years and were undergoing elective cardiothoracic surgery; Mean: 6.04 ± 4.68 yrs; Majority male; n=160	Congenital cardiac surgery	The degree of agreement between CUS and CXR studies was substantial for atelectasis, interstitial oedema and diaphragmatic weakness. The degree of agreement between CUS and CXR studies was almost perfect for pneumothorax and fair for pleural effusion.
Parlevliet 2016 Netherlands	To assess whether routine LUS can detect cr-PPCs earlier than routine CXR in patients after cardiac surgery.	Observational - cohort	Tertiary ICU	Cardiac surgical patients, n=40	NR	LUS detects the more PPCs and cr-PPCs than CXR and in an earlier stage.
Phillips 2017 USA	To describe a case where handheld ultrasound was used to assess a	Observational - case study/report	NR	A woman in her 90's	Valve repair/replacement,	This case illustrates the versatility of handheld ultrasound in augmenting the physical examination to rapidly

	deteriorating woman in her 90's.				Pacemaker Implantation	assess potentially malignant causes of dyspnoea and reinforces the notion that complicated does not exclude the common.
Piccoli 2005 Italy	To assess the potential value of hand-carried ultrasound (HCU) devices in the diagnosis and follow-up of patients with pleural effusion after cardiac surgery.	Observational - cohort	NR	Patients admitted to a centre to participate in a cardiac rehabilitation program after cardiac surgery; Mean: 68 ± 9 yrs; Majority male; n=70	CABG, Valve repair/replacement, Vascular replacement	The correlation between ultrasound and radiographic scores was statistically significant.
Polito 2016 Italy	To report the case of a 12-day-old newborn affected by coarctation of the aorta and intraventricular defect who underwent coarctectomy and pulmonary artery banding.	Observational - case study/report	CICU/CITU	A 12-day-old newborn affected by coarctation of the aorta and intraventricular defect who underwent coarctectomy and pulmonary artery banding	Congenital cardiac surgery	Our case and published evidence suggest that ultrasound assists in early diagnosis and prompt treatment of reversible causes of asystole/pulseless electric activity obtaining rapid return of spontaneous circulation.
Ramelli 2016 Italy	To evaluate if physiotherapy treatment was able to induce changing in lung ultrasound pattern in the postoperative patients.	Observational - cohort	NR	Cardiac surgery patients; Majority male; n=19	NR	Physiotherapy may induce increase of reaeration when evaluated with LUS even though it is not able to reduce consolidation.
Ricci 2016 Italy	To evaluate the diagnostic performance of cardiopulmonary ultrasound (CPUS) for early rule-in and rule-out diagnosis of postoperative heart failure (PHF).	Observational - cohort	CICU/CITU	Elective cardiac surgery patients; Mean: 69.6 ± 2.7 yrs; n=81	NR	CPUS provides unique opportunity for early rule-in and rule-out of PHF in cardiac surgery ICU.
Ricci 2015 Italy	To evaluate the prognostic value of pulmonary and haemodynamic congestion, as assessed by cardiopulmonary ultrasound (CPUS), for the prediction of	Observational - cohort	CICU/CITU	Cardiac surgery patients; Mean: 69.6 ± 2.7 yrs; n=55	NR	CPUS provides unique opportunity for early detection and non-invasive bedside monitoring of pulmonary and haemodynamic congestion.

	the 1-year composite outcome of cardiac death, cardiovascular hospitalizations and worsening NYHA functional status, in a cohort of patients admitted to the cardiac surgery intensive care unit of our hospital.					
Ricci 2014 Italy	To assess the diagnostic performance of ULCs, alone or in combination with transthoracic echocardiography (TTE), compared with CXR and NT-proBNP, for the early diagnosis of acute heart failure (AHF) in a cohort of patients admitted to the cardiac surgery intensive care unit (CSICU) of our hospital.	Observational - cohort	CICU/CITU	Cardiac surgery patients; Mean: 71.1 ± 8.8 yrs; n=42	NR	In post-cardiac surgery LUS allows rapid and reliable ruling-out of AHF. LUS represents an attractive, radiation-free, bedside, non-invasive tool for early detection of extravascular lung water.
Ricci 2014 Italy	To investigate accuracy of LUS in assessing lung water in critically ill children with pulmonary overflow.	Observational - case-control	NR	Critically ill children with pulmonary overflow, n=10	NR	LUS B-lines are correlated with EVLW in neonates and children with congenital heart diseases characterized by pulmonary overflow.
Richard 2021 Canada	To assess whether increased pre-operative semi-quantitative assessment of B-lines with LUS was associated with prolonged intensive care unit (ICU) and hospital length of stays (LOS) after heart surgery	Secondary Analysis	General ICU/ITU	Adults undergoing non-emergent cardiac surgery; Mean: 63.7 ± 10.4 yrs; Majority male; n=115	CABG, Valve repair/replacement, Ascending Aorta repair	The presence of preoperative pulmonary oedema identified with semi-quantitative assessment of B-lines with LUS is associated with a longer hospital and ICU LOS.

Sausse 2021 France	To describe the incidence and severity of the alteration of the Transoesophageal Lung Ultrasound (TELUS) imaging before and after cardiopulmonary bypass (CPB) in adult cardiac surgery and the relation of these changes to the occurrence of Postoperative respiratory events (PORE).	Observational - cohort	General ICU/ITU	Patients with cardiac surgery and cardiopulmonary bypass and TEE monitoring; n=72	NR	Patients with PORE have a significantly higher TELUS post CPB suggesting that structural changes and lung de-aeration captured by TELUS occur during CPB.
Sengel 2018 Turkey	To identify pulmonary interstitial oedema with lung ultrasonography after open-heart surgery and searching the reasons of oedema.	Observational - case-control	General ICU/ITU	Patients with or without interstitial oedema after open-heart surgery	NR	Because of non-invasiveness and bedside usage, we though that the use of LUS should be generalised.
Senniappan 2019 India	To compare the diagnosis predicted from LUS to the diagnosis made from routine bedside CXR and to find the degree of agreement in diagnosis made by both modalities in different cardiopulmonary pathologies in ICUs.	Observational - cohort	CICU/CITU	Patient between 18 and 75 years of age, undergoing elective cardiothoracic and vascular surgery; Mean: 55.45 ± 13.81 yrs; Majority male; n=250	CABG, Valve repair/replacement, Congenital cardiac surgery	For specific cardiopulmonary pathologies, the degree of agreement was moderate for pleural effusion (κ = 0.561), substantial for atelectasis (κ = 0.673) and interstitial oedema (κ = 0.707) and perfect for pneumothorax (κ = 0.931).
Singh 2020 India	To observe the correlation between weaning failure, which we defined as re-intubation within 24-48 hours of extubation and ultrasonic assessment of EVLW and Diaphragm function in paediatric patients on mechanical	Observational - cohort	Cardiothoracic surgical ICU	Patients aged 1 month to 18 years undergoing cardiac surgery under CPB; Mean(range); Group 1: 1 (0.25-7) yrs; Group 2: 3 (0.25-17) yrs; Majority male; n=50	Congenital cardiac surgery	LUS cannot predict weaning failure. The diaphragmatic thickening fraction <17.15% was found to be a predictor of weaning failure in our patients.

	ventilation after cardiac surgery.					
Song 2018 South Korea	To assess the utility of perioperative lung ultrasound and effect of ultrasound guided recruitment manoeuvre in paediatric cardiac surgery.	RCT	PICU, OR	Paediatric patients aged 5 yr old or younger who were scheduled for cardiac surgery of acyanotic congenital heart disease; Control Group: 10 months ± 14; Intervention: 15 months ± 16; Majority male; n=122	Congenital cardiac surgery	Perioperative LUS examination followed by ultrasound-guided recruitment manoeuvre helped decrease postoperative desaturation events and shorten the duration of mechanical ventilation in paediatric cardiac patients.
Steenvoorden 2018 Netherlands	To present a unique case of the presence of lung point in the absence of pneumothorax in a 75-year-old man admitted after coronary artery bypass graft.	Observational - case study/report	NR	75-year-old man admitted after coronary artery bypass graft	CABG	Absent lung sliding and lung point can be observed in cases of pleural thickening and adhesion and may thus warrant revision of the perception that lung point is pathognomonic for pneumothorax.
Sun 2020 China	To explore the effect of incremental positive end-expiratory pressure recruitment manoeuvre (iPEEPRM) in children with congenital heart diseases (CHDs) using lung ultrasound.	Observational - cohort	NR	Children aged between 3 months and 5 years old with CHD who were scheduled for elective cardiac surgery under general anaesthesia; Mean (range): 12 (5.3-34.5) mo.; Majority male; n=36	Congenital cardiac surgery	LUS was used as an outcome measure for incremental PEEP recruitment manoeuvre in children undergoing cardiac surgery.
Thuraisingam 2015 Australia	To compare the accuracy of LUS to CXR when assessing postoperative cardiac surgery patients.	Observational - cohort	NR	Postoperative cardiac surgery patients; Mean: 61 ± 18.7 [range 31 – 82]; Majority male; n=28	NR	These pilot data suggest neither clinical examination nor CXR have high accuracy for three common postoperative chest complications in postoperative cardiac surgery patients when compared to lung ultrasound.

Touw 2018 Netherlands	To compare the performance of lung ultrasound with CXR in detecting PPCs and clinically-relevant PPCs, defined as PPCs that required treatment, after cardiothoracic surgery.	Observational - cohort	General ICU/ITU	Cardiothoracic surgery patients; Mean (SD): 68 (10) yrs; Majority male; n=177	CABG, Valve repair/replacement	Overall inter-observer agreement for lung ultrasound was excellent (K = 0.907, p < 0.001).
Ueda 2011 USA	To describe two cases in which intraoperative transthoracic ultrasound rapidly established a diagnosis of pneumothorax and facilitated timely utilization of resources for definitive treatment.	Observational - case study/report	OR	A 58-yr-old male with multiple psychiatric disorders, including schizophrenia, was brought to the emergency treatment centre after jumping from the second story of a building	Endovascular repair of the aorta dissection	Transthoracic ultrasound can provide critical information pertaining to diagnosis of a pneumothorax in the operation room setting.
Usta 2010 Germany	To establish a practical simplified formula to facilitate the management of a frequently occurring postoperative complication, pleural effusion.	Observational - cohort	NR	Spontaneous breathing cardiac surgery patients requiring thoracenteses performed under ultrasound guidance; Median (range): 60 (45-67) yrs; Majority male; n=150	CABG, Valve repair/replacement	With our simplified formula we could easily quantify pleural effusion and could decide cost and time effectively whether or not to perform a thoracentesis.
Vargas 1994 NR	To prospectively analyse the relationship between pericardial effusion and pleural effusion in patients undergoing CABG.	Observational - case-control	NR	Patients undergoing elective myocardial revascularization for treatment of their coronary artery disease; Mean (yrs) SVG Group: 62.10 ± 10.12; IMA Group: 59.72±7.73; Majority male; n=47	CABG	LUS was used to assess for pleural effusions after different grafts.
Vergara Sanchez 2019 Spain	To study the correlation between the number of B-lines at the time of	Observational - cohort	CCU	Patients undergoing valvular surgery, coronary revascularization surgery	CABG, Valve repair/replacement, Transcatheter	Patients who were readmitted to the CCU or hospital ward usually have more number of B lines at discharge,

	discharge from the critical care unit (CCU) and the rate of readmission and mortality in cardiac surgery patients.			with and without CPB, transcatheter aortic valve implantation and combined surgeries; Majority male; n=104	aortic valve implantation	without being this difference statistically significant.
Vezzani 2014 Italy	To evaluate whether chest ultrasound could be able to identify early abnormalities after cardiac surgery in comparison with chest auscultation and chest x-ray.	Observational - cohort	Cardiac Surgery ICU	Adult patients undergoing cardiac surgery; Mean: 70 ± 10 yrs; Majority male; n=151	CABG, Valve repair/replacement	There was a highly significant correlation between abnormalities detected by chest ultrasound and x-ray (k = 0.90), but a poor correlation between chest auscultation and x-ray abnormalities (k = 0.15).
Vitale 2014 Italy	To describe 5 paediatric cardiac patients who had postoperative lung complications.	Observational - case series	Paediatric Cardiac ICU	Paediatric cardiac patients who had postoperative lung complications; 2 yrs, 30 days, 15 days, 5 mo., 4 yrs; n=5	Congenital cardiac surgery	LUS provides a non-invasive way to diagnose perioperative lung complications (pleural effusion, pneumothorax, atelectasis, and pneumonia) of children affected by congenital heart diseases with real-time monitoring, complementing radiographic images, and potentially decreasing the total number of radiographs made in the paediatric intensive care unit.
Vitale 2017 Italy	To explore the association between lung ultrasound (LUS) and clinical variables in children undergoing cardiopulmonary bypass (CPB).	Secondary Analysis	Paediatric Cardiac ICU	Children whose body weight was <20 kg and who had an Aristotle score ≤9 who required elective cardiac surgery on CPB; Median(IQR): 3.25 (3.0–7.25) mo.; Majority male; n=20	Congenital cardiac surgery	In a small cohort of children undergoing CPB, the LUS profile on POD1 was associated with CPB time, aortic cross-clamp time and mechanical ventilation duration.
Vitomskyi 2020 Ukraine	To determine the impact of implementing an extra early mobilization protocol and other factors on effusion in	Secondary Analysis	General ICU/ITU	Adult cardiac surgery patients; Median (upper; lower quartile); EEM Group: 58(65; 71) yrs; EM	CABG, Valve repair/replacement, Ventricular Aneurysm	LUS was used as an outcome measure for the study.

	patients undergoing cardiac surgical procedures.			Group: 56(63.5; 71) yrs; Majority male; n=351		
Wang 2020 China	To investigate the value of LUS in the diagnosis and treatment of atelectasis after cardiac surgery.	Observational - cohort	NR	Patients with secondary respiratory failure within 1 week after cardiac surgery; Range: 32-67 yrs; Mean: 47±5 yrs; Majority male; n=45	CABG, Valve repair/replacement, Aortic Dissection	The accuracy of LUS in evaluating atelectasis after cardiovascular surgery is consistent with that of chest CT.
Wu 2019 China	To determine the most efficient region to assess changes in atelectasis in children with congenital heart disease under general anaesthesia.	RCT	OR	Paediatric patients scheduled for elective CHD surgery under general anaesthesia; Median (IQR) mo; PEEP Group: 9.5 (4.3–16.8); Control: 11.5 (8.3–25.8); Equal split; n=40	Congenital cardiac surgery	LUS in inferoposterior lung regions may be more likely to reflect changes in atelectasis and save examination time.
Wu 2018 China	To explore the feasibility of using lung ultrasound (LUS) to assess pulmonary overcirculation in congenital heart disease children and compare the diagnostic performance of LUS and CXR for the detection of pulmonary overcirculation.	Observational - cohort	NR	Children aged between 3 months and 7 years and scheduled for elective congenital heart surgeries under general anaesthesia; Median (IQR): 10 (5-26) mo.; Majority male; n=59	Congenital cardiac surgery	The sensitivity, specificity, and diagnostic accuracy of PO were 96%, 94%, and 95% for LUS and 74%, 50%, and 63% for CXR. The percentage of mild, moderate, and severe PO diagnosed via LUS were 31% (18/59), 19% (11/59), and 2% (1/59), respectively.
Young 2014 USA	To present a rare case of post-cardiac injury syndrome (PCIS) with atypical features following radiofrequency catheter ablation (RFCA).	Observational - case study/report	NR	A 58-year-old male with atrial fibrillation underwent RFCA	Catheter ablation	CXR revealed minimal pleural effusions. Pleural ultrasonography showed trivial effusions not amenable to thoracentesis. PCIS went unnoticed.

Narrative Reviews; Narrative, Opinion, and Text

Lead Author, Year, and Country	Aim	Type	Setting	Participant Description	Type of Surgery	Author's Description of Key Findings

Antonella 2016 Italy	To evaluate the usefulness and therapeutic efficacy of auscultation, ultrasound, and CXR for identifying clinically significant findings in cardiac surgery patients.	Letter to the Editor	General ICU/ITU	Cardiac surgery ICU patients; n=151	NR	Chest ultrasound identified all abnormalities requiring interventions and showed a good agreement with CXR.
Bertolone 2022 Italy	To summarise LUS applications for the evaluation and management of patients admitted to Cardiac Rehabilitation Unit.	Narrative review	Cardiac rehab unit	Patients admitted to the cardiac rehab unit; n=NR	NR	LUS should be performed in six scan each hemithorax, covering twelve imagine regions. For each scan will be noted a specific physiologic or pathological pattern. Furthermore, we suggest for each patient, the use of the Lung Ultrasound Score (LUS score) to obtain a global view of lung aeration and to monitor any changes during the hospitalization.
Cantinotti 2018 Italy	To review the different ways of exploring the entire chest before and after cardiac surgery.	Editorial Commentary	NR	NA	NR	Chest radiography is a fundamental tool in cardiac surgery, but it may be replaced by CT preoperatively, at least in selected cases, and by LUS to monitor common postoperative pulmonary complications.
Cantinotti 2022 Italy	To provide a comprehensive overview and list of current potential applications for LUS in children with congenital heart disease (CHD), post-surgery, with the hope of encouraging its use for this important patient population.	Narrative review	General ICU/ITU, NICU, PICU	Cardiac surgery patients	NR	LUS is an easy, accurate, fast, cheap, and radiation-free tool for the diagnosis and follow-up of major pulmonary complications in paediatric cardiac surgery, and we strongly encourage its use in routine practice.
Cantinotti 2020 Italy	To discuss the use of LUS to reduce radiographic examinations in paediatric cardiac surgery patients.	Letter to the Editor	General ICU/ITU	Paediatric cardiac surgery patients; Study #1 Mean: 7.09 ± 12.34 yrs; Range: 0–17 yrs; n=1487 Study #2	NR	Judicious use of LUS in paediatric cardiac surgery (1) significantly reduced the amount of chest radiographic examinations without any adverse patient outcome, and (2)

				Median age: 9.3 mo.; n=79		was associated with substantial cost benefit.
Cantinotti 2020 Italy	Responding to a comment by Sperandeo regarding an article.	Letter to the Editor	NR	NA	NR	LUS is a valuable test in paediatric cardiac surgery that complements traditional chest radiography and could also have prognostic potential. When performing LUS, it is important to keep limitations in mind, particularly the difficulty to understand the aetiologies of B-lines.
Cantinotti 2017 Italy	To discuss research concerning the use of LUS in the paediatric cardiac surgery setting.	Editorial	General ICU/ITU, NICU	Children undergoing paediatric cardiac surgery	NR	LUS may provide not only diagnostic but also prognostic information in paediatric cardiac surgery setting. LUS should become a basic diagnostic tool for multiple professional skills involved in the care of the children undergoing cardiac surgery for CHD including cardiologist, anaesthetists, surgeons, physiotherapists, and nurses.
Cantinotti 2016 Italy	To review the existing scientific literature about applications of LUS in cardiac surgery, with special attention to the paediatric population.	Narrative review	NR	Cardiac surgery patients with a focus on paediatrics	NR	Implementation of LUS in clinical practice may help to reduce excessive and unnecessary radiology tools, thereby decreasing radiation exposure, time and costs. Up to now the use of LUS in cardiac surgery has been mainly limited to the evaluation of pleural effusion and more recently to the assessment of diaphragmatic mobility in children.
Efremov 2020 Russia	To improve the awareness of LUS among specialists involved in the treatment of cardiac patients.	Narrative review	General ICU/ITU	NA	NR	The authors believe that the following points must be addressed urgently to successfully implement LUS in routine practice: (1) standardized LUS protocols, (2) educational standards and training

						programs focused on LUS, and (3) studies regarding the effects of LUS-guided interventions on clinically relevant outcomes.
Garduno-Lopez 2019 Mexico	To lay out the need for the creation of a new ultrasonographic protocol focused on the initial assessment of cardiac surgery post-operative patients.	Narrative review	CICU/CITU	Cardiac surgery post-operative patients	NR	Ultrasound is a highly useful tool for approach and decision-making in patients in critical conditions.
Hamadah 2017 Saudi Arabia	To highlight the role of US in detecting the most common causes of respiratory weaning difficulties and extubation failure in postoperative cardiac children through proposed illustration and algorithm.	Narrative review	Paediatric Cardiac ICU	The first group consists of patients who failed an extubation trial post surgery and required reintubation; the second group is those patients who experienced respiratory weaning difficulties after paediatric cardiac surgery.	NR	Paediatric Cardiac Intensive Care Unit (PCICU) ultrasound (US) stands as a simple, basic bedside tool that can be performed by trained intensivists for the diagnosis with immediate implication on therapeutic decisions in multiple scenarios that physicians may face in PCICU.
Santos-Martinez 2020 Mexico	To discuss the use of pulmonary ultrasound to evaluate hemodynamic status of post-cardiac surgery patients.	Scientific Letter	CICU/CITU	Cardiac surgery patients	NR	LUS can be used to assess hemodynamic evaluation in the early post-operative period of cardiac surgery.
Saranteas 2011 Greece	To underline a case where the role of ultrasound examination as an important diagnostic tool in the ICU setting.	Letter to the Editor	General ICU/ITU	79-year-old man who underwent coronary artery bypass graft cardiac surgery	CABG	This case underlines the role of ultrasound examination as an important diagnostic tool in the ICU setting.
Saranteas 2011 Greece	To present an interesting case in which both transthoracic echocardiography (TTE) and lung ultrasound aided in the	Letter to the Editor	General ICU/ITU	A 52-year-old woman underwent tricuspid valve repair and was referred to the intensive care unit.	Valve repair/replacement	Our case shows that ultrasound monitoring not only aided in the diagnosis of pericardial tamponade but also contributed to the suitable therapeutic management.

	differentiation between pericardial and left pleural effusion in a cardiac surgery patient.					
Sperandeo 2020 Italy	To comment on research done by Cantinotti et al. (2020).	Letter to the Editor	NR	NA	NA	Limitations of thoracic US and complementarity to standard radiology should be kept in mind in order to avoid fatal errors.
Steppan 2020 USA	To discuss LUS use in the US PICU and discuss Cantinotti's contribution.	Editorial	PICU	Paediatric population	NR	It is on the community to participate in the design and implementation of prospective randomized controlled trials to assess its feasibility and utility.
Townsley 2021 USA	To discuss the use of LUS in paediatric cardiac surgery.	Editorial	NR	Paediatric cardiac surgery patients	NR	Both applications of LUS in the domain of paediatric cardiac surgery offer exciting potential for more widespread adoption of this modality in the immediate future.

APPENDIX 3 – Physiotherapist Recruitment Email

Email recruitment for cardiothoracic physiotherapists

To be sent by the gatekeeper and local Principal Investigator

Dear colleague,

You are being invited to take part in a research study being led by a Doctor of Physiotherapy student at Robert Gordon University called "The impact of lung ultrasound on physiotherapy practice: a mixed method study". Taking part in the study involves completing questionnaires before and after lung ultrasound for each of your patients who consent to taking part. It also involves an optional one-to-one interview with the researcher.

Please read the enclosed study information sheet and contact the research team directly if you have any questions or want to volunteer to take part.

Kind regards,

[name]

APPENDIX 4 – Physiotherapist Information Sheet

Study Title: The impact of lung ultrasound on physiotherapy practice: a mixed method study

My name is Casey Farrell, and I am a Doctor of Physiotherapy student at the School of Health Sciences, Robert Gordon University (RGU), Aberdeen. As part of my doctoral degree, I am undertaking a research study to investigate how lung ultrasound impacts physiotherapy practice in post-operative cardiac care.

You are being invited to take part in this research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part. Thank you for reading this.

What is the purpose of this study?

Lung ultrasound is a low-risk diagnostic tool that can create real-time images of the lungs with no radiation and can performed at the bedside. Lung ultrasound is used to look for lung problems that can occur after heart surgery in many medical fields. Some of the physiotherapists at this centre have become certified in lung ultrasound and often do lung ultrasound to assess patients after heart surgery. I am interested in measuring how lung ultrasound is impacting current physiotherapy practice. This study will be the first to explore lung ultrasound use in current practice by physiotherapists.

Why have I been chosen?

You have been chosen because you are a qualified physiotherapist working in cardiothoracic care.

Do I have to take part?

Your participation is voluntary. If you do decide to take part, you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?

If you agree to take part, you will assess all your consenting cardiac surgery patients during the study period as normal. You will then document your findings on a paper-based questionnaire, including patient demographics, surgery-related information, pathology identification (if any), confidence in the pathology, and management plan. A physiotherapist trained in lung ultrasound will then assess the patient and document their findings on a separate paper-based questionnaire. You will be asked to document whether their impression matches yours, whether your management plan will change based on the lung ultrasound results, and if so in what way the management plan will change.

After a four-month period, the questionnaires will stop. You may also be invited to take part in an optional semi-structured interview lasting approximately an hour. The interview will be conducted by the researcher over MS Teams and audio recorded. The interview will explore your perceptions and experiences of using lung ultrasound.

What are the possible benefits of taking part?

There are no direct benefits to you from taking part in this study. Your patients may receive a post-operative LUS where they would not routinely have done so, and it is therefore possible that post-operative complications may be detected earlier.

What are the possible disadvantages and risks of taking part?

We do not anticipate any disadvantages to taking part in this study. Up to 10-15 minutes will be required to fill in the paper questionnaires; this will be additional to completing routine patient documentation. If you take part the interview phase, this will require up to an hour of your time.

Will my taking part in this study be kept confidential?

All the data we collect from you will be anonymised i.e., your name will not be linked to the information we collect. In addition, your participation in this study will be confidential and we will not disclose the names of any participants. Your data will only be seen by the researcher and the researcher's supervisory team. Analysed data and anonymised quotes will be presented in the research report and paper, but it will not be possible to identify individuals from the data presented. All information will be collected and stored within the requirements of the Data Protection Act (2018) and RGU data storage and retention policy (2016).

What happens if there is a problem?

Please discuss any problems with the researcher or her principal supervisor. Contact details are given at the bottom of this letter. If you have a complaint, please send details to the Convenor of the School of Health Sciences Research Ethics Committee, Robert Gordon University, Garthdee Road, Aberdeen AB10 7QG SREC@rgu.ac.uk or Ms Laura Binnie, Head of School of Health Sciences, Robert Gordon University, Garthdee Road, Aberdeen AB10 7QG l.m.binnie@rgu.ac.uk

What will happen to my research data?

The data will be analysed and presented in the researcher's doctoral thesis and may be more widely disseminated as papers and presentations in academic and professional journals and at conferences. The data we collect from you will be assessed for retention at the end of the research study once all the reporting is complete. Digital voice recordings, transcriptions, and personal data will be destroyed at the end of the study. Anonymised, non-identifiable research data will be stored on the Robert Gordon University research repository "OpenAir" for 10 years to facilitate further analysis and output in accordance with the RGU data storage and retention policy (2016). If you would like to receive a summary of the study results, let the research team know and you will be emailed once it becomes available.

Who has reviewed the study?

The South East Scotland REC 1 Research Ethics Committee has approved this study [insert number], and the Research and Development Departments of the participating health board have approved it for their board area.

What happens now?

Please feel free to discuss this letter with anyone you wish. If, after consideration, you would like to take part in this study, please contact Casey Farrell at the address below.

Any questions?

If you have any questions, please contact the researcher, Casey, at the address below.

Further information and contact details:

Researcher	**Research Supervisor**
Casey Farrell Doctor of Physiotherapy Student School of Health Sciences Robert Gordon University Garthdee Road Aberdeen AB10 7QG Email: c.farrell5@rgu.ac.uk	Craig Walker Lecturer and Course Leader School of Health Sciences Robert Gordon University Garthdee Road Aberdeen AB10 7QG Email: c.a.walker3@rgu.ac.uk
Data Protection Officer Robert Gordon University Garthdee Aberdeen AB10 7QB Email: dp@rgu.ac.uk Tel. +44 (0)1224 262076	

Data Protection Statement

Robert Gordon University (RGU) is sponsoring this research. This section explains how we (RGU) will information about you for the purposes of this research.

How will we use the information we collect about you?

The information will include your age, gender, and work experience. If you decide to take part in the interview it will also include your name and contact details.

People will use this information to do the research or to check your records to make sure that the research is being done properly. People who do not need to know who you are will not be able to see your name or contact details. Your data will have a code instead.

We will keep all information about you safe and secure.

Once we have finished the study, we will keep some of the data so we can check the results. We will write our reports in a way that no-one can work out that you took part in the study.

What are your choices about how your information is used?

- You can stop being part of the study at any time, without giving a reason, but we will keep information about you that we already have
- We need to manage your records in specific ways for the research to be reliable. This means that we won't be able to let you see or change data we hold about you.
- If you agree to take part in this study, you will have the option to take part in future research using your data saved from this study stored anonymously on RGU's research repository OpenAir

Where can you find out more about how your information is used

You can find out more about how we use your information:

- At https://www.hra.nhs.uk/information-about-patients/
- By asking one of the research team (contacts above)
- Our leaflet available from http://www.hra.nhs.uk/patientdataandresearch
- By sending an email to dp@rgu.ac.uk (Data protection Officer RGU)
- By ringing us on +44 (0) 1224 262076

APPENDIX 5 – Physiotherapist Consent Form

Consent Form

IRAS ID 316369 **Physiotherapist Identification Letter**:

Study title: The impact of lung ultrasound on physiotherapy practice: a mixed method study

Name of Researcher: Casey Farrell

Please initial box

1. I confirm that I have read and understand the information sheet dated 10/11/2022 (version 3) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. Data collected up until the point of withdrawal may still be used in analysis.
3. I understand that data collected during the study will be looked at by individuals from The Robert Gordon University, the regulatory authorities if appropriate, or from the NHS Trust where it is relevant to my taking part in this research. I give permission for these individuals to have access to the data.
4. I understand that participation involves completing a paper-based questionnaire for each heart surgery patient included in the study.
5. I consent to taking part in an audio-recorded one-to-one interview of 60 minutes
6. I consent to my anonymised quotes being used in the write-up of the results
7. I give permission for my research data to be used for other similar purposes in the future (e.g. other research projects) on the understanding that it will not be possible to identify me from the data provided.
8. I agree to take part in the above study.

I would like to receive a summary of the study findings (Please circle one):

Yes No

Name of participant (printed) Date
Signature

Name of person taking consent (printed) Date
Signature

Two copies to be retained: one for researcher and one for participant.

APPENDIX 6 – Patient Recruitment Letter

Dear Sir/Madam

You are being invited to take part in a research study called *"The impact of lung ultrasound on physiotherapy practice: a mixed method study".* The aim of the study is to explore use of lung ultrasound among physiotherapists working in [place]. The research team want to find out what impact lung ultrasound is having on the way physiotherapists assess patients who have had heart surgery.

You have been chosen as you are receiving heart surgery at [place].

I would be grateful if you would read the enclosed study information sheet. After reading this, if you are interested in taking part in the study, please complete the enclosed consent form and bring it with you when you check in for your surgery.

Yours sincerely

[Insert signature of relevant gatekeeper]

APPENDIX 7 – Patient Information Sheet

Study Title: The impact of lung ultrasound on physiotherapy practice: a mixed method study

My name is Casey Farrell and I am a Doctor of Physiotherapy student at the School of Health Sciences at Robert Gordon University (RGU), Aberdeen. As part of my doctoral degree, I am undertaking a research project to investigate how a device called lung ultrasound impacts physiotherapy practice when seeing patients after heart surgery.

You are being invited to take part in this research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part. Thank you for reading this information sheet.

What is the purpose of this study?

Lung ultrasound is a low-risk diagnostic tool that can create real-time images of the lungs with no radiation and can be done at the bedside. A lung ultrasound is a painless tool used by a physiotherapist with a probe and cool gel on your chest and back. Lung ultrasound is used to look for lung problems that can occur after heart surgery.

Some of the physiotherapists at this centre have become certified in lung ultrasound and often do lung ultrasound to assess patients after heart surgery. I am interested in measuring how lung ultrasound is impacting their current practice. This study will be the first to explore lung ultrasound use in current practice by physiotherapists.

Why have I been chosen?

We are looking for adults of any gender 18 years or older. You have been chosen because you are having elective or inpatient heart surgery at [place] to receive a bypass, valve replacement, or a combination of both.

Do I have to take part?

Your participation is voluntary. If you do decide to take part, you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

What will happen to me if I take part?

If you agree to take part, you will be assessed by a physiotherapist after your surgery as normal. In addition to a physiotherapy assessment, a lung ultrasound is occasionally done in this hospital when a physiotherapist feels they require additional information to make informed decisions. In this study, you will be assessed with lung ultrasound regardless of the results of the physiotherapist's assessment. The lung ultrasound will be operated by a trained physiotherapist and takes about 10-15 minutes.

Both physiotherapists will write down what they find and they will collect anonymous demographic and surgery-related information from you (e.g., age, sex, height, weight, relevant past medical history, and type of surgery). The information collected will be used to see if lung ultrasound may be useful for specific demographics or types of surgeries.

If the lung ultrasound operator finds something that is significant, unusual, or out of the scope of physiotherapy practice, then this will be taken to either the surgeon's team, the on-call anaesthetist, or both for further discussion and treatment.

What are the possible benefits of taking part?

Lung ultrasound is currently not done for every patient. If a lung problem were to develop after your surgery, it is possible it could be missed initially by the medical team until symptoms develop. If you take part in this study you will receive a lung ultrasound after your surgery; it is therefore possible that the lung ultrasound may diagnose any problems early so you can receive appropriate treatment quickly.

What are the possible disadvantages and risks of taking part?

As lung ultrasound does not emit radiation and remains outside your body, there is minimal risk to you. There may be some slight discomfort to reposition you for the ultrasound scan. The assessment takes 10-15 minutes of your time.

Will my taking part in this study be kept confidential?

All the data we collect from you will be anonymised i.e., your name will not be linked to the demographic and surgery-related information we collect. In addition, your participation in this study will be confidential and we will not disclose the names of any patients. Your data will only be seen by the researcher and the researcher's academic supervisors. Analysed data and anonymised information will be presented in the research report and paper; but it will not be possible to identify individuals from the data presented. All information will be collected and stored within the requirements of the Data Protection Act (2018) and RGU data storage and retention policy (2016).

What happens if there is a problem?

Please discuss any problems with the researcher or her principal supervisor. Contact details are given at the bottom of this letter. If you have a complaint, please send details to the Convenor of the School of Health Sciences Research Ethics Committee, Robert Gordon University, Garthdee Road, Aberdeen AB10 7QG SREC@rgu.ac.uk or Ms Laura Binnie, Head of School of Health Sciences, Robert Gordon University, Garthdee Road, Aberdeen AB10 7QG l.m.binnie@rgu.ac.uk

What will happen to my research data?

The data will be analysed and presented in the researcher's doctoral thesis and may be more widely disseminated as papers and presentations in academic and professional journals and at conferences. The data we collect from you will be assessed for retention at the end of the research study once all the reporting is complete. Personal data and lung ultrasound scans will be destroyed at the end of the study. Anonymised, non-identifiable research data will be stored on the Robert Gordon University research repository "OpenAir" for 10 years to facilitate further analysis and output in accordance with the RGU data storage and retention policy (2016). If you would like to receive a summary of the study results, please write your email on the consent form.

Who has reviewed the study?

The South East Scotland REC 1 Research Ethics Committee has approved this study [insert number], and the Research and Development Departments of the participating health board have approved it for their board area.

What happens now?

Please feel free to discuss this letter with anyone you wish. If, after consideration, you would like to take part in this study, you will sign a consent form when you return for your surgery.

Any questions?

If you have any questions, please contact the researcher, Casey, at the address below.

Further information and contact details:

Researcher	**Research Supervisor**
Casey Farrell	Craig Walker
Doctor of Physiotherapy Student	Lecturer and Course Leader
School of Health Sciences	School of Health Sciences
Robert Gordon University	Robert Gordon University
Garthdee Road	Garthdee Road
Aberdeen AB10 7QG	Aberdeen AB10 7QG
Email: c.farrell5@rgu.ac.uk	**Email:** c.a.walker3@rgu.ac.uk
Data Protection Officer	
Robert Gordon University	
Garthdee	
Aberdeen	
AB10 7QB	
Email: dp@rgu.ac.uk	
Tel. +44 (0)1224 262076	

Data Protection Statement

Robert Gordon University (RGU) is sponsoring this research. This section explains how we (RGU) will use information about you for the purposes of this research.

How will we use the information we collect about you?

The information will include your age, sex, height, weight, relevant past medical history, and surgery details. People will use this information to do the research or to check your records to make sure that the research is being done properly. People who do not need to know who you are will not be able to see your name. Your data will have a code instead.

We will keep all information about you safe and secure.

Once we have finished the study, we will keep some of the data so we can check the results. We will write our reports in a way that no-one can work out that you took part in the study.

What are your choices about how your information is used?

- You can stop being part of the study at any time, without giving a reason, but we will keep information about you that we already have
- We need to manage your records in specific ways for the research to be reliable. This means that we won't be able to let you see or change data we hold about you.
- If you agree to take part in this study, you will have the option to take part in future research using your data saved from this study stored anonymously on RGU's research repository OpenAir

Where can you find out more about how your information is used?

You can find out more about how we use your information:

- At https://www.hra.nhs.uk/information-about-patients/
- By asking one of the research team (contacts above)
- Our leaflet available from http://www.hra.nhs.uk/patientdataandresearch
- By sending an email to dp@rgu.ac.uk (Data protection Officer RGU)
- By ringing us on +44 (0) 1224 262076

APPENDIX 8 – Patient Consent Form

Consent Form

IRAS ID: 316369 **PIN**:

Study title: The impact of lung ultrasound on physiotherapy practice: a mixed method study

Name of Researcher: Casey Farrell

Please initial box

1. I confirm that I have read and understand the information sheet dated 10/11/2022 (version 3) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. Data collected up until the point of withdrawal may still be used in analysis.
3. I understand that data collected during the study will be looked at by individuals from The Robert Gordon University, the regulatory authorities if appropriate, or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to the data.
4. I understand that participation involves receiving a lung ultrasound after my heart surgery.
5. I give permission for my research data to be used for other similar purposes in the future (e.g., other research projects) on the understanding that it will not be possible to identify me from the data provided.
6. I agree to take part in the above study.

I would like to receive a summary of the study findings (Please circle one):

Yes No

Email to receive a summary of the study findings:

Name of participant (printed) Date
Signature

Name of person taking consent (printed) Date
Signature

Two copies to be retained: one for researcher and one for participant.

APPENDIX 9 – Physiotherapist Demographic Questionnaire

Online Questionnaire – Physiotherapist Demographics & Background Information

Outline

1. Please enter your provided anonymised code:
   - ❑ Open text
2. What is your age?
   - ❑ 18-24
   - ❑ 25-34
   - ❑ 35-44
   - ❑ 45-54
   - ❑ 55-64
   - ❑ 65 or over
3. What is your gender?
   - ❑ Male
   - ❑ Female
   - ❑ Other:
   - ❑ Prefer not to say
4. Please indicate your Physiotherapy professional qualification:
   - ❑ Diploma
   - ❑ Bachelor of Science (BSc)
   - ❑ Pre-registration Master of Science (MSc)
   - ❑ MPhys
   - ❑ Doctorate or PhD
   - ❑ Prefer not to say
5. How long have you been a qualified physiotherapist? (Enter in the format X years and X months; e.g. 2 years and 5 months)
   - ❑ Open text
6. Please indicate your current post. (optional)
   - ❑ Static Band 7
   - ❑ Static Band 6
   - ❑ Respiratory Rotational 6
   - ❑ Rotational 6
   - ❑ Rotational 5
7. How long have you worked with cardiac surgery patients? (Enter in the format X years and X months; e.g. 2 years and 5 months)
   - ❑ Open text
8. What experience do you have with lung ultrasound?
   - ❑ Mentor
   - ❑ Accredited
   - ❑ I am currently in training

- ❑ None, but I am interested
- ❑ None, and I am not interested
- ❑ Don’t know

9. If accredited, how many months and years of experience do you have actively using lung ultrasound? (Enter in the format X years and X months; e.g. 2 years and 5 months)
    - ❑ Open text
10. What consists of your standard initial physiotherapy objective assessment after cardiac surgery?
    - ❑ Open text

APPENDIX 10 – Questionnaire #1

Paper Questionnaire #1 – Initial Physiotherapy Assessment

Time Stamp

1. Please enter the date of the assessment:

2. Please enter the time of the assessment:

Patient Identification Number

3. Please enter your Physiotherapist Identification Letter:
4. Please enter the Patient Identification Number (PIN):

Patient Demographics

5. Please enter the patient's age:
6. What is the patient's sex?
   - ☐ Female
   - ☐ Male
   - ☐ Non-binary

7. Please enter the patient's height (include unit of measurement):
8. Please enter the patient's weight (include unit of measurement):
9. Please identify if the patient has any of these medical conditions:
   - ☐ History of Smoking
   - ☐ Chronic obstructive pulmonary disease
   - ☐ Asthma
   - ☐ Congestive heart failure
   - ☐ Intravenous drug user
   - ☐ Functional dependence (frailty)
   - ☐ Pulmonary hypertension
   - ☐ Phrenic nerve injury

10. What type of surgery was done? Please select all that apply.
    - ☐ CABG x1
    - ☐ CABG x2
    - ☐ CABG x3
    - ☐ CABG x4
    - ☐ CABG x5
    - ☐ AVR
    - ☐ TVR
    - ☐ MVR

11. Was the surgery eventful?
    - ☐ No
    - ☐ Yes

12. If yes, how was the surgery eventful? Please select all that apply.
    - ☐ Significant blood loss
    - ☐ Prolonged time under anaesthesia
    - ☐ Deterioration during surgery
    - ☐ Return to theatre
    - ☐ Significant respiratory and/or cardiac pathology prior to operation
    - ☐ Not reported
    - ☐ Other

13. Please provide additional details relating to the question above, if applicable:

Physiotherapy Assessment

14. Please mark 3 lines for each pathology in accordance with the bisection method:

a) Based on your initial assessment, what do you believe is the probability (0 to 100%) that the patient is presenting with this pathology. Select your value such that the “correct” probability is equally likely to lie below or above your value.

b) Suppose the "correct" probability is definitely below your initial value. Please specify an updated value (0 to 100%) such that the "correct" probability is equally likely to lie below or above your updated value.

c) Suppose the "correct" probability is definitely above your initial value. Please specify an updated value (0 to 100%) such that the "correct" probability is equally likely to lie below or above your updated value.

ATELECTASIS

Not at all likely (0%) Extremely Likely (100%)

PLEURAL FLUID

Not at all likely (0%) Extremely Likely (100%)

PNEUMOTHORAX

Not at all likely (0%) Extremely Likely (100%)

15. What is your overall impression of this patient?

16. What treatment(s) will you consider for this patient?

17. How often do you plan to see this patient per day to begin with, and for how long?

18. Will you need to deliberate with medical staff regarding possible medical treatment?

- ☐ Yes. Please specify:
- ☐ No
- ☐ Unsure

19. Will an invasive procedure possibly be required?

- ☐ Yes. Please specify:
- ☐ No
- ☐ Unsure

20. Would you have ordered a lung ultrasound for this patient?

- ☐ Yes
- ☐ No

APPENDIX 11 – Questionnaire #2

Questionnaire #2 – *For the **LUS Scanner** to complete*

Time Stamp

1. Please enter the date of the assessment:

2. Please enter the length of time of the assessment:

Anonymous Identifier

3. Please enter the Patient Identification Number (PIN):

Lung Ultrasound Assessment

4. What is the overall impression from your LUS scan?

5. Please mark 3 lines on the line below by considering the following:

   a) Based on your initial assessment, what do you believe is the probability (0 to 100%) that the patient is presenting with your impression. Select your value such that the "correct" probability is equally likely to lie below or above your value.

   b) Suppose the "correct" probability is definitely below your initial value. Please specify an updated value (0 to 100%) such that the "correct" probability is equally likely to lie below or above your updated value.

   c) Suppose the "correct" probability is definitely above your initial value. Please specify an updated value (0 to 100%) such that the

   "correct" probability is equally likely to lie below or above your updated value.

Not at all likely (0%) Extremely Likely (100%)

Please verbally share the results of the LUS with the assessing physiotherapist. Do not show this part of the questionnaire to the physiotherapist.

APPENDIX 12 – Questionnaire #3

Questionnaire #3 – *For the **Physiotherapist** to complete*

Anonymous Identifier

1. Please enter the Patient Identification Number (PIN):

Physiotherapist Response

2. Do you feel the LUS findings match your own impression of the patient's presentation?

☐ Yes

☐ No

3. What is your **new** overall impression of this patient (if changed)?

4. Please repeat marking 3 lines for each pathology in accordance with the bisection method:

ATELECTASIS

Not at all likely (0%) Extremely Likely (100%)

PLEURAL FLUID

Not at all likely (0%) Extremely Likely (100%)

PNEUMOTHORAX

Not at all likely (0%) Extremely Likely (100%)

5. Will your current management/treatment plan change in **any** way (e.g., frequency, intensity, type)?

- ☐ Yes
- ☐ No

6. If your treatment plan will change, please indicate **why** (select all that apply):

- ☐ The patient's condition is **more** severe than I initially thought
- ☐ The patient's condition is **less** severe than I initially thought
- ☐ The patient would benefit from medical input prior to starting physiotherapy
- ☐ Medical input is not needed prior to starting physiotherapy
- ☐ The patient is not suitable for physiotherapy
- ☐ Other. Please specify:

7. If your treatment plan will change, please indicate **how** (select all that apply). Please specify exactly how what you have selected will change:

	Y	N	If yes, please specify:
Treatment option has been **added**			*What has been added?*
Treatment option has been **removed**			*What has been removed?*

Frequency of treatment(s) will **increase**			*How often per day? Per session?*
Frequency of treatment(s) will **decrease**			*How often per day? Per session?*
Intensity of the treatment(s) will **increase**			*How will the intensity increase?*
Intensity of the treatment(s) will **decrease**			*How will the intensity decrease?*
Other:			

8. Will you need to deliberate with medical staff regarding possible medical treatment?

- ☐ Yes. Please specify:
- ☐ No
- ☐ Unsure

9. Will an invasive procedure possibly be required?

- ☐ Yes. Please specify:
- ☐ No
- ☐ Unsure

10. Please provide any further comments or thoughts:

APPENDIX 13 – Interview Topic Guide

IRAS ID: 316369

The impact of lung ultrasound on physiotherapy management: a mixed method study

Interviews with cardiothoracic physiotherapists who use lung ultrasound in daily practice

Draft Interview Guide (These topics are likely to be covered, although the final guide will be informed by the data from the quantitative phase, developed by the team, and piloted)

I: Housekeeping

- Welcome participant – *I want to start by* ***thanking you again*** *for agreeing to participate in this study and for your contribution so far. As a* ***reminder,*** *I am Casey Farrell, and I am currently completing my Doctor of Physiotherapy degree. My thesis* ***is exploring the use of lung ultrasound within physiotherapy and its impact*** *on physiotherapy practice. So far, we have collected* ***objective data*** *to measure the impact LUS may have on physiotherapy practice, but the goal of these interviews is to gain insight into your experiences and perceptions of using LUS in your practice to get a* ***more in-depth understanding*** *of how LUS is used in this department.*
- Explain how confidentiality & anonymity will be ensured
    - *All of your information will be kept safely and securely with your* ***name and any identifiable information*** *kept separate from your responses. We will be using the* ***physiotherapist identification letter*** *you have been provided to link the data from both phases together.*
- *With your permission, interviews will be* ***recorded on a separate device.***
- *I* ***will listen back*** *to our conversation, write it up into* ***a transcript****, and it will* ***be deleted from this device****.*
- Remind that the estimated time of the interview will be likely **30 to 60** minutes.
- **Any questions?**
- Consent to start recording & for notes to be taken – ***Are you happy for me to start recording?*** *Your responses are important, so I will be taking notes throughout the interview which may result in me looking off-screen.*

Turn ON voice recorder

This is the interview for Participant ___.

II: Interview begins

1. Lung Ultrasound Concept

- In your words, what is lung ultrasound and how is it used?

2. Lung Ultrasound Use

- Are you accredited in lung ultrasound?
    - If yes:
        - What made you want to become accredited?
        - What did the process look like for you to become accredited in lung ultrasound?
        - How confident do you feel in your interpretation of lung ultrasound images?
    - If no:
        - Why not?
        - Do you have any interest in becoming accredited?
- Do you ask for/perform lung ultrasound on your patients?
    - If yes:
        - When do you decide you want to have a lung ultrasound done on a patient? Could you provide some examples?
        - What are the most common postoperative pulmonary complications you find through lung ultrasound?
    - If no:
        - Why not?
- Do you feel lung ultrasound has an impact on physiotherapy practice?
    - If yes:
        - What do you feel the impact of lung ultrasound is on your pathology identification for patients you see after cardiac surgery?
        - What do you feel the impact of lung ultrasound is on your management of postoperative pulmonary complications for patients you see after cardiac surgery?
        - What overall role do you feel lung ultrasound plays in your practice?
    - If no:
        - Why not?

3. Quantitative Phase Reflection

- How have you found the study so far?
- Is there anything you noticed or took your interest in as you progressed through the study?

I will now report to you some of the preliminary findings from the first phase of the study. This will be broken down into how your confidence shifted for each pathology, the times you would have requested LUS, the times you would not have requested LUS, and how often your management changed. After each report of the results, I will ask for your thoughts.

Report to physiotherapists their confidence levels and percentage change for pathology identification & management

- RESULTS
  - CONFIDENCE SHIFTS – What are your thoughts on these results?
  - WOULD HAVE REQUESTED LUS – What are your thoughts on these results?
  - WOULD NOT HAVE REQUESTED LUS – What are your thoughts on these results?
  - MANAGEMENT CHANGE – What are your thoughts on these results?
- Has this experience altered the way you consider the role of lung ultrasound in your practice?
  - If yes:
    - How?
  - If no:
    - Why not?

4. Future of Lung Ultrasound

- Do you think there are barriers to using lung ultrasound?
  - If yes:
    - What are some of the barriers to using lung ultrasound in physiotherapy practice?
      - ❖ Have you experienced any barriers to using lung ultrasound?
      - ❖ How might these be overcome?
  - If no:
    - Could you please explain further as to why not?
- Do you think there are facilitators to using lung ultrasound?
  - If yes:
    - What are some of the facilitators to using lung ultrasound in physiotherapy practice?
      - ❖ Have you experienced any facilitators to using lung ultrasound?
  - If no:
    - Could you please explain further as to why not?
- Do you think physiotherapy practice would benefit from implementing lung ultrasound into practice?
  - If yes:
    - How so?

  - If no:
    - Why not?
- Do you think implementing lung ultrasound into physiotherapy practice would change the field?
  - If yes:
    - How?
    - Would this change be significant?
  - If no:
    - Why not?
- Within the multidisciplinary team, whose role should it be to perform LUS in the context of physiotherapy practice for cardiac surgery patients?
  - Should it be the physiotherapists?
  - Who in the physiotherapy team?

III: Ending the interview

- Review answers – ensure these have been documented accurately.
- Is there anything else you would like to cover regarding lung ultrasound that we haven't already discussed?
- Any questions?

****Turn OFF voice recorder**

- Thank physiotherapist for taking part in interview and providing valuable information
- Reminder regarding confidentiality and anonymity
- Inform physiotherapist that a summary of results will be made available to them if they wish – note this and make sure to have preferred contact details.

APPENDIX 14 – Initial Coding Index

Uses of LUS
Definition of LUS. Multi-purpose Real-time imaging Assessment • Identifying pathologies. • Assessing respiratory status. • Changing pathology identification due to LUS. Management Planning • Indicating treatment. • Ruling out contraindications to management. • Changing management due to LUS Tracking and Monitoring • Tracking and monitoring patient status. • Tracking and monitoring the progression of pathologies. • LUS as an outcome measure. Clinical reasoning Confidence • Confidence in assessment. • Confidence in management planning. Clarity • Clarity in assessment. • Clarity in management planning. On-call
Pathology Identification
Ruling in or out pathologies with LUS. Using LUS to identify pathologies. • Using LUS to identify consolidation. • Using LUS to identify pneumothorax. • Using LUS to identify atelectasis. • Using LUS to identify pleural effusion. Comparing LUS to CXR. Using CXR to identify pathologies. • Using CXR to identify pneumothorax. • Using CXR to identify atelectasis. • Using CXR to identify pleural effusion. Using LUS to identify pleural effusion for medical staff.
LUS Indications
LUS indicated. LUS not as indicated. Patient well. Patient is unwell. Patient not improving. Patient deteriorating. Patient weaning.

Patient weaning well. Patient not weaning well. High oxygen demand. Patient ventilated. Unknown explanation for patient's status.
Interest in LUS
Interest in respiratory physiotherapy. Advanced skill in respiratory physiotherapy.
Barriers
Time • Time to do LUS. • Time to obtain LUS machine. • Time to find staff for LUS if not accredited. • Time to become accredited in LUS. Equipment • Access to equipment. • Quality of equipment. Training • Access to training. Staff • Access to staff if not accredited. • Staffing pressures.
Facilitators
Staff • Availability of accredited staff and mentors. • Respect of the physio ability and role. • Support from MDT. Exposure to LUS • Exposure to LUS through university. • Exposure to LUS through social media. • Exposure to LUS through work. Experience with LUS
Overcoming Barriers
Funding. More equipment. Including LUS in caseload planning during huddles. Producing evidence. Building a case for LUS. Increasing exposure and awareness of LUS.
LUS Population
Cardiothoracic population. Routine patients. Day One patients. ITU population. Acute population. Chronic population. Long-term population. Patients several days after surgery. Patients with a tracheostomy.

Patients with poor respiratory status.
Future of LUS
LUS impact on physio practice. LUS beneficial. LUS not beneficial. LUS changing the field. LUS not changing the field.
Changing Role/Scope of Practice
MDT/Physio interaction • Medical staff asking physio to perform out of scope. • Redefining physio role in MDT. • Change in how MDT view physios. • Assisting MDT with LUS. Physios using LUS for physio purposes. Senior physios using LUS. Junior physios using LUS. More experienced physios using LUS. Less experienced physios using LUS. Accredited physios using LUS. Non-accredited physios using LUS.
Other Labels
Positive. Neutral. Mixed. Negative. Unsure. Significant. Not significant.

APPENDIX 15 – Example of a Framework Matrix in NVivo

Implementing LUS

	A : Interest in LUS	B : Facilitators	C : Barriers
1 : PT1 Post = Respiratory Rotational Band 6 LUS X = I am accredited in lung ultrasound Age = 25-34 Sex = Male	Liked respiratory physio and found interesting from uni. Had a talk from a lecturer about [name]. Tweeted [name] to spend a day with him. Once started, it was an advanced skill in respiratory he knew people were using, so tried to train as quick as possible; another feather in my bow.	Had a talk from a lecturer who had been to some trainings and he told them about LUS. LUS can be quick If they've got questions or not sure on something, the people that have been doing it for years, those type of people to get expert opinions of, they're lucky to have there. The medical teams as well, like on ITU	He thinks part of the issue is that they don't have the scanner 24/7. They don't have someone to bring it up everyday so it's down in the dept. The time it would take to go get the scanner, do the scan, and return could take 25-30 min. You've got to be pretty sure that that assessment technique is indicated because that's a chunk of your time and day that you need or could be seeing someone else. If the resource was there 24/7 and always available, they'd probably use it a lot more.
2 : PT3 Post = Respiratory Rotational Band 6 LUS X = I am accredited in lung ultrasound Age = 25-34 Sex = Male	It's learning a new skill; it was quite a new upcoming skill in physio. Definitely a way to get a better understanding of pathology and the impact we can have on pathology; get a more accurate idea of what's going on. A higher level skill. To him, it's more of a medical skill and that's how it's seen. So it may attract more students to physio courses because it's a more advanced skill	It definitely helped having a designated scanner [during the study]. Made it a lot easier. They've got the highest density of certified physios. If they were somewhere else, he thinks his perspective would be a bit more proactive in getting LUS out there more. You can certainly see the importance of studies like this to support its use.	Accessibility of the equipment, mentors, and the actual introduction course. Not necessarily actually training on it, but knowledge fo what it does something physios can train in. He doesn't think many people would be fully aware that it's something they can do. The regional spread is not good in terms of equal opportunity. He had a friend who traveled to do the course, but went back to no mentors that were physios and the doctors didn't want to support him. Nothing ever
3 : PT5 Post = Static Band 6 LUS X = I am accredited in lung ultrasound Age = 25-34 Sex = Female	Great tool to use, espeically in the area she's working as a respiratory physio. Adds to the toolbox of assessment and skills. Comes in very useful if you're unsure of why the patient isn't progressing. Just an additional tool to help us mystery solve.	They do only have two [machines] that they can use upstairs, but she doesn't think that's a barrier because there will always be one free at some point. You've got to go through the training, so that might be a barrier to begin with, but it is available. She thinks it's quite accessible and the staff upstairs are happy for them to use it. Got quite a few mentors	You've got to go through the training first, she doesn't know how accessible that is to other trusts; It's funding and having that time. How on board the units are with physios doing LUS, they might just want consultants scanning. Doesn't feel like she had any barriers.

APPENDIX 16 – School of Health Sciences Ethics

ROBERT GORDON UNIVERSITY ABERDEEN

SCHOOL OF HEALTH SCIENCES
The Ishbel Gordon Building
Robert Gordon University
Garthdee Road
Aberdeen
AB10 7QG
United Kingdom
Tel: 01224 263250
www.rgu.ac.uk

Date: 09th August 2022

Dear Ms Casey Farrell,

Re: School of Health Sciences Research Ethics Committee Peer-review Request

Study Title: The impact of lung ultrasound on physiotherapy practice: a mixed method study

Reference N umber: IRAS Ref 316369

Thank you for submitting your study documentation for peer-review. The peer-review process has identified this as an interesting, relevant, and well-designed study. Some minor recommendations were made regarding the inclusion of a recruitment pack for the lung ultrasound-operators; providing further details to the study methods in the protocol; and reviewing aspects of the participant information sheets and interview topic guides.

Thank you for satisfactorily addressing these suggestions and amending your study documents as appropriate.

Head of School
Laura Binnie
MSc BSc FHEA

I can confirm that you have approval to proceed with the IRAS application and I wish you every success with this study.

Yours sincerely,

Dr Joanna S C Shim

APPENDIX 17 – Health Research Authority Ethics

Mr Craig Walker

School of Health Sciences

Robert Gordon University

Ishbel Gordon Building

AB10 7QE

Email:HCRW.approvals@wales.nhs.uk

25 November 2022

Dear Mr Walker

HRA and Health and Care

Study title:	**The impact of lung ultrasound on physiotherapy practice: a mixed method study**
IRAS project ID:	**316369**
Protocol number:	**316369**
REC reference:	**22/SS/0089**
Sponsor	**Robert Gordon University**

I am pleased to confirm that **HRA and Health and Care Research Wales (HCRW) Approval** has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications received. You should not expect to receive anything further relating to this application.

Please now work with participating NHS organisations to confirm capacity and capability, in line with the instructions provided in the "Information to support study set up" section towards the end of this letter.

How should I work with participating NHS/HSC organisations in Northern Ireland and Scotland?

HRA and HCRW Approval does not apply to NHS/HSC organisations within Northern Ireland and Scotland.

If you indicated in your IRAS form that you do have participating organisations in either of these devolved administrations, the final document set and the study wide governance report (including this letter) have been sent to the coordinating centre of each participating nation. The relevant national coordinating function/s will contact you as appropriate.

Please see IRAS Help for information on working with NHS/HSC organisations in Northern Ireland and Scotland.

How should I work with participating non-NHS organisations?

HRA and HCRW Approval does not apply to non-NHS organisations. You should work with your non-NHS organisations to obtain local agreement in accordance with their procedures.

What are my notification responsibilities during the study?

The standard conditions document "*After Ethical Review – guidance for sponsors and investigators*", issued with your REC favourable opinion, gives detailed guidance on reporting expectations for studies, including:

- Registration of research
- Notifying amendments
- Notifying the end of the study

The HRA website also provides guidance on these topics, and is updated in the light of changes in reporting expectations or procedures.

Who should I contact for further information?

Please do not hesitate to contact me for assistance with this application. My contact details are below.

Your IRAS project ID is **316369**. Please quote this on all correspondence.

Yours sincerely,

Sue Byng

Approvals Specialist

Email: HCRW.approvals@wales.nhs.uk

Copy to: *Ms Jill Johnston* **List of Documents**

The final document set assessed and approved by HRA and HCRW Approval is listed below.

Document	*Version*	*Date*
Evidence of Sponsor insurance or indemnity (non NHS Sponsors only) [RGU Insurance Cover]		01 August 2022
Interview schedules or topic guides for participants [Qual Interview Topic Guide]	1.0	09 August 2022
IRAS Application Form [IRAS_Form_30082022]		30 August 2022
Letter from sponsor [Internal Peer Review Letter]		09 August 2022
Letters of invitation to participant [Patient Letter]	1.0	09 August 2022
Letters of invitation to participant [Staff Email]	1.0	09 August 2022
Non-validated questionnaire [Initial Physio Assessment Questionnaire]	1.0	09 August 2022
Non-validated questionnaire [LUS Assessment Questionnaire]	1.0	09 August 2022
Non-validated questionnaire [Physio Demographics Questionnaire]	1.0	09 August 2022
Organisation Information Document [Organisation Information Document]	1	30 August 2022
Participant consent form [Physio Consent Form]	3.0	21 November 2022
Participant consent form [Patient Consent Form]	3.0	21 November 2022
Participant information sheet (PIS) [PIS Physio]	3.0	10 November 2022
Participant information sheet (PIS) [PIS Patients]	3.0	10 November 2022
Research protocol or project proposal [Protocol]	2.0	13 October 2022
Schedule of Events or SoECAT [Schedule of Events]	2	28 October 2022
Summary CV for Chief Investigator (CI) [CV - Craig Walker]	1.0	09 August 2022
Summary CV for student [CV - Casey Farrell]		09 August 2022
Summary CV for supervisor (student research) [CV - Kay Cooper]		09 August 2022
Summary CV for supervisor (student research) [CV - Simon Hayward]		09 August 2022

APPENDIX 18 – Regression Analysis

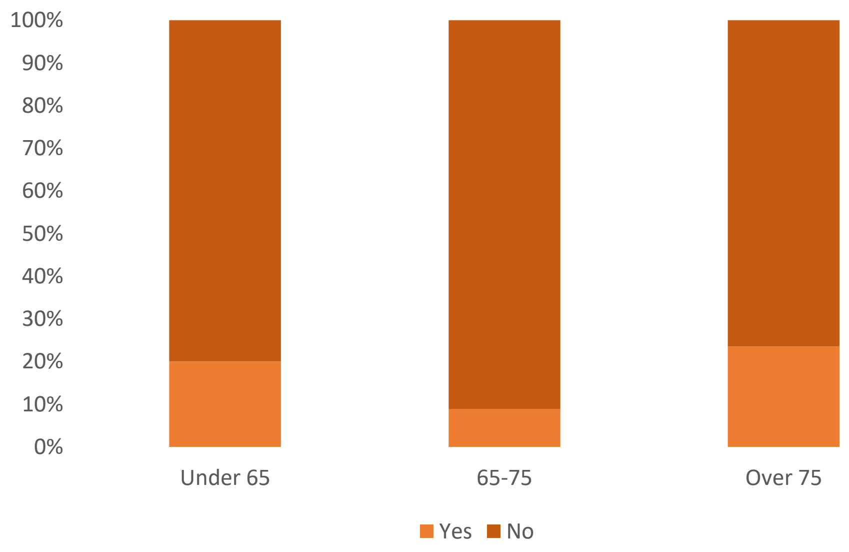
1. Patient Demographics & Surgery Details

Due to there being only one patient with an underweight BMI, this category was removed from regression analysis.

1.1 Management Change

1.1.1 Effects of Age

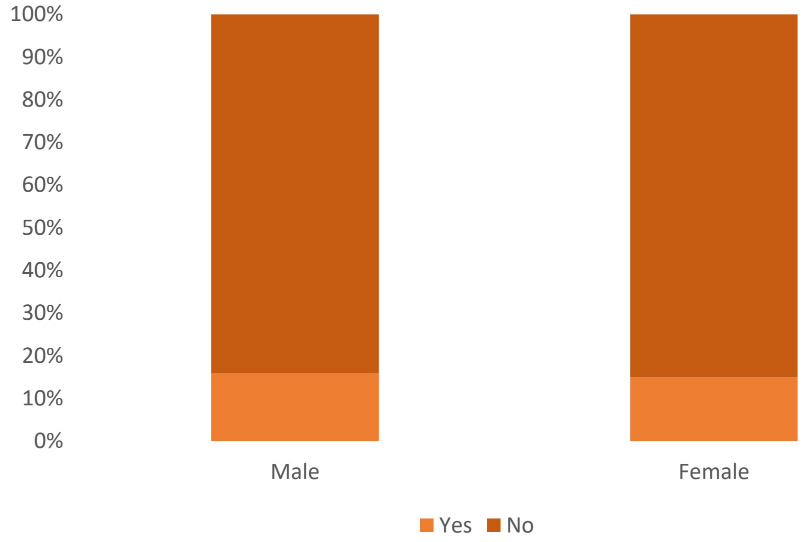
Of the 25 patients under 65 years of age, five (20%) had their management changed; Of the 34 patients between 65 and 75 years of age, three (8.8%) had their management changed; Of the 17 patients over 75 years of age, four (23.5%) had their management changed. See Appendix Figure 1. Age was found to be non-significant ($OR_{under65:65-75}$=0.39, p=0.226; $OR_{under65:over75}$=1.23, p=0.785).



Appendix Figure 1 Management Change and Patient Age.

1.1.2 Effects of Sex

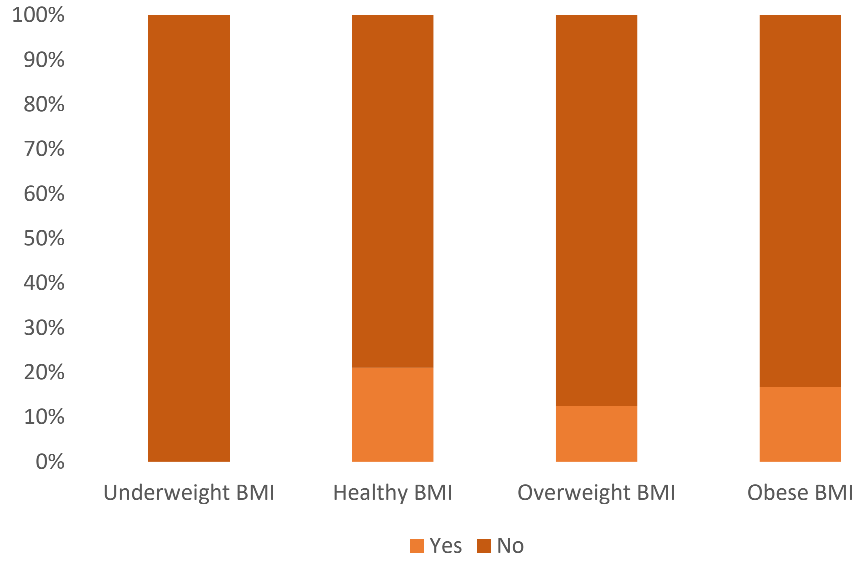
Of the 57 male patients, nine (15.8%) had their management changed; Of 20 female patients, three (15%) had their management changed. See Appendix Figure 2. Sex was found to be non-significant ($OR_{male:female}$=0.94, p=0.933).



Appendix Figure 2 Management Change and Patient Sex.

1.1.3 Effects of BMI

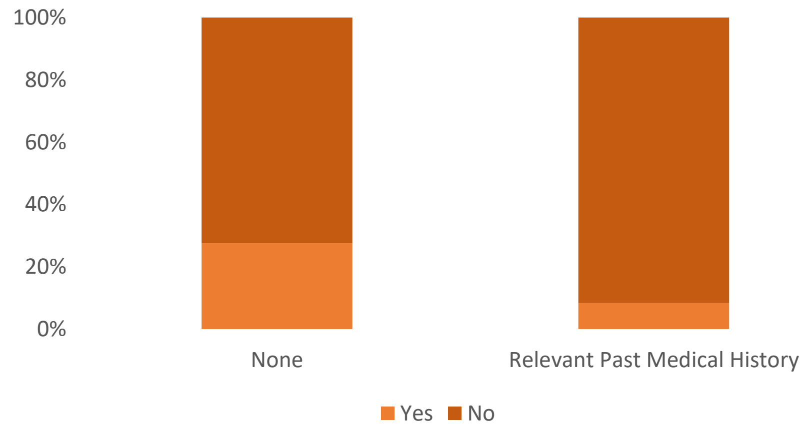
Of the 19 patients with a healthy BMI, four (21.1%) had their management changed; Of the 32 patients with an overweight BMI, four (12.5%) had their management changed; Of the 24 patients with an obese BMI, four (16.7%) had their management changed. See Appendix Figure 3. BMI was found to be non-significant ($OR_{healthy:overweight}$=0.54, p=0.0421; $OR_{healthy:obese}$=0.75, p=0.714).



Appendix Figure 3 Management Change and Body Mass Index.

1.1.4 Effects of Relevant Past Medical History

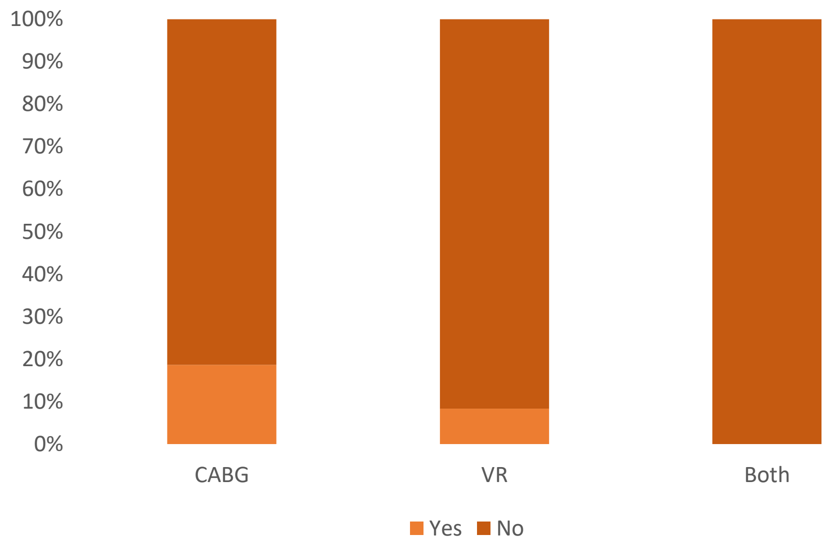
Of the 29 patients with no relevant past medical history (PMH), eight (27.6%) had their management changed; Of the 48 patients with relevant PMH, four (8.3%) had their management changed. See Appendix Figure 4. The absence of relevant PMH was found to be significant ($OR_{none:PMH}$=0.24, p=0.032).



Appendix Figure 4 Management Change and Relevant Past Medical History.

1.1.5 Effects of Surgery Type

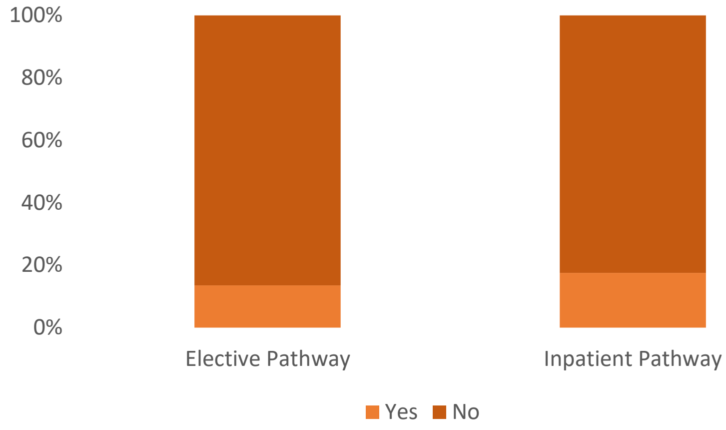
Of the 59 patients who received only a coronary artery bypass graft (CABG), 11 (18.6%) had their management changed; Of the 12 patients who received only a valve replacement/repair (VR), one (8.3%) had their management changed; Of the six patients who received both a CABG and VR, none (0%) had their management changed, therefore regression analysis was not done with this variable. See Appendix Figure 5. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=0.34, p=0.399).



Appendix Figure 5 Management Change and Type of Surgery.

1.1.6 Effects of Surgical Pathway

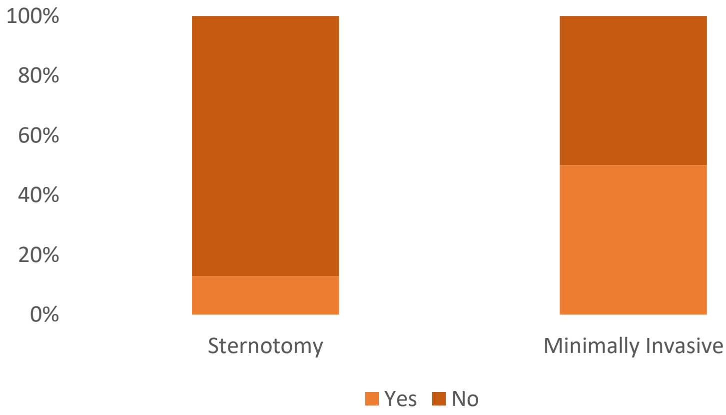
Of the 37 patients recruited from the elective surgical pathway (EP), five (13.5%) had their management changed; Of the 40 patients recruited from the inpatient surgical pathway (IP), seven (17.5%) had their management changed. See Appendix Figure 6. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=1.35, p=0.631).



Appendix Figure 6 Management Change and Surgical Pathway.

1.1.7 Effects of Surgical Incision

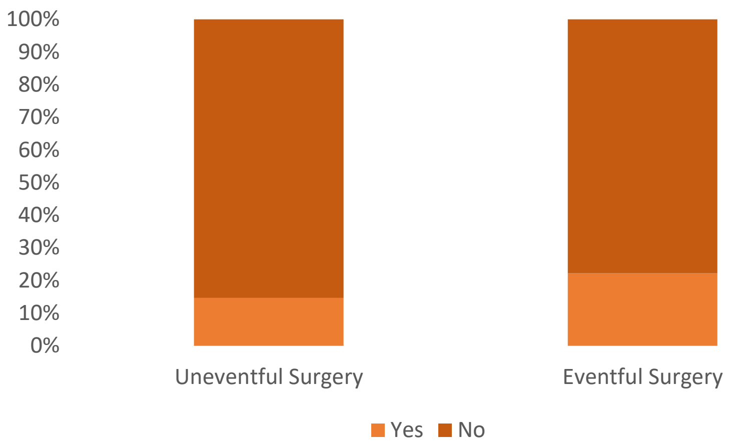
Of the 70 patients who had a sternotomy, nine (12.9%) had their management changed; Of the six patients who had a minimally invasive approach, three (50%) had their management changed. See Appendix Figure 7. A minimally invasive approach was found to be significant ($OR_{sternotomy:MIS}$=6.778, p=0.032).



Appendix Figure 7 Management Change and Surgical Incision.

1.1.8 Effects of Eventful Surgery

Of the 68 patients with an uneventful surgery, ten (14.7%) had their management changed; Of the nine patients with an eventful surgery, two (22.2%) had their management changed. See Appendix Figure 8. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=1.65, p=0.562).

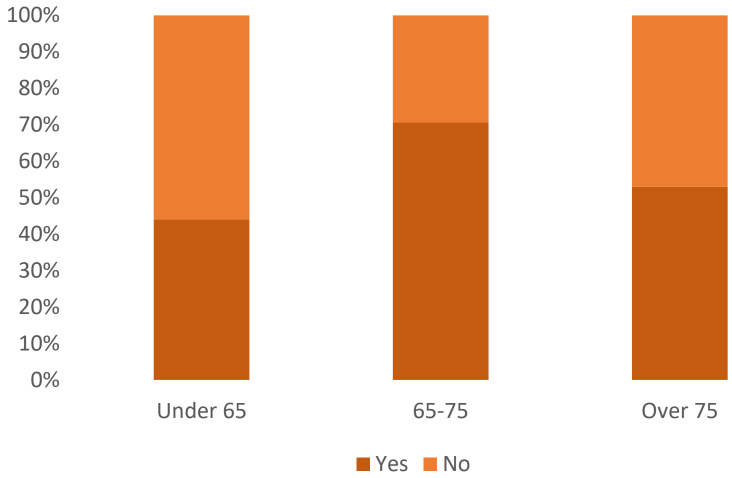


Appendix Figure 8 Management Change and Eventful Surgery.

1.2 Concordant Impressions

1.2.1 Effects of Age

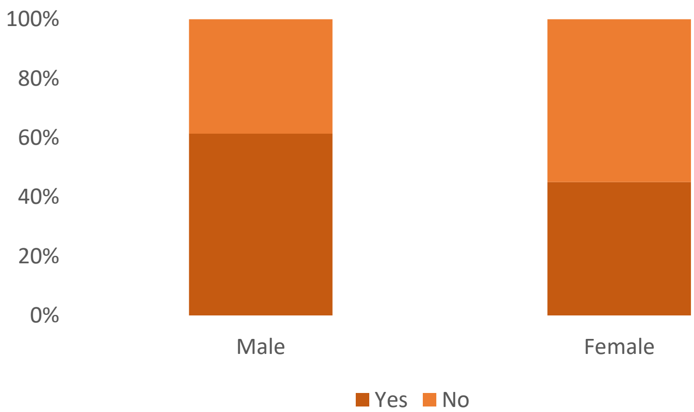
Of the 25 patients under 65 years of age, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 11 patients (44%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 24 patients (70.6%); Of the 17 patients over 75 years of age, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 9 patients (52.9%). See Appendix Figure 9. The age category between 65 and 75 years of age was found to be significant ($OR_{under65:65\text{-}75}$=0.33, p=0.043). The age category for over 75 years of age was found to be non-significant ($OR_{under65:over75}$=0.69, p=0.570).



Appendix Figure 9 Concordant Impressions and Patient Age.

1.2.2 Effects of Sex

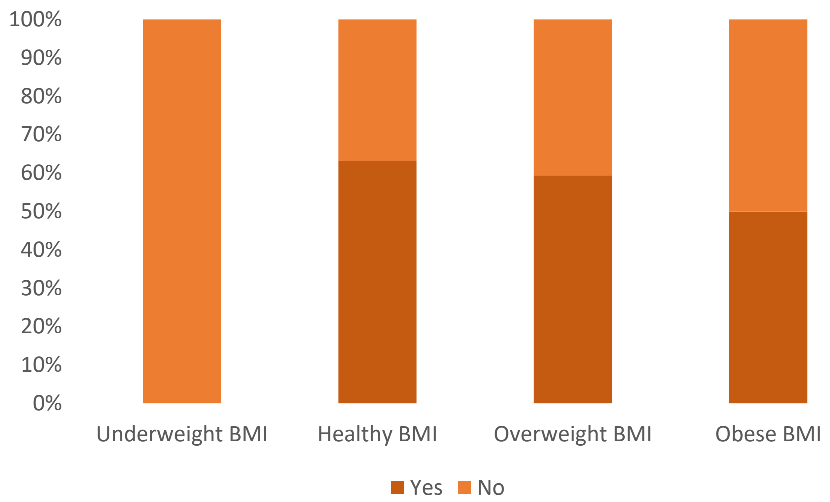
Of the 57 male patients, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 35 patients (61.5%); Of the 20 female patients, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for three patients (45%). See Appendix Figure 10. Sex was found to be non-significant ($OR_{male:female}$=1.94, p=0.206).



Appendix Figure 10 Concordant Impressions and Patient Sex.

1.2.3 Effects of BMI

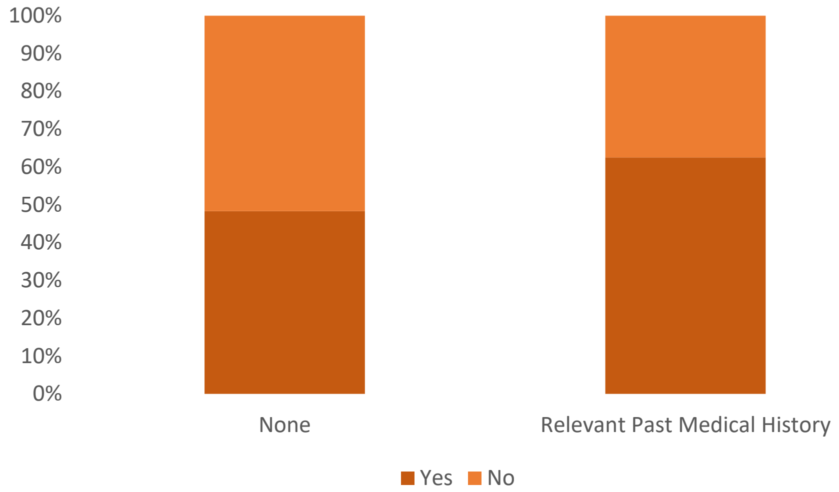
Of the 19 patients with a healthy BMI, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 12 patients (63.2%); Of the 32 patients with an overweight BMI, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 19 patients (59.4%); Of the 24 patients with an obese BMI, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 12 patients (50%). See Appendix Figure 11. BMI was found to be non-significant ($OR_{healthy:overweight}$=1.17, p=0.789; $OR_{healthy:obese}$=1.71, p=0.390).



Appendix Figure 11 Concordant Impressions and Body Mass Index.

1.2.4 Effects of Relevant Past Medical History

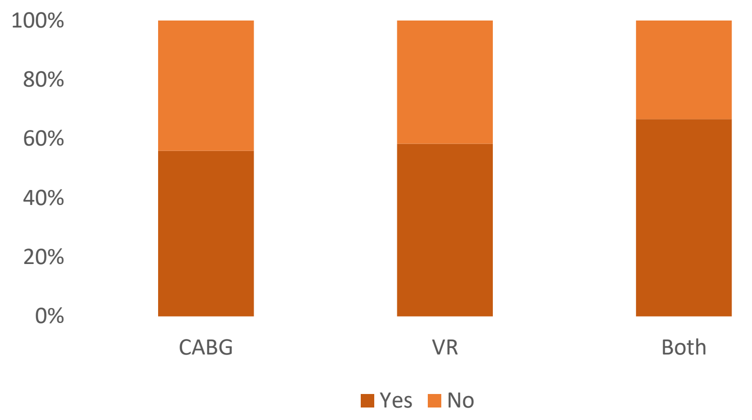
Of the 29 patients with no relevant past medical history, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 14 patients (48.3%); Of the 48 patients with relevant past medical history, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 30 patients (62.5%). See Appendix Figure 12. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=0.56, p=0.224).



Appendix Figure 12 Concordant Impressions and Relevant Past Medical History.

1.2.5 Effects of Surgery Type

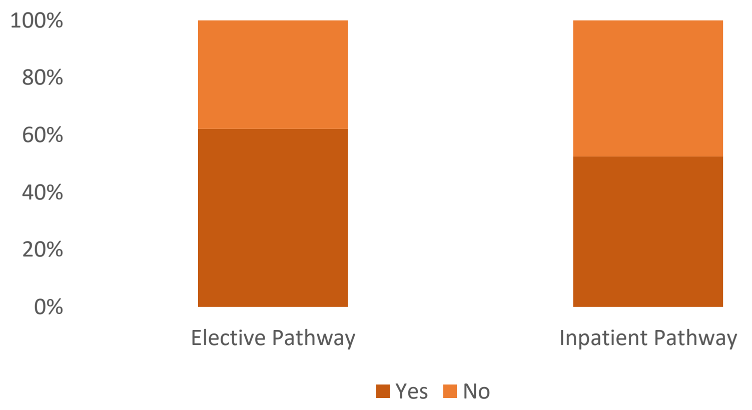
Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 33 patients (55.9%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for seven patients (58.3%); Of the six patients who received both a CABG and VR, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for four patients (66.7%). See Appendix Figure 13. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=0.91, p=0.879; $OR_{CABG:both}$=0.64, p=0.615).



Appendix Figure 13 Concordant Impressions and Type of Surgery.

1.2.6 Effects of Surgical Pathway

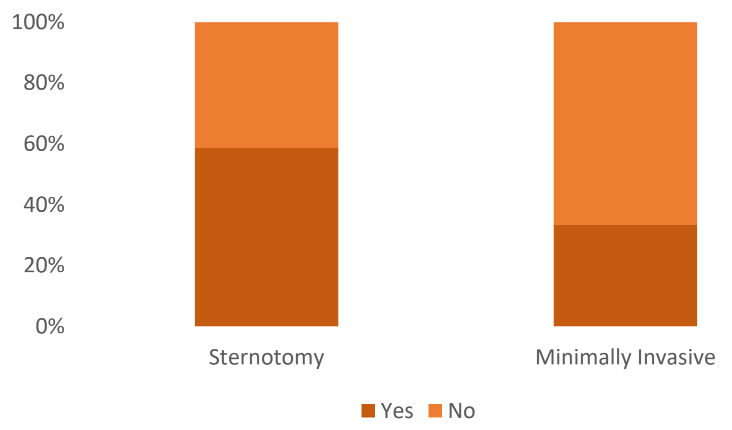
Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 23 patients (62.2%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 21 patients (52.5%). See Appendix Figure 14. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=1.49, p=0.393).



Appendix Figure 14 Concordant Impressions and Surgical Pathway.

1.2.7 Effects of Surgical Incision

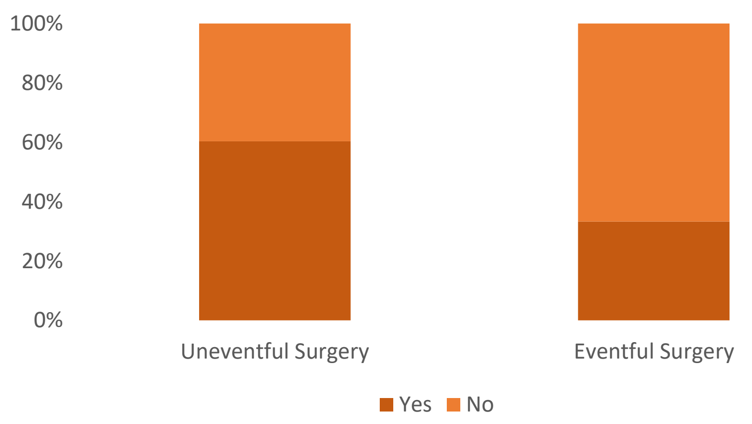
Of the 70 patients who had a sternotomy, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 41 patients (58.6%); Of the six patients who had a minimally invasive approach, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for two patients (33.3%). See Appendix Figure 15. A minimally invasive approach was found to be non-significant ($OR_{sternotomy:MIS}$=2.83, p=0.248).



Appendix Figure 15 Concordant Impressions and Surgical Incision.

1.2.8 Effects of Eventful Surgery

Of the 68 patients who had uneventful surgery, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for 41 patients (60.3%); Of the nine patients who had eventful surgery, the physiotherapist's perceived their clinical impression of the patient matched that of the LUS Scanner for three patients (33.3%). See Appendix Figure 16. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=3.04, p=0.138).

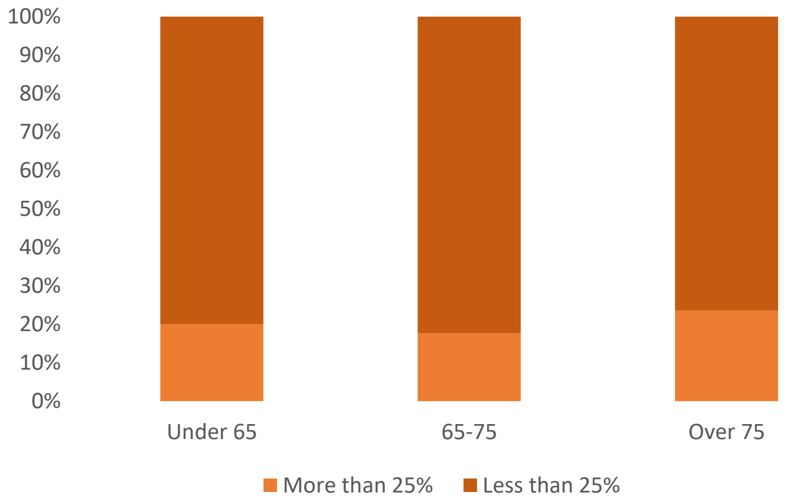


Appendix Figure 16 Concordant Impressions and Eventful Surgery.

1.3 Shift in Probability

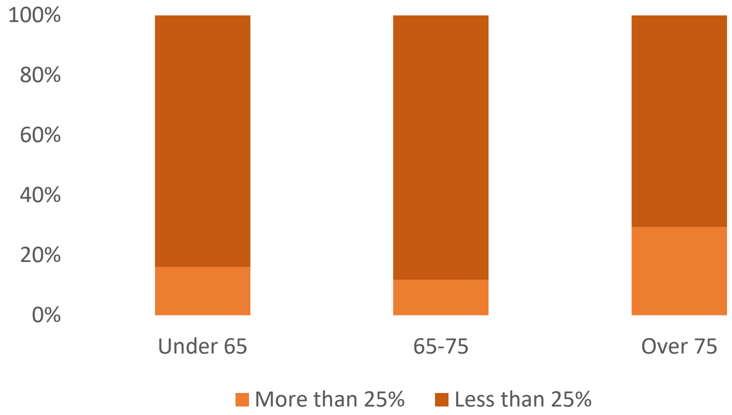
1.3.1 Effects of Age

Of the 25 patients under 65 years of age, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for five patients (20%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for six patients (17.6%); Of the 17 patients over 75 years of age, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for four patients (23.5%). See Appendix Figure 17. Age was found to be non-significant ($OR_{under65:65-75}$=0.86, p=0.819; $OR_{under65:over75}$=1.23, p=0.785).



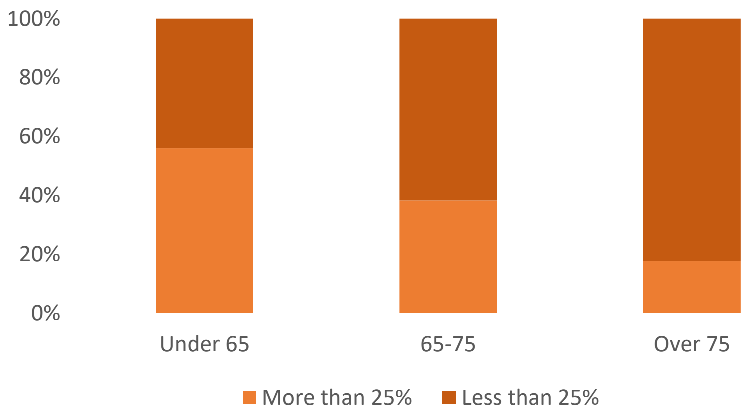
Appendix Figure 17 Shift in Probability of Atelectasis and Patient Age.

Of the 25 patients under 65 years of age, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 14 patients (56%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 13 patients (38.2%); Of the 17 patients over 75 years of age, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for three patients (17.6%). See Appendix Figure 18. An age between 65 and 75 years of age was found to be non-significant ($OR_{under65:65-75}$=0.49, p=0.178) An age above 75 years of age was found to be significant ($OR_{under65:over75}$=0.17, p=0.018).



Appendix Figure 18 Shift in Probability of Pleural Fluid and Patient Age.

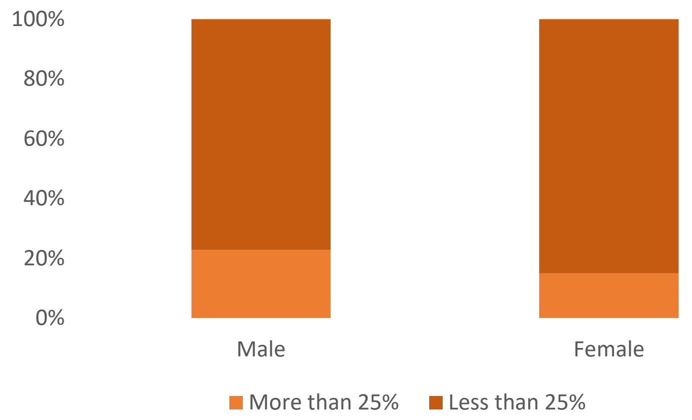
Of the 25 patients under 65 years of age, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for four patients (16%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for four patients (11.8%); Of the 17 patients over 75 years of age, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for five patients (29.4%). See Appendix Figure 19. Age was found to be non-significant ($OR_{under65:65-75}$=0.70, p=0.640; $OR_{under65:over75}$=2.19, p=0.304).



Appendix Figure 19 Shift in Probability of Pneumothorax and Patient Age.

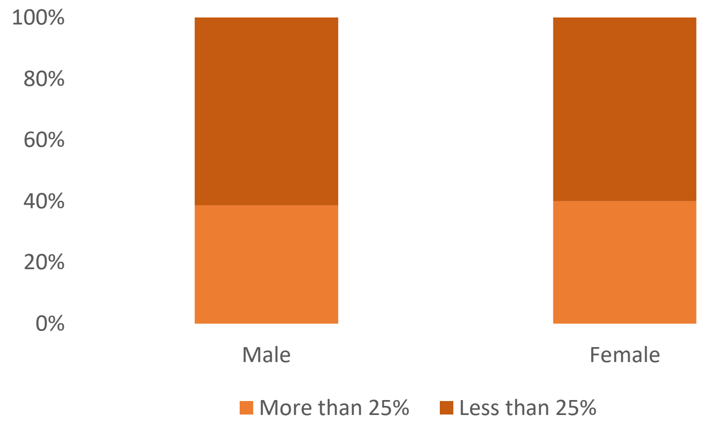
1.3.2 Effects of Sex

Of the 57 male patients, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for 13 patients (22.8%); Of the 20 female patients, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for three patients (15%). See Appendix Figure 20. Sex was found to be non-significant ($OR_{male:female}$=1.67, p=0.462).



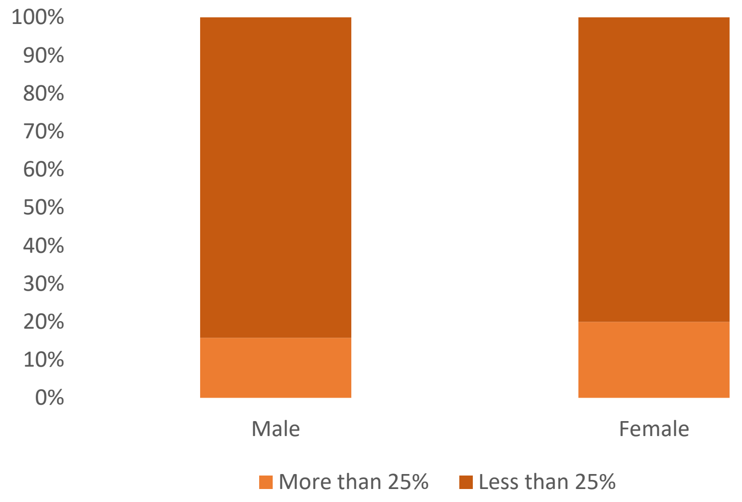
Appendix Figure 20 Shift in Probability of Atelectasis and Patient Sex.

Of the 57 male patients, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 22 patients (38.6%); Of the 20 female patients, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for eight patients (40%). See Appendix Figure 21. Sex was found to be non-significant ($OR_{male:female}$=1.06, p=0.912).



Appendix Figure 21 Shift in Probability of Pleural Fluid and Patient Sex.

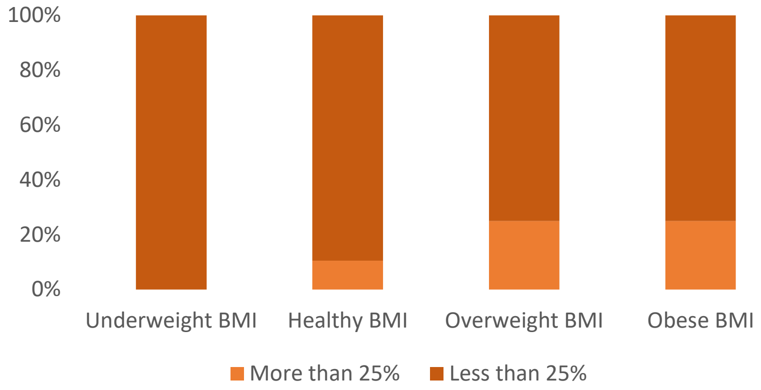
Of the 57 male patients, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for nine patients (15.8%); Of the 20 female patients, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for four patients (20%). See Appendix Figure 22. Sex was found to be non-significant ($OR_{male:female}$=1.33, p=0.666).



Appendix Figure 22 Shift in Probability of Pneumothorax and Patient Sex.

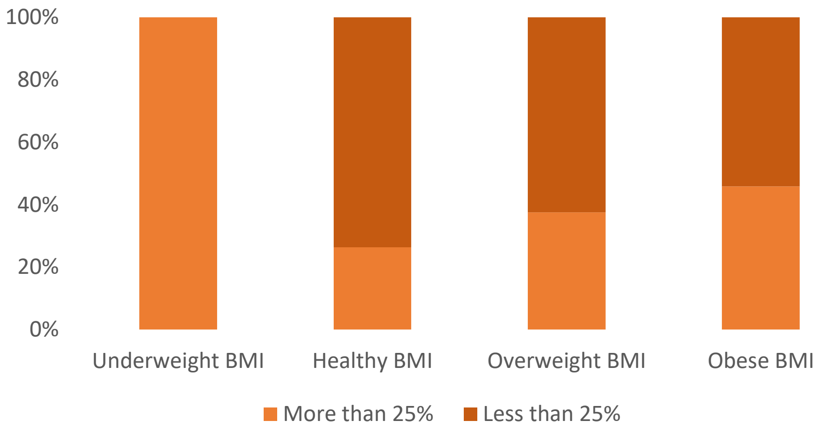
1.3.3 Effects of BMI

Of the 19 patients with a healthy BMI, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for two patients (10.5%); Of the 32 patients with an overweight BMI, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for eight patients (25%); Of the 24 patients with an obese BMI, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for six patients (25%). See Appendix Figure 23. BMI was found to be non-significant ($OR_{healthy:overweight}$=2.83, p=0.221; $OR_{healthy:obese}$=2.83, p=0.239).



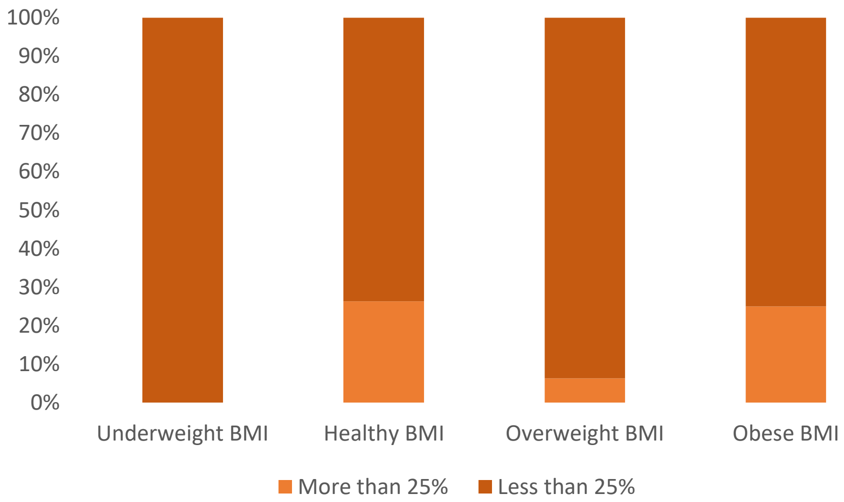
Appendix Figure 23 Shift in Probability of Atelectasis and Body Mass Index.

Of the 19 patients with a healthy BMI, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for five patients (26.3%); Of the 32 patients with an overweight BMI, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 12 patients (37.5%); Of the 24 patients with an obese BMI, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 11 patients (45.8%). See Appendix Figure 24. BMI was found to be non-significant ($OR_{healthy:overweight}$=1.68, p=0.415; $OR_{healthy:obese}$=2.37, p=0.193).



Appendix Figure 24 Shift in Probability of Pleural Fluid and Body Mass Index.

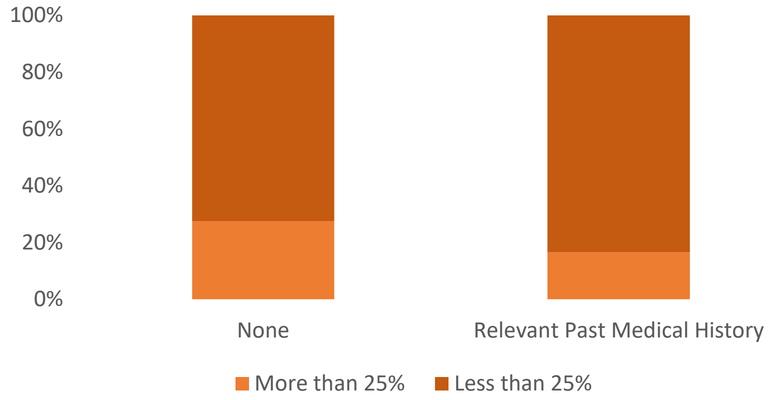
Of the 19 patients with a healthy BMI, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for five patients (26.3%); Of the 32 patients with an overweight BMI, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for two patients (6.3%); Of the 24 patients with an obese BMI, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for six patients (25%). See Appendix Figure 25. BMI was found to be non-significant ($OR_{healthy:overweight}$=0.19, p=0.061; $OR_{healthy:obese}$=0.93, p=0.922).



Appendix Figure 25 Shift in Probability of Pneumothorax and Body Mass Index.

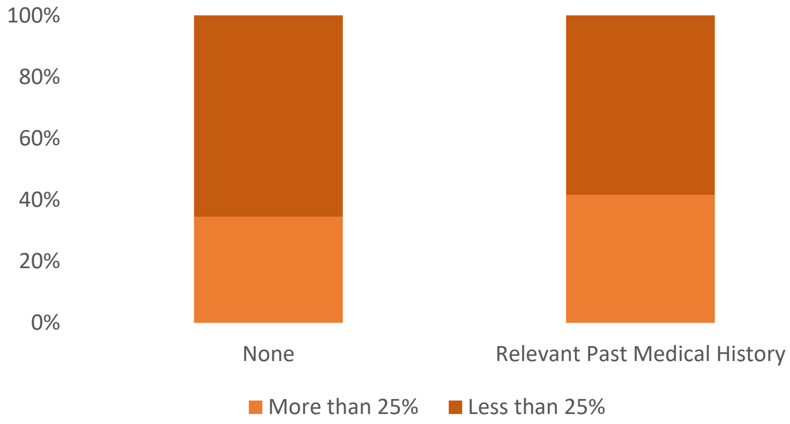
1.3.4 Effects of Relevant Past Medical History

Of the 29 patients with no relevant past medical history, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for eight patients (27.6%); Of the 48 patients with relevant past medical history, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for eight patients (16.7%). See Appendix Figure 26. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=0.53, p=0.257).



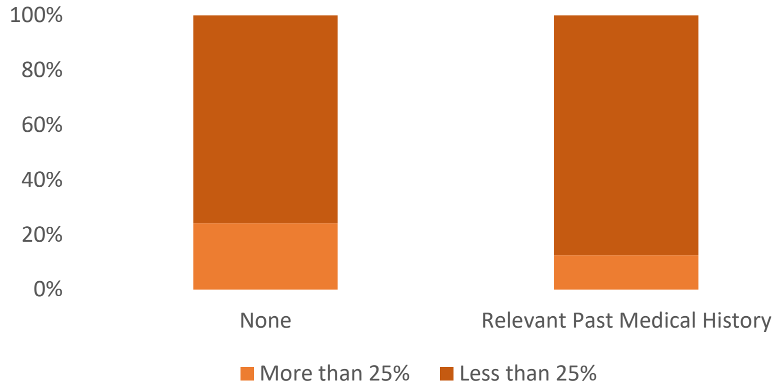
Appendix Figure 26 Shift in Probability of Atelectasis and Relevant Past Medical History.

Of the 29 patients with no relevant past medical history, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for ten patients (34.5%); Of the 48 patients with relevant past medical history, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 20 patients (41.7%). See Appendix Figure 27. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=1.36, p=0.532).



Appendix Figure 27 Shift in Probability of Pleural Fluid and Relevant Past Medical History.

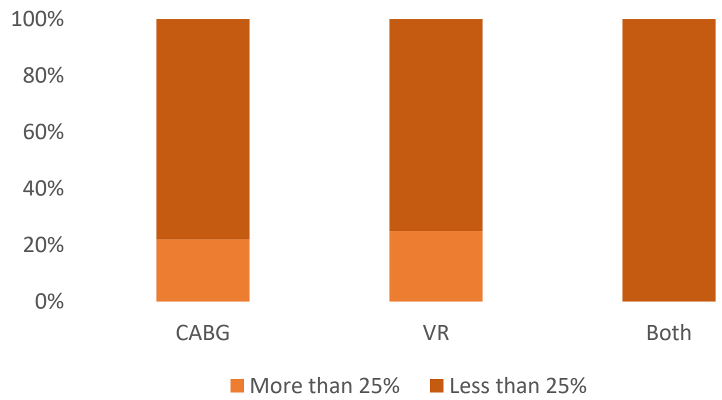
Of the 29 patients with no relevant past medical history, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for seven patients (24.1%); Of the 48 patients with relevant past medical history, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for six patients (25%). See Appendix Figure 28. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=0.45, p=0.193).



Appendix Figure 28 Shift in Probability of Pneumothorax and Relevant Past Medical History.

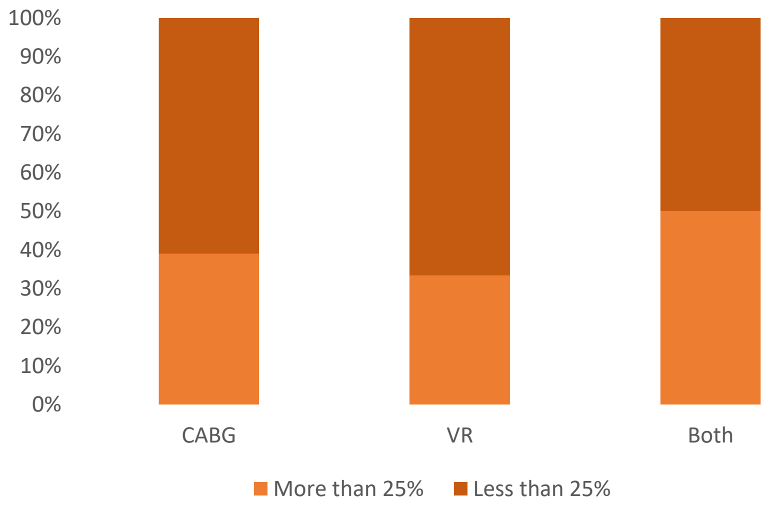
1.3.5 Effects of Surgery Type

Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for 13 patients (22%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for three patients (25%); Of the six patients who received both a CABG and VR, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for none of the patients (0%), therefore no regression analysis was done on this category. See Appendix Figure 29. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=1.18, p=0.823).



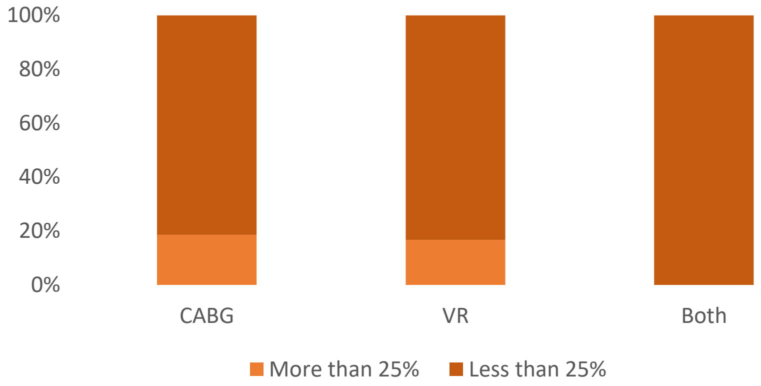
Appendix Figure 29 Shift in Probability of Atelectasis and Type of Surgery.

Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 23 patients (39%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for four patients (33.3%); Of the six patients who received both a CABG and VR, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for three patients (50%). See Appendix Figure 30. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=0.78, p=0.714; $OR_{CABG:both}$=1.57, p=0.602).



Appendix Figure 30 Shift in Probability of Pleural Fluid and Type of Surgery.

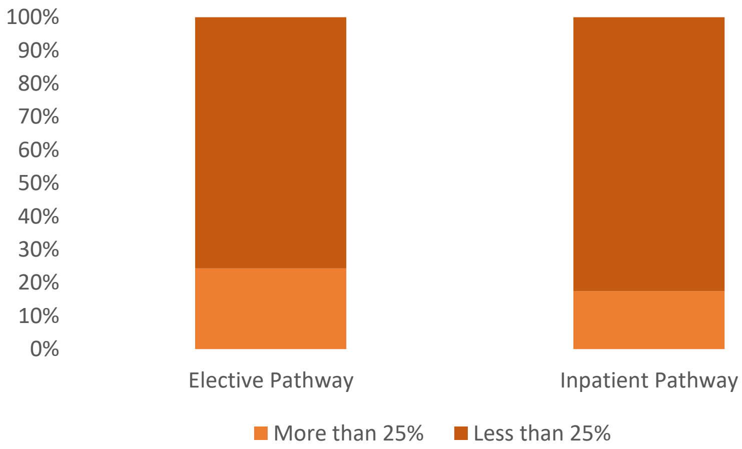
Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for 11 patients (18.6%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for two patients (16.7%); Of the six patients who received both a CABG and VR, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for none of the patients (0%), therefore regression analysis was not done on this category. See Appendix Figure 31. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=0.87, p=0.872).



Appendix Figure 31 Shift in Probability of Pneumothorax and Type of Surgery.

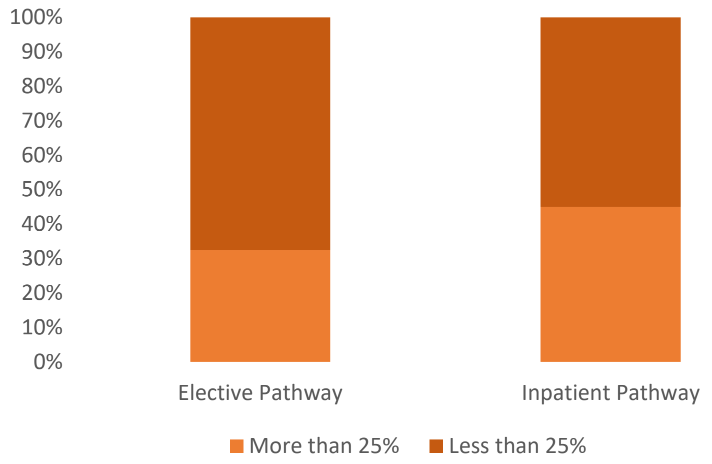
1.3.6 Effects of Surgical Pathway

Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for nine patients (24.3%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for seven patients (17.5%). See Appendix Figure 32. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=0.66, p=0.463).



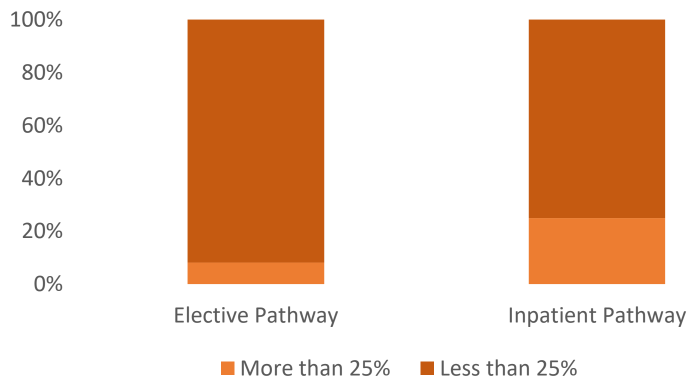
Appendix Figure 32 Shift in Probability of Atelectasis and Surgical Pathway.

Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 12 patients (32.4%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 18 patients (45%). See Appendix Figure 33. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=1.71, p=0.260).



Appendix Figure 33 Shift in Probability of Pleural Fluid and Surgical Pathway.

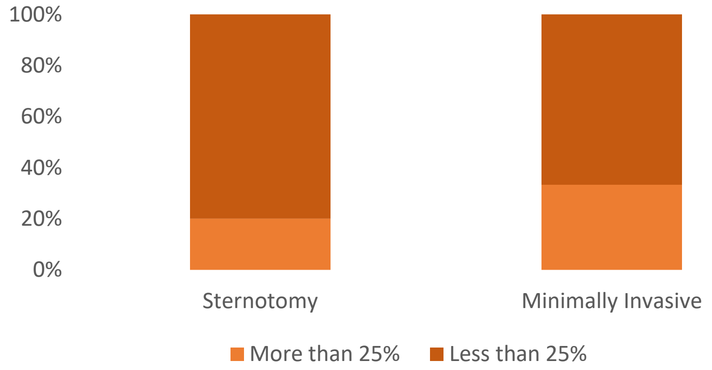
Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for three patients (8.1%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for ten patients (25%). See Appendix Figure 34. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=3.78, p=0.059).



Appendix Figure 34 Shift in Probability of Pneumothorax and Surgical Pathway.

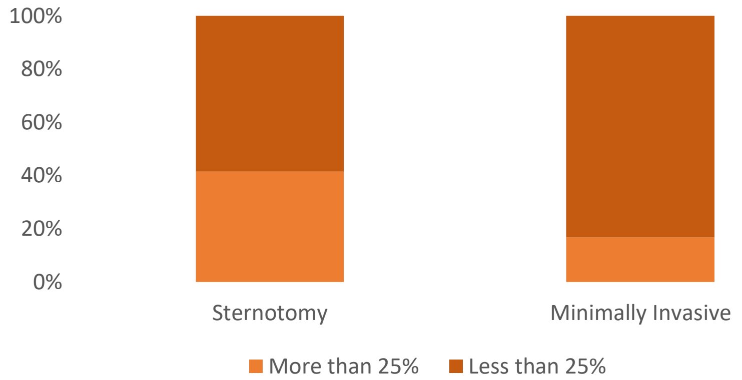
1.3.7 Effects of Surgical Incision

Of the 70 patients who had a sternotomy, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for 14 patients (20%); Of the six patients who had a minimally invasive approach, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for two patients (33.3%). See Appendix Figure 35. A minimally invasive approach was found to be non-significant ($OR_{sternotomy:MIS}$=2.00, p=0.449).



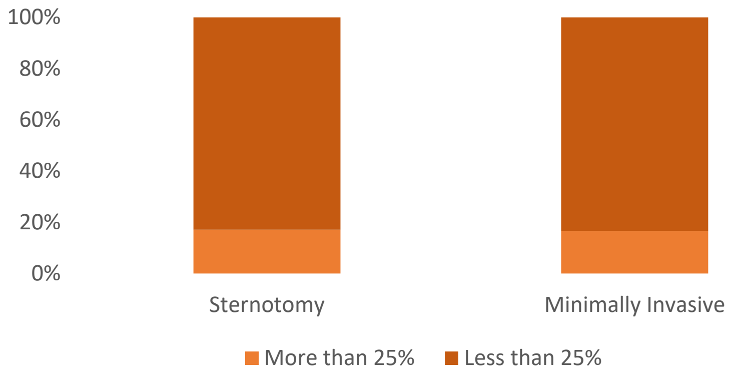
Appendix Figure 35 Shift in Probability of Atelectasis and Surgical Incision.

Of the 70 patients who had a sternotomy, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 29 (41.4%); Of the six patients who had a minimally invasive approach, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for one patient (16.7%). See Appendix Figure 36. A minimally invasive approach was found to be non-significant ($OR_{sternotomy:MIS}$=0.28, p=0.260).



Appendix Figure 36 Shift in Probability of Pleural Fluid and Surgical Incision.

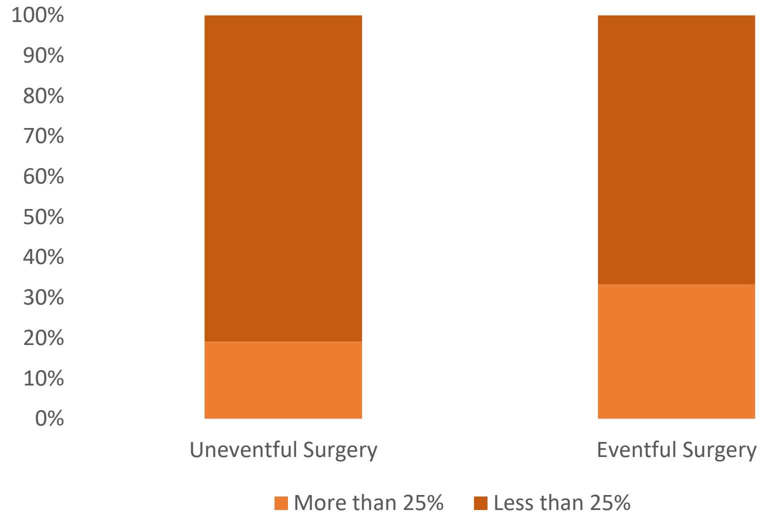
Of the 70 patients who had a sternotomy, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for 12 patients (17.1%); Of the six patients who had a minimally invasive approach, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for one patient (16.7%). See Appendix Figure 37. A minimally invasive approach was found to be non-significant ($OR_{sternotomy:MIS}$=0.97, p=0.976).



Appendix Figure 37 Shift in Probability of Pneumothorax and Surgical Incision.

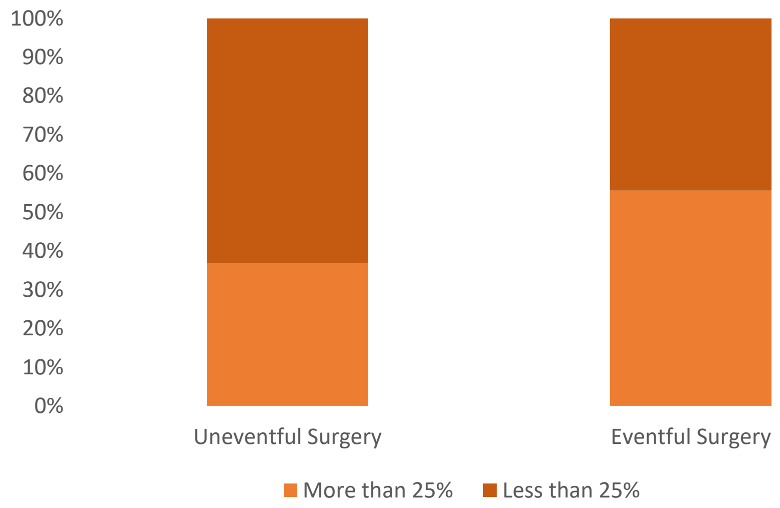
1.3.8 Effects of Eventful Surgery

Of the 68 patients who had uneventful surgery, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for 13 patients (19.1%); Of the nine patients who had eventful surgery, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS for three patients (33.3%). See Appendix Figure 38. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=2.12, p=0.331).



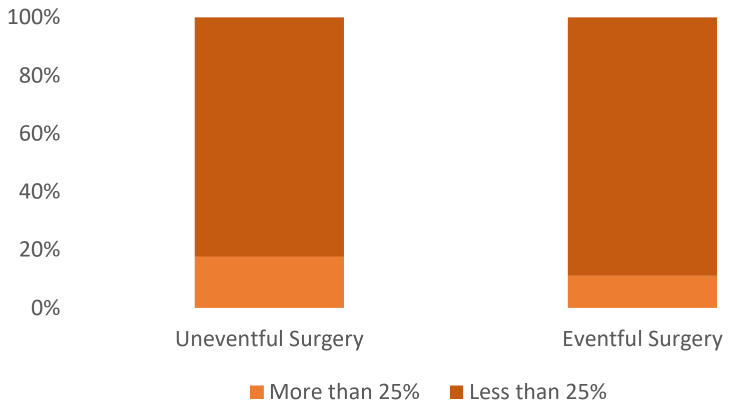
Appendix Figure 38 Shift in Probability of Atelectasis and Eventful Surgery.

Of the 68 patients who had uneventful surgery, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for 25 patients (36.8%); Of the nine patients who had eventful surgery, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS for five patients (55.6%). See Appendix Figure 39. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=2.15, p=0.285).



Appendix Figure 39 Shift in Probability of Pleural Fluid and Eventful Surgery.

Of the 68 patients who had uneventful surgery, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for 12 patients (17.6%); Of the nine patients who had eventful surgery, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS for one patient (11.1%). See Appendix Figure 40. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=0.58, p=0.626).

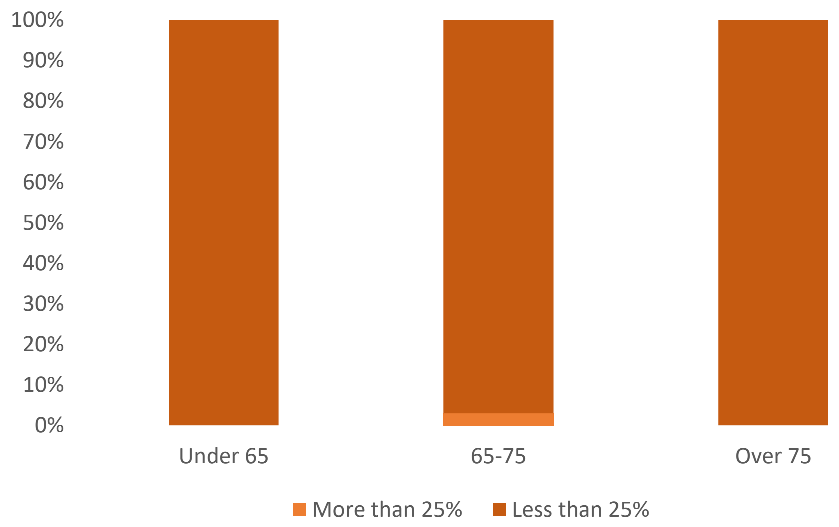


Appendix Figure 40 Shift in Probability of Pneumothorax and Eventful Surgery.

1.4 Change in Uncertainty

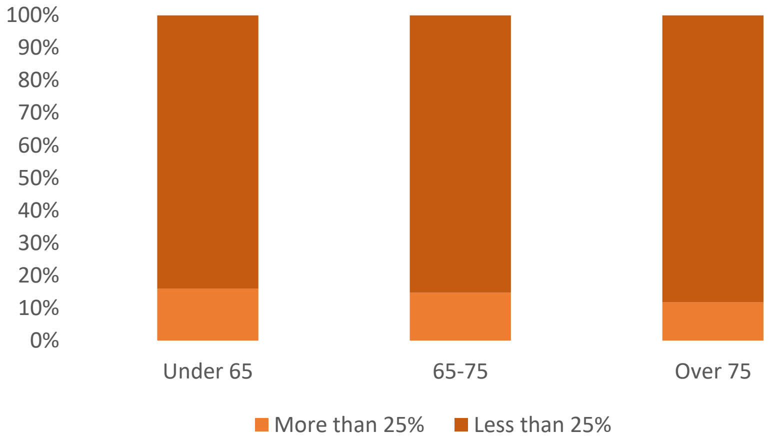
1.4.1 Effects of Age

Of the 25 patients under 65 years of age, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for one patient (2.9%); Of the 17 patients over 75 years of age, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 41.



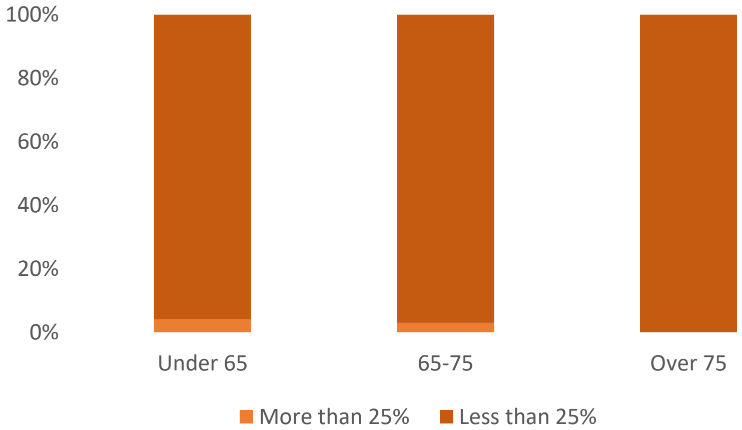
Appendix Figure 41 Change in Uncertainty of Atelectasis and Patient Age.

Of the 25 patients under 65 years of age, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for four patients (16%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for five patients (14.7%); Of the 17 patients over 75 years of age, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for two patients (11.8%). See Appendix Figure 42. Age was found to be non-significant ($OR_{under65:65-75}$=0.91, p=0.891; $OR_{under65:over75}$=0.70, p=0.701).



Appendix Figure 42 Change in Uncertainty of Pleural Fluid and Patient Age.

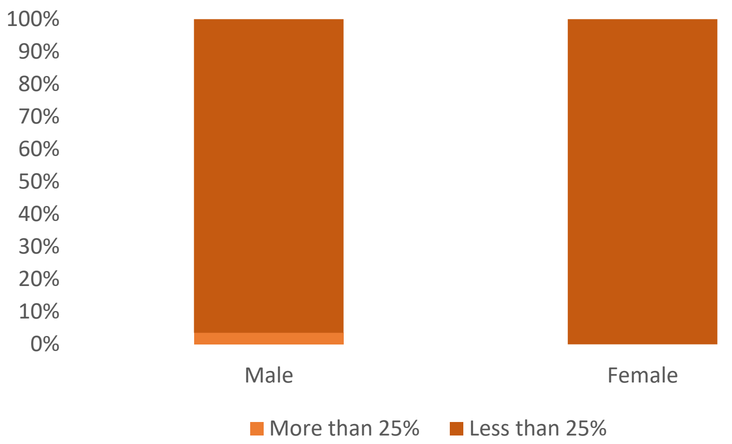
Of the 25 patients under 65 years of age, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for one patient (4%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for one patient (2.9%); Of the 17 patients over 75 years of age, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%), therefore no regression analysis was done on this category. See Appendix Figure 43. Age was found to be non-significant ($OR_{under65:65\text{-}75}$=0.73, p=0.825).



Appendix Figure 43 Change in Uncertainty of Pneumothorax and Patient Age.

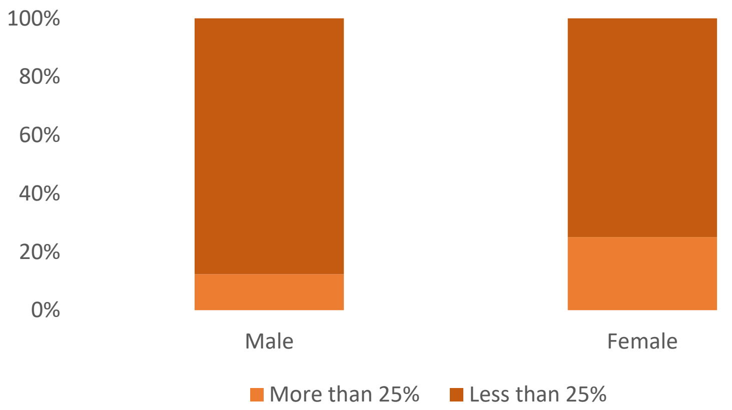
1.4.2 Effects of Sex

Of the 57 male patients, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for two patients (3.5%); Of the 20 female patients, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 44.



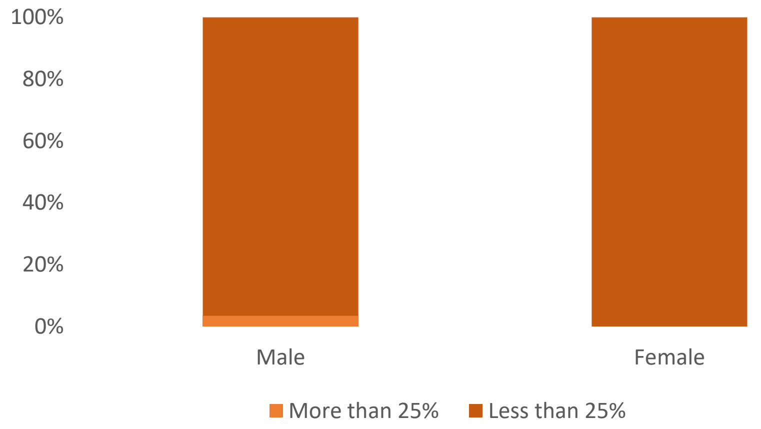
Appendix Figure 44 Change in Uncertainty of Atelectasis and Patient Sex.

Of the 57 male patients, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for seven patients (12.3%); Of the 20 female patients, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for five patients (25%). See Appendix Figure 45. Sex was found to be non-significant ($OR_{male:female}$=2.38, p=0.186).



Appendix Figure 45 Change in Uncertainty of Pleural Fluid and Patient Sex.

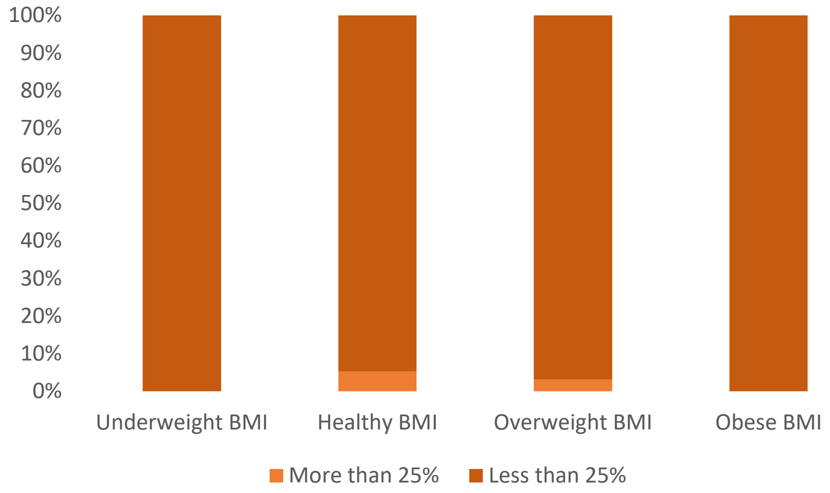
Of the 57 male patients, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for two patients (3.5%); Of the 20 female patients, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 46.



Appendix Figure 46 Change in Uncertainty of Pneumothorax and Patient Sex.

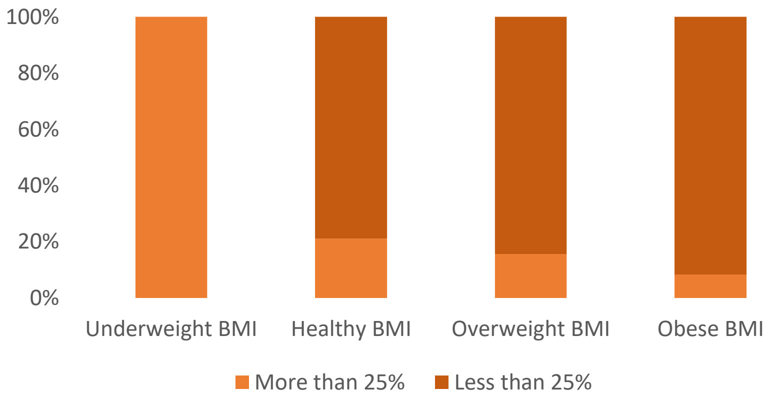
1.4.3 Effects of BMI

Of the 19 patients with a healthy BMI, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for one patient (5.3%); Of the 32 patients with an overweight BMI, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for one patient (3.1%); Of the 24 patients with an obese BMI, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%), therefore no regression analysis was done on this category. See Appendix Figure 47. BMI was found to be non-significant ($OR_{healthy:overweight}$=0.58, p=0.707).



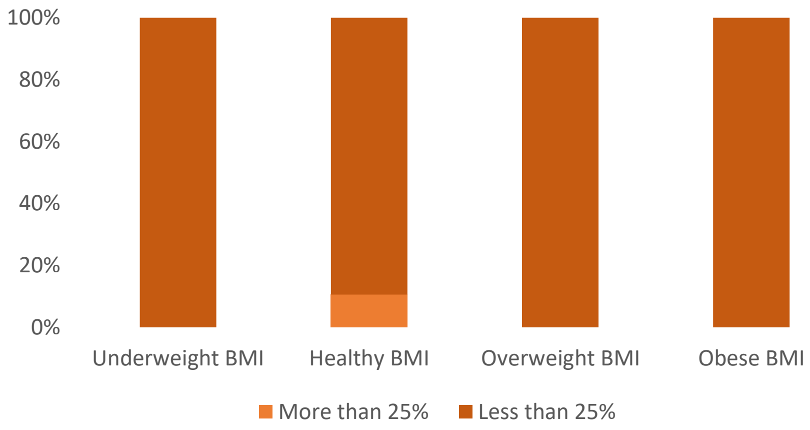
Appendix Figure 47 Change in Uncertainty of Atelectasis and Body Mass Index.

Of the 19 patients with a healthy BMI, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for four patients (21.1%); Of the 32 patients with an overweight BMI, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for five patients (15.6%); Of the 24 patients with an obese BMI, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for two patients (18.3%). See Appendix Figure 48. BMI was found to be non-significant ($OR_{healthy:overweight}$=0.69, p=0.624; $OR_{healthy:obese}$=0.34, p=0.246).



Appendix Figure 48 Change in Uncertainty of Pleural Fluid and Body Mass Index.

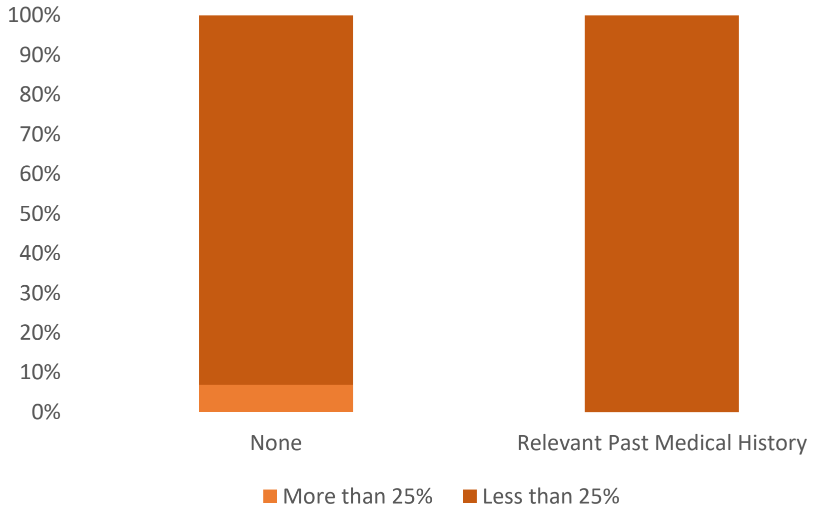
Of the 19 patients with a healthy BMI, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for two patient (10.5%); Of the 32 patients with an overweight BMI, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%); Of the 24 patients with an obese BMI, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 49.



Appendix Figure 49 Change in Uncertainty of Pneumothorax and Body Mass Index.

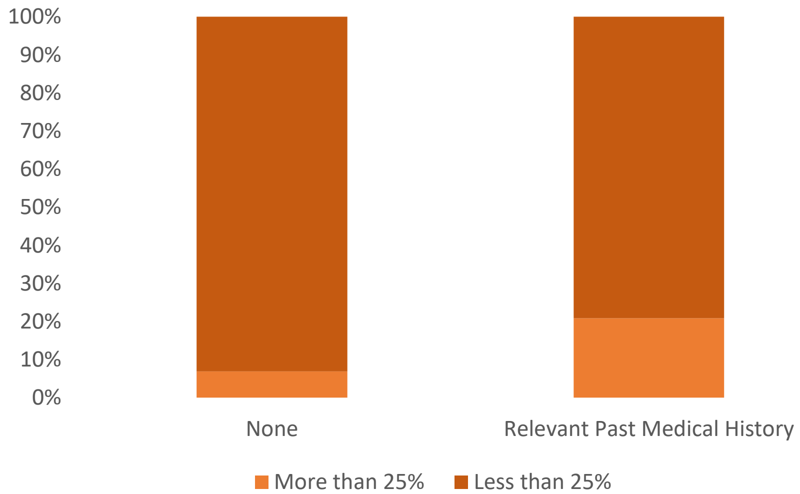
1.4.4 Effects of Relevant Past Medical History

Of the 29 patients with no relevant past medical history, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for two patients (6.9%); Of the 48 patients with relevant past medical history, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 50.



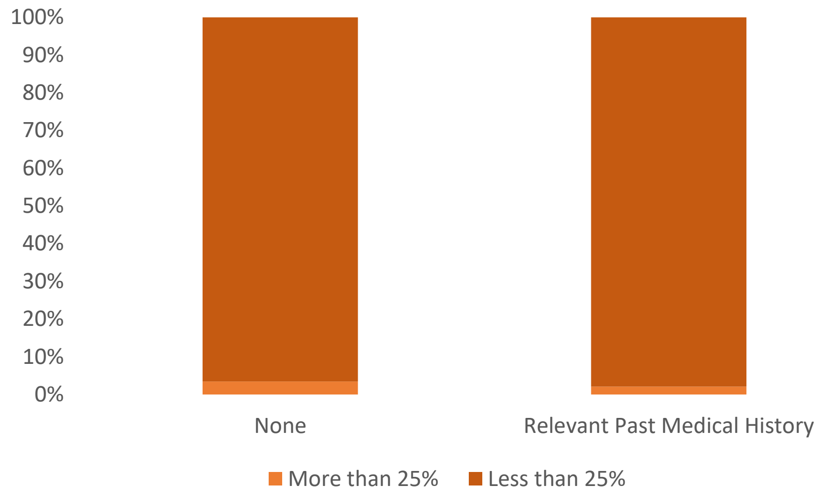
Appendix Figure 50 Change in Uncertainty of Atelectasis and Relevant Past Medical History.

Of the 29 patients with no relevant past medical history, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for two patients (6.9%); Of the 48 patients with relevant past medical history, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for ten patients (20.8%). See Appendix Figure 51. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=3.55, p=0.120).



Appendix Figure 51 Change in Uncertainty of Pleural Fluid and Relevant Past Medical History.

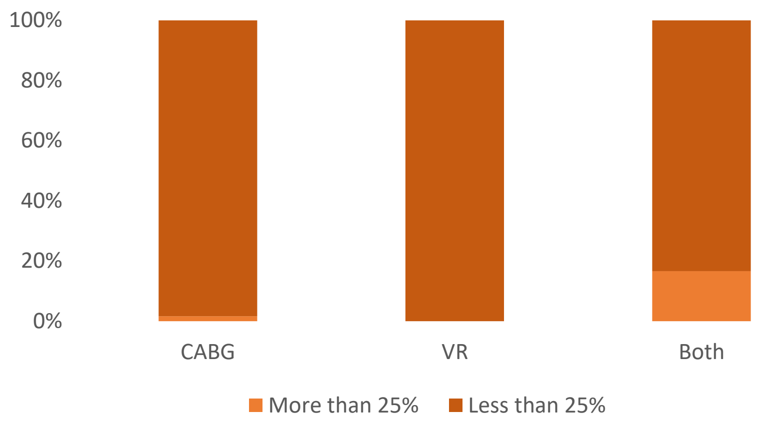
Of the 29 patients with no relevant past medical history, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for one patient (3.4%); Of the 48 patients with relevant past medical history, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for one patient (2.1%). See Appendix Figure 52. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=0.60, p=0.718).



Appendix Figure 52 Change in Uncertainty of Pneumothorax and Relevant Past Medical History.

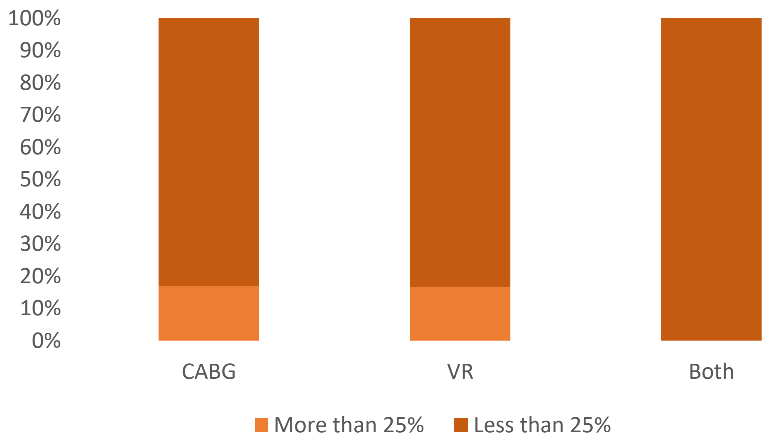
1.4.5 Effects of Surgery Type

Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for one patient (1.7%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%), therefore no regression analysis was done on this category; Of the six patients who received both a CABG and VR, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for one patient (16.7%). See Appendix Figure 53. Type of surgery was found to be non-significant ($OR_{CABG:both}$=11.60, p=0.100).



Appendix Figure 53 Change in Uncertainty of Atelectasis and Type of Surgery.

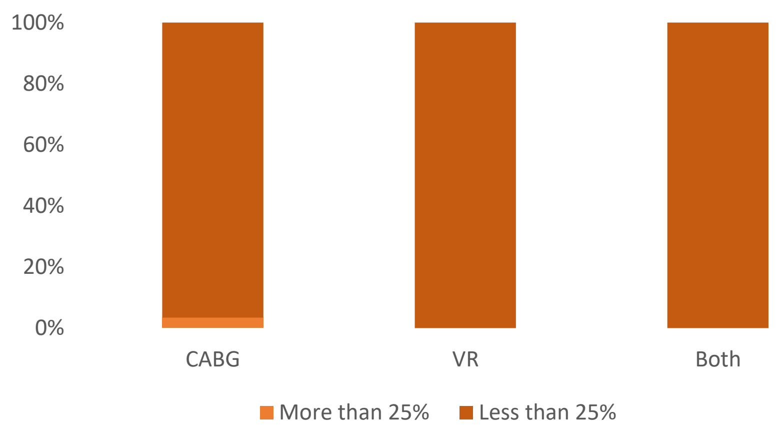
Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for ten patients (16.9%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for two patients (16.7%); Of the six patients who received both a CABG and VR, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for none of the patients (0%), therefore no regression analysis was done on this category. See Appendix Figure 54. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=0.98, p=0.981).



Appendix Figure 54 Change in Uncertainty of Pleural Fluid and Type of Surgery.

Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for two patients

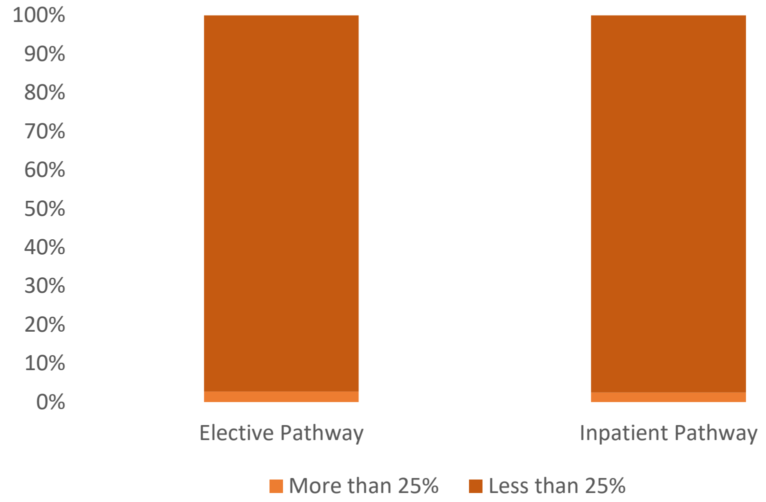
(3.4%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%); Of the six patients who received both a CABG and VR, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 55.



Appendix Figure 55 Change in Uncertainty of Pneumothorax and Type of Surgery.

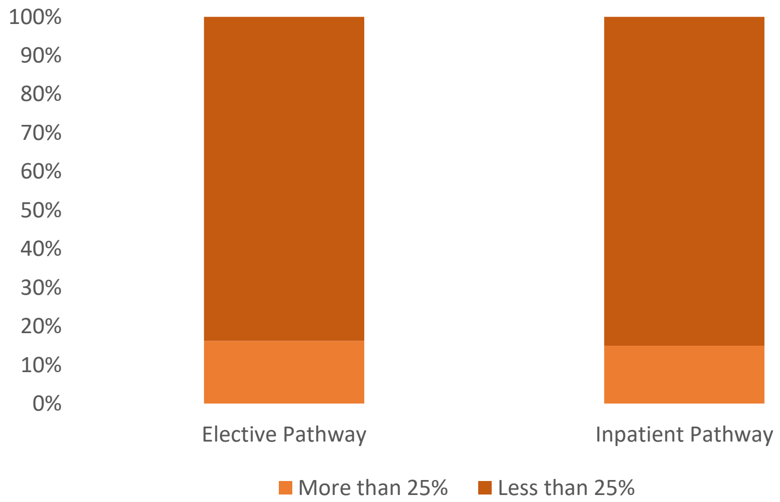
1.4.6 Effects of Surgical Pathway

Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for one patient (2.7%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%). See Appendix Figure 56. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=0.92, p=0.955).



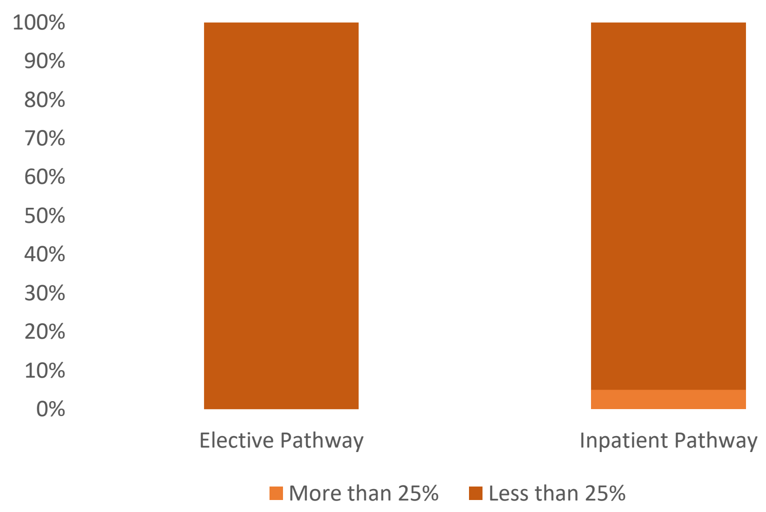
Appendix Figure 56 Change in Uncertainty of Atelectasis and Surgical Pathway.

Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for six patients (16.2%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for six patients (15%). See Appendix Figure 57. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=0.91, p=0.883).



Appendix Figure 57- Change in Uncertainty of Pleural Fluid and Surgical Pathway.

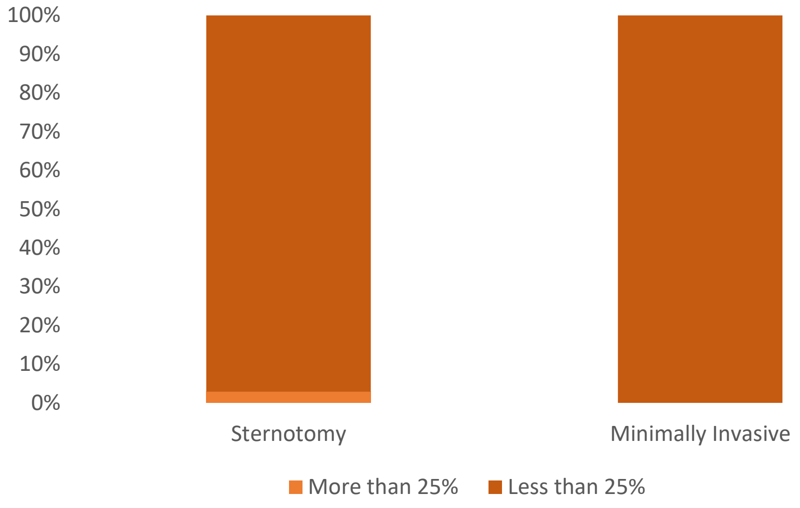
Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for two patients (5%). No regression analysis was done in this category due to low variability. See Appendix Figure 58.



Appendix Figure 58 Change in Uncertainty of Pneumothorax and Surgical Pathway.

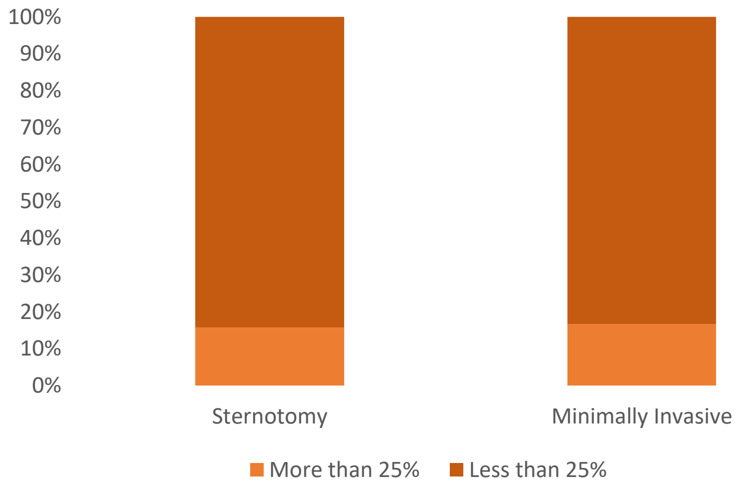
1.4.7 Effects of Surgical Incision

Of the 70 patients who had a sternotomy, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for two patients (2.9%); Of the six patients who had a minimally invasive approach, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 59.



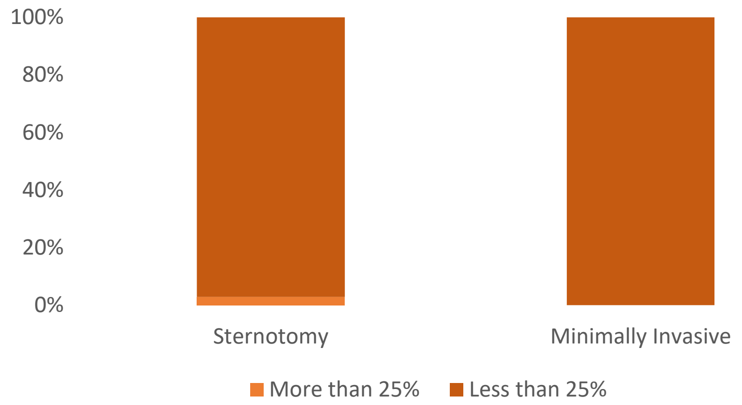
Appendix Figure 59 Change in Uncertainty of Atelectasis and Surgical Incision.

Of the 70 patients who had a sternotomy, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for 11 patients (15.7%); Of the six patients who had a minimally invasive approach, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for one patient (16.7%). See Appendix Figure 60. A minimally invasive approach was found to be non-significant ($OR_{sternotomy:MIS}$=1.07, p=0.951).



Appendix Figure 60 Change in Uncertainty of Pleural Fluid and Surgical Incision.

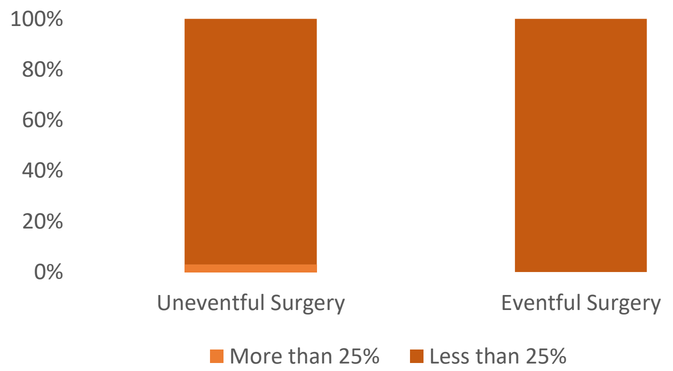
Of the 70 patients who had a sternotomy, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for two patients (2.9%); Of the six patients who had a minimally invasive approach, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 61.



Appendix Figure 61 Change in Uncertainty of Pneumothorax and Surgical Incision.

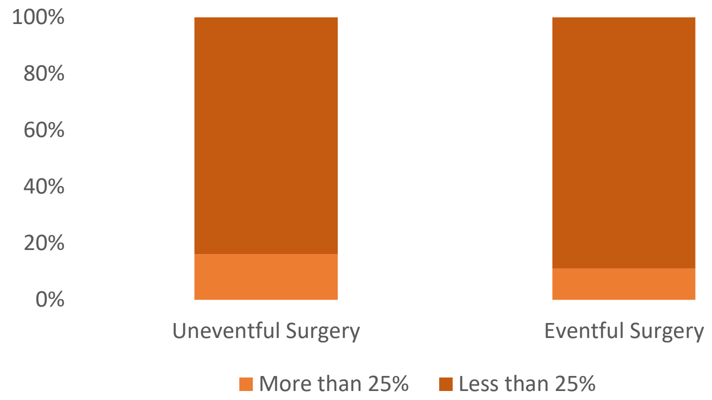
1.4.8 Effects of Eventful Surgery

Of the 68 patients who had uneventful surgery, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for two patients (2.9%); Of the nine patients who had eventful surgery, the physiotherapist's uncertainty concerning atelectasis reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 62.



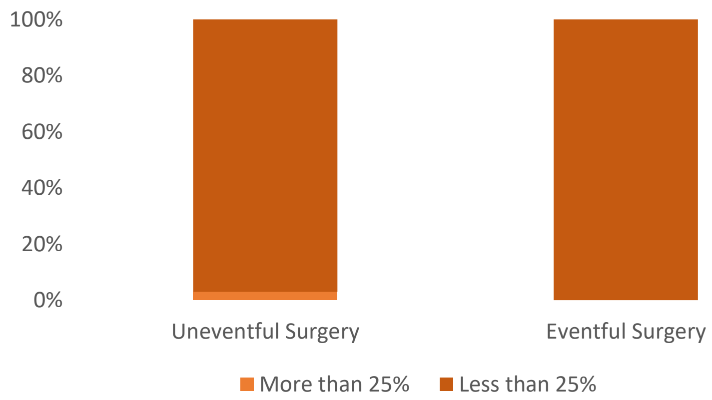
Appendix Figure 62 Change in Uncertainty of Atelectasis and Eventful Surgery.

Of the 68 patients who had uneventful surgery, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for 11 patients (16.2%); Of the nine patients who had eventful surgery, the physiotherapist's uncertainty concerning pleural fluid reduced by more than 25% following LUS for one patient (11.1%). See Appendix Figure 63. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=0.65, p=0.696).



Appendix Figure 63 Change in Uncertainty of Pleural Fluid and Eventful Surgery.

Of the 68 patients who had uneventful surgery, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for two of the patients (2.9%); Of the nine patients who had eventful surgery, the physiotherapist's uncertainty concerning pneumothorax reduced by more than 25% following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 64.

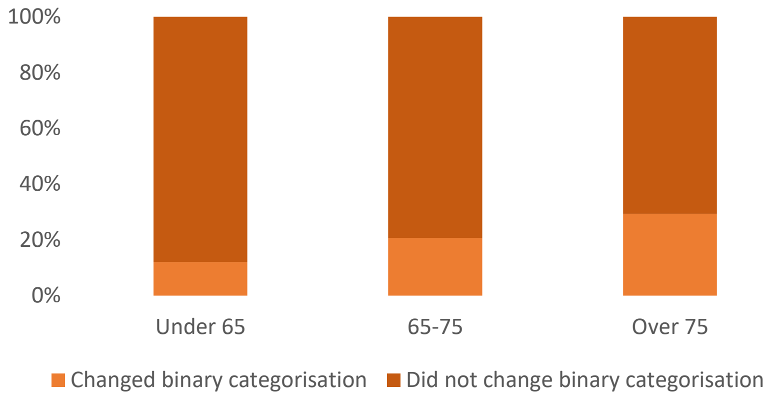


Appendix Figure 64 Change in Uncertainty of Pneumothorax and Eventful Surgery.

1.5 Change in Overall Identification

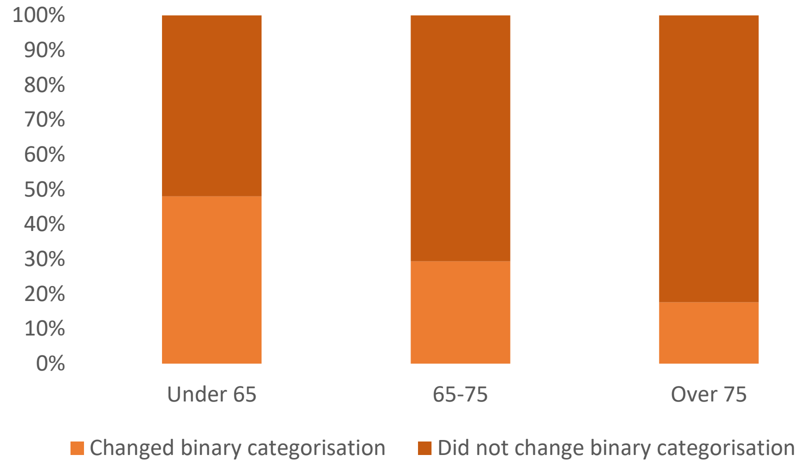
1.5.1 Effects of Age

Of the 25 patients under 65 years of age, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for three patients (12%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for seven patients (20.6%); Of the 17 patients over 75 years of age, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for five patients (29.4%). See Appendix Figure 65. Age was found to be non-significant ($OR_{under65:65-75}$=1.90, p=0.390; $OR_{under65:over75}$=3.06, p=0.170).



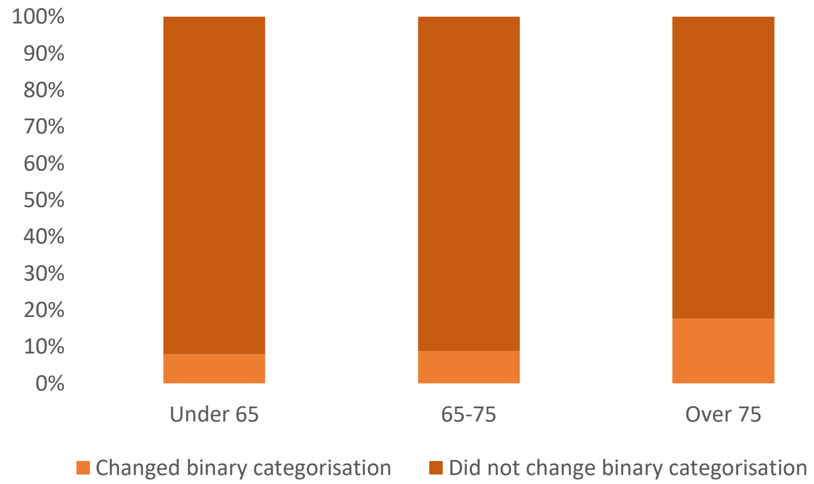
Appendix Figure 65 Re-categorisation of Atelectasis and Patient Age.

Of the 25 patients under 65 years of age, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 12 patients (48%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for ten patients (29.4%); Of the 17 patients over 75 years of age, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for three patients (17.6%). See Appendix Figure 66. Age was found to be non-significant ($OR_{under65:65-75}$=0.45, p=0.148; $OR_{under65:over75}$=0.84, p=0.052).



Appendix Figure 66 Re-categorisation of Pleural Fluid and Patient Age.

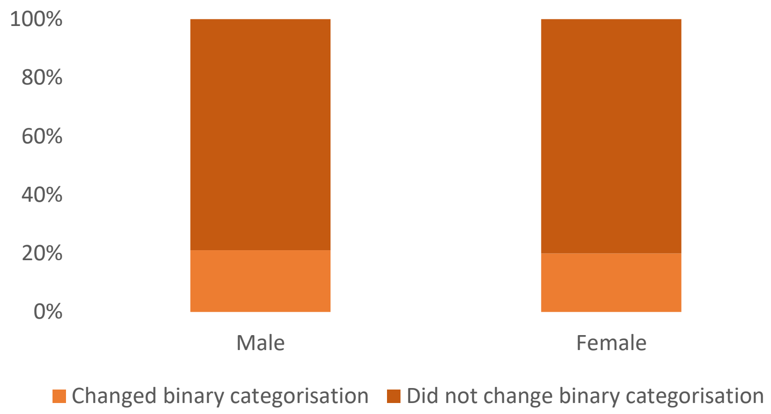
Of the 25 patients under 65 years of age, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for two patients (8%); Of the 34 patients between 65 and 75 years of age, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for three patients (8.8%); Of the 17 patients over 75 years of age, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for three patients (17.6%). See Appendix Figure 67. Age was found to be non-significant ($OR_{under65:65-75}$=1.11, p=0.911; $OR_{under65:over75}$=2.46, p=0.354).



Appendix Figure 67 Re-categorisation of Pneumothorax and Patient Age.

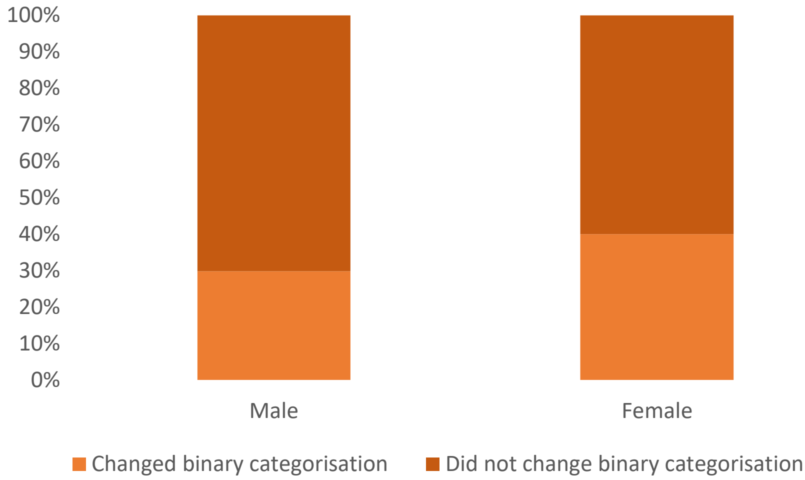
1.5.2 Effects of Sex

Of the 57 male patients the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for 12 patients (21.1%); Of the 20 female patients, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for four patients (20%). See Appendix Figure 68. Sex was found to be non-significant ($OR_{male:female}$=0.94, p=0.920).



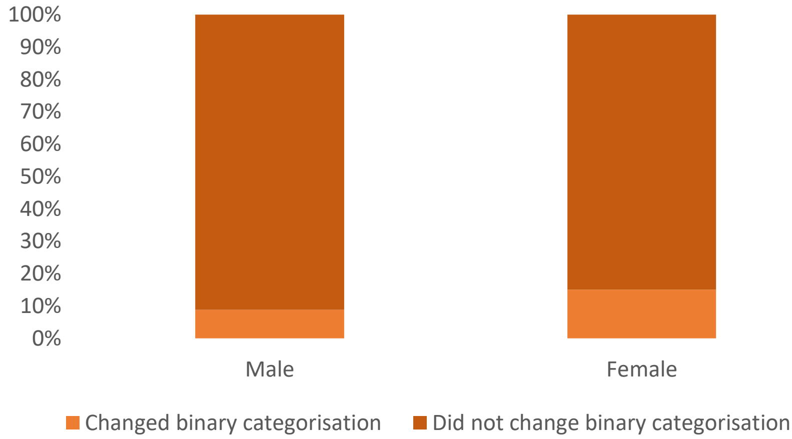
Appendix Figure 68 Re-categorisation of Atelectasis and Patient Sex.

Of the 57 male patients the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 17 patients (29.8%); Of the 20 female patients, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for eight patients (40%). See Appendix Figure 69. Sex was found to be non-significant ($OR_{male:female}$=1.57, p=0.405).



Appendix Figure 69 Re-categorisation of Pleural Fluid and Patient Sex.

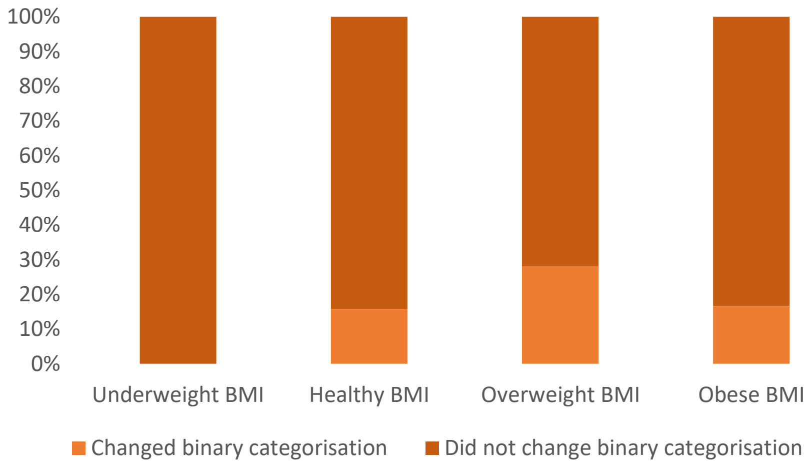
Of the 57 male patients the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for five patients (8.8%); Of the 20 female patients, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for three patients (15%). See Appendix Figure 70. Sex was found to be non-significant ($OR_{male:female}$=0.55, p=0.437).



Appendix Figure 70 Re-categorisation of Pneumothorax and Patient Sex.

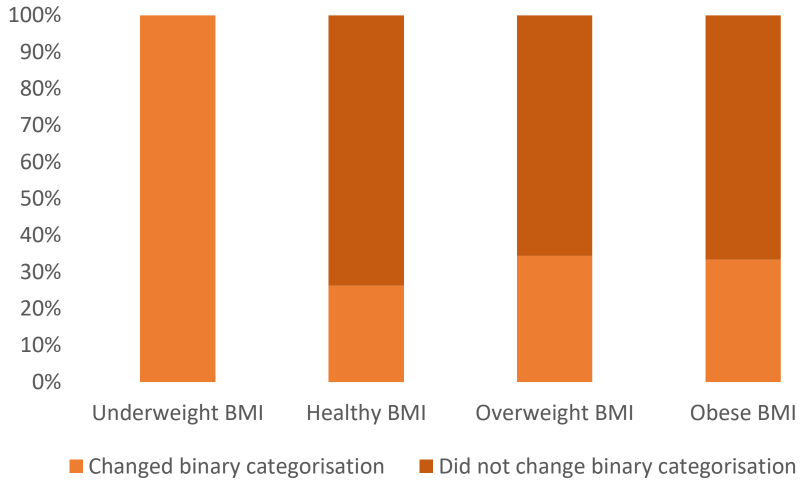
1.5.3 Effects of BMI

Of the 19 patients with a healthy BMI, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for three patients (15.8%); Of the 32 patients with an overweight BMI, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for nine patients (28.1%); Of the 24 patients with an obese BMI, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for four patients (16.7%). See Appendix Figure 71. BMI was found to be non-significant ($OR_{healthy:overweight}$=2.09, p=0.321; $OR_{healthy:obese}$=1.07, p=0.938).



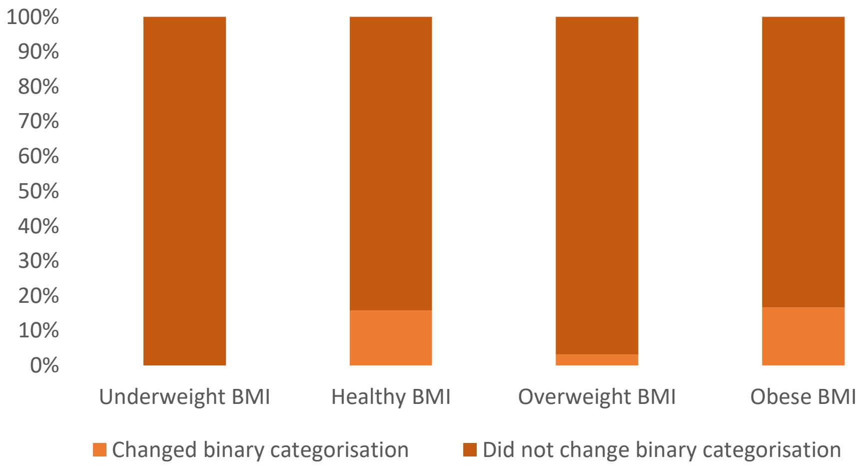
Appendix Figure 71 Re-categorisation of Atelectasis and Body Mass Index.

Of the 19 patients with a healthy BMI, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for five patients (26.3%); Of the 32 patients with an overweight BMI, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 11 patients (34.4%); Of the 24 patients with an obese BMI, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for eight patients (33.3%). See Appendix Figure 72. BMI was found to be non-significant ($OR_{healthy:overweight}$=1.47, p=0.550; $OR_{healthy:obese}$=1.40, p=0.619).



Appendix Figure 72 Re-categorisation of Pleural Fluid and Body Mass Index.

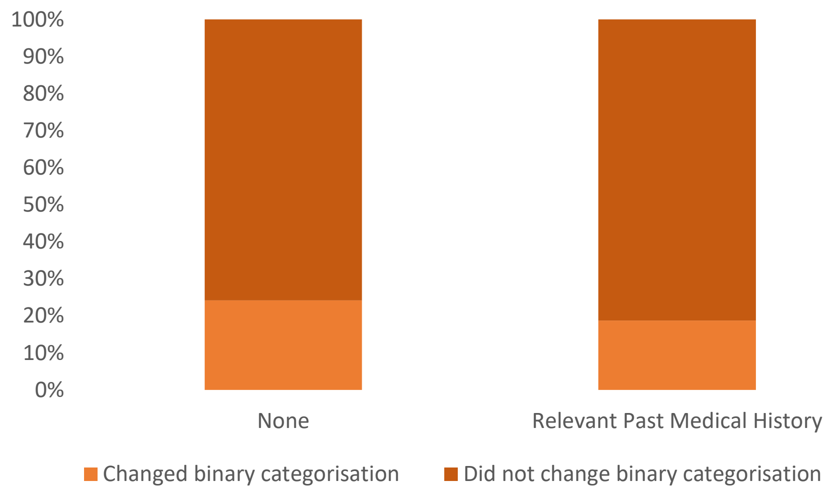
Of the 19 patients with a healthy BMI, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for three patients (15.8%); Of the 32 patients with an overweight BMI, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for one patient (3.1%); Of the 24 patients with an obese BMI, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for four patients (16.7%). See Appendix Figure 73. BMI was found to be non-significant ($OR_{healthy:overweight}$=0.17; p=0.141, $OR_{healthy:obese}$=1.07, p=0.938).



Appendix Figure 73 Re-categorisation of Pneumothorax and Body Mass Index.

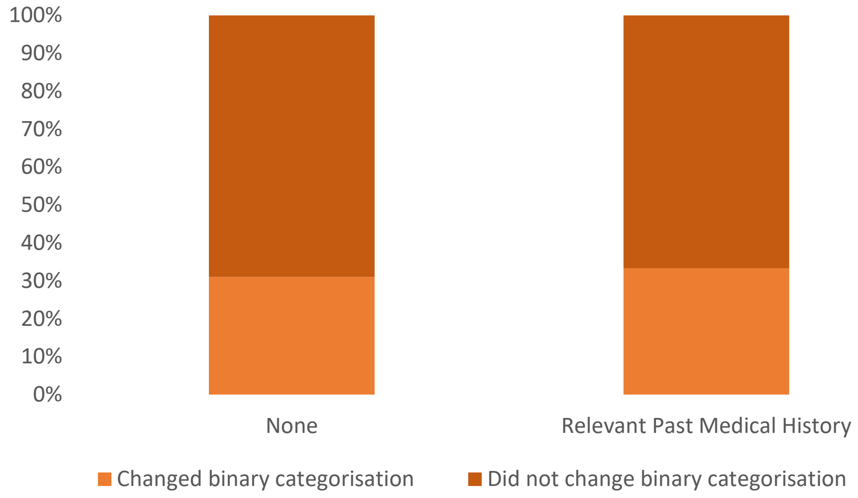
1.5.4 Effects of Relevant Past Medical History

Of the 29 patients with no relevant past medical history, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for seven patients (24.1%); Of the 48 patients with relevant past medical history, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for nine patients (18.8%). See Appendix Figure 74. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=0.73, p=0.573).



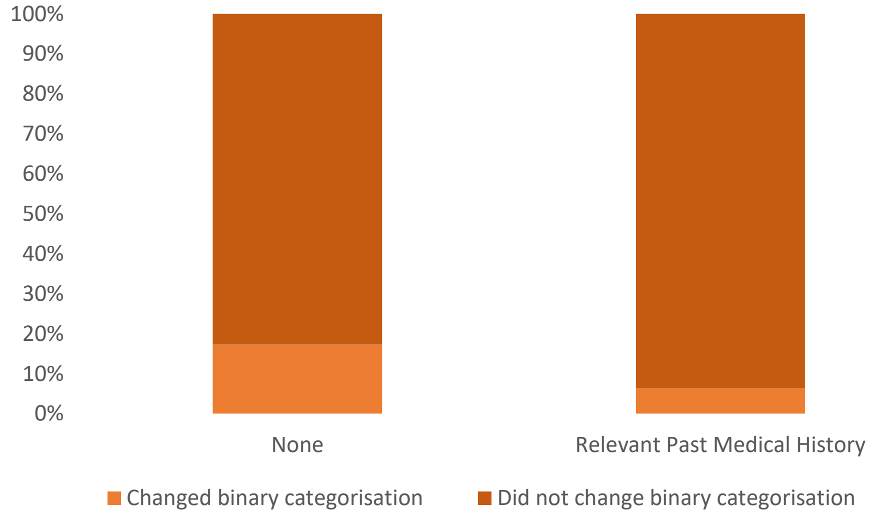
Appendix Figure 74 Re-categorisation of Atelectasis and Relevant Past Medical History.

Of the 29 patients with no relevant past medical history, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for nine patients (31%); Of the 48 patients with relevant past medical history, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 16 patients (33.3%). See Appendix Figure 75. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=1.11, p=0.835).



Appendix Figure 75 Re-categorisation of Pleural Fluid and Relevant Past Medical History.

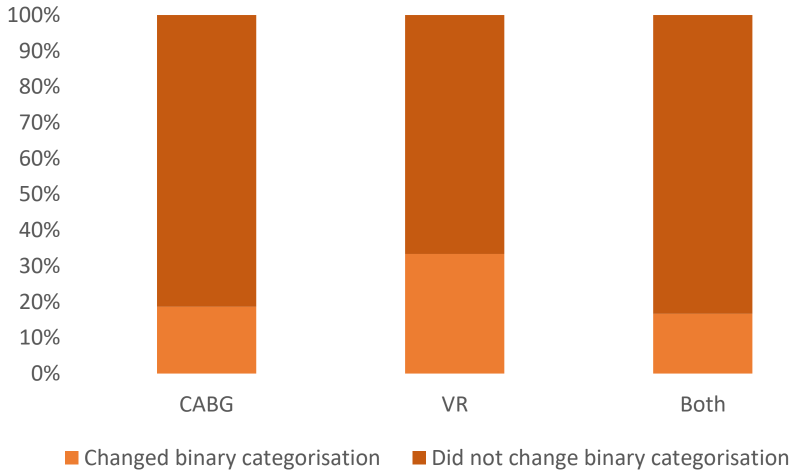
Of the 29 patients with no relevant past medical history, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for five patients (17.2%); Of the 48 patients with relevant past medical history, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for three patients (6.3%). See Appendix Figure 76. The absence of relevant PMH was found to be non-significant ($OR_{none:PMH}$=0.32, p=0.140).



Appendix Figure 76 Re-categorisation of Pneumothorax and Relevant Past Medical History.

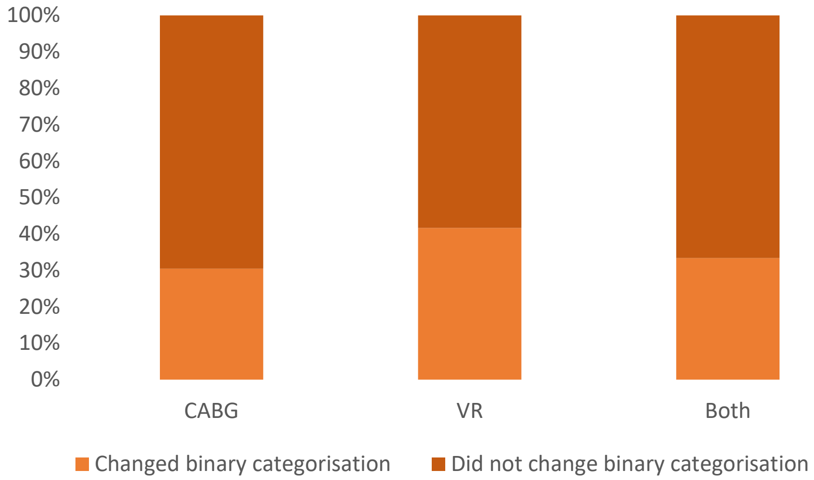
1.5.5 Effects of Surgery Type

Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for 11 patients (18.6%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for four patients (33.3%); Of the six patients who received both a CABG and VR, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for one patient (16.7%). See Appendix Figure 77. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=2.18, p=0.263; $OR_{CABG:both}$=0.87, p=0.905).



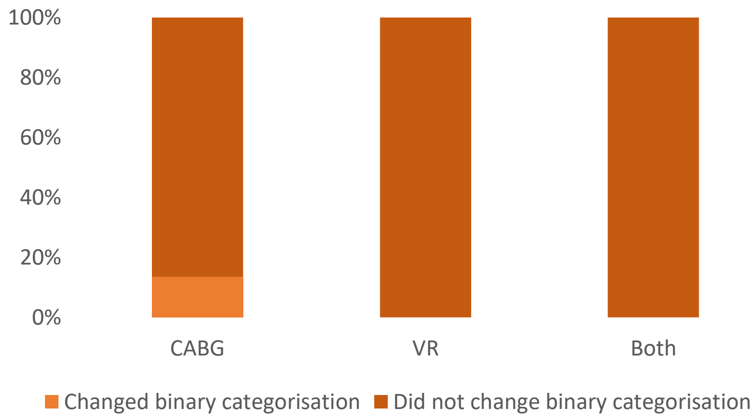
Appendix Figure 77 Re-categorisation of Atelectasis and Type of Surgery.

Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 18 patients (30.5%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for five patients (41.7%); Of the six patients who received both a CABG and VR, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for two patients (33.3%). See Appendix Figure 78. Type of surgery was found to be non-significant ($OR_{CABG:VR}$=1.63, p=0.454; $OR_{CABG:both}$=1.14, p=0.886).



Appendix Figure 78 Re-categorisation of Pleural Fluid and Type of Surgery.

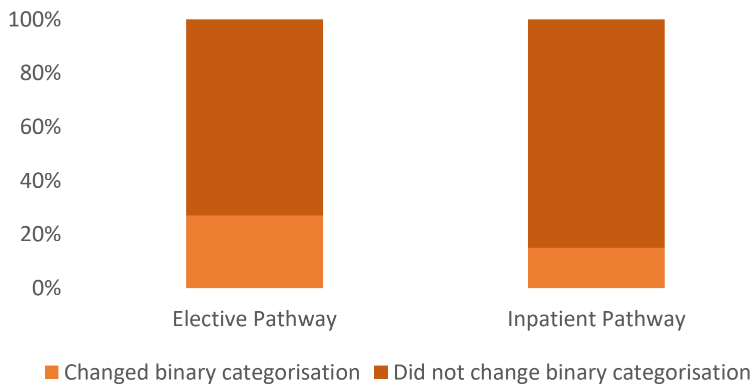
Of the 59 patients who received only a coronary artery bypass graft (CABG), the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for eight patients (13.6%); Of the 12 patients who received only a valve replacement/repair (VR), the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for none of the patients (0%); Of the six patients who received both a CABG and VR, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 79.



Appendix Figure 79 Re-categorisation of Pneumothorax and Type of Surgery.

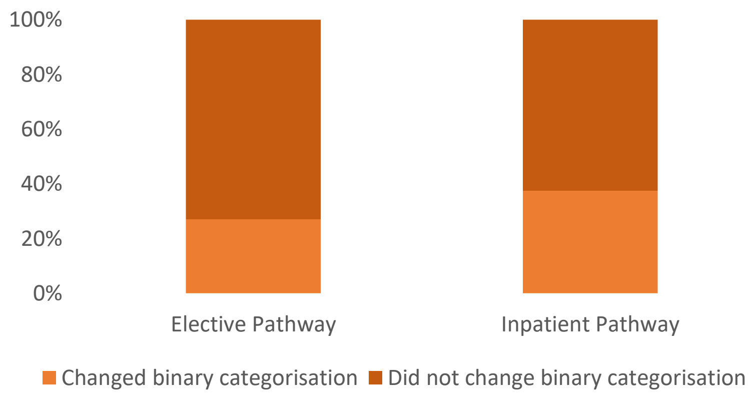
1.5.6 Effects of Surgical Pathway

Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for ten patients (27%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for six patients (15%). See Appendix Figure 80. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=0.48, p=0.199).



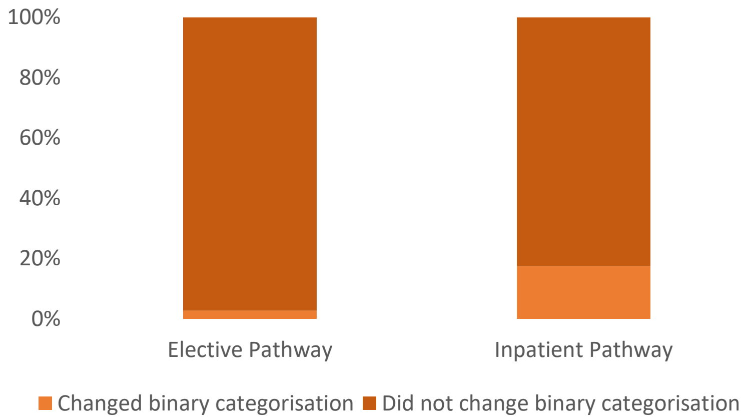
Appendix Figure 80 Re-categorisation of Atelectasis and Surgical Pathway.

Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for ten patient (27%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 15 patients (37.5%). See Appendix Figure 81. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=1.62, p=0.328).



Appendix Figure 81 Re-categorisation of Pleural Fluid and Surgical Pathway.

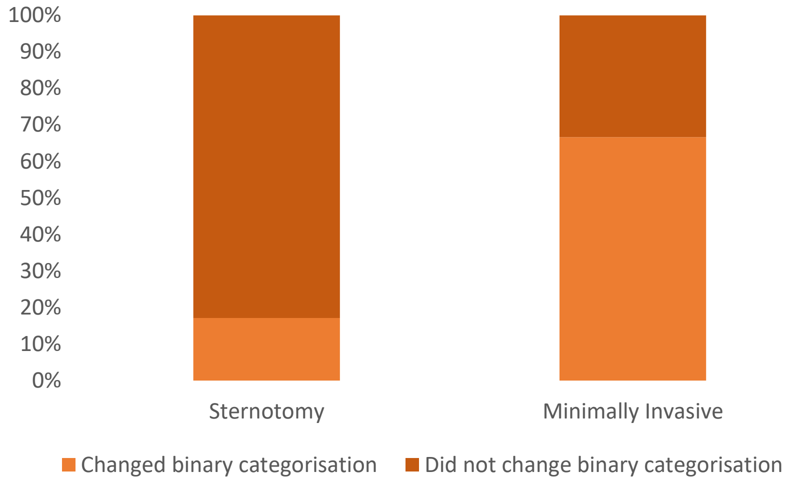
Of the 37 patients recruited from the elective surgical pathway (EP), the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for one patient (2.7%); Of the 40 patients recruited from the inpatient surgical pathway (IP), the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for seven patients (17.5%). See Appendix Figure 82. Surgical pathway was found to be non-significant ($OR_{EP:IP}$=7.64, p=0.064).



Appendix Figure 82 Re-categorisation of Pneumothorax and Surgical Pathway.

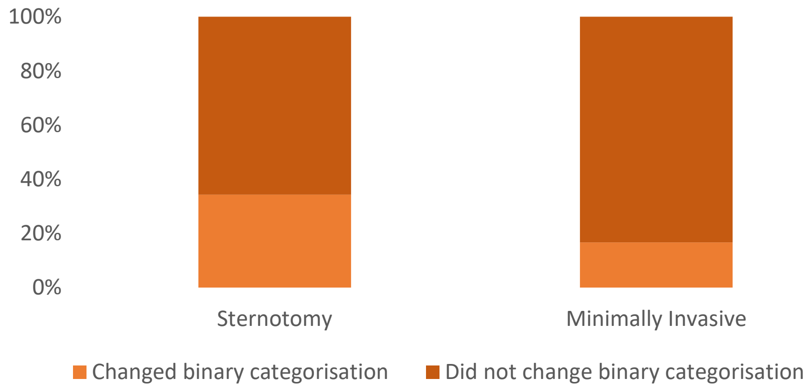
1.5.7 Effects of Surgical Incision

Of the 70 patients who had a sternotomy, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for 12 patients (17.1%); Of the six patients who had a minimally invasive approach, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for four patients (66.7%). See Appendix Figure 83. A minimally invasive approach was found to be significant ($OR_{sternotomy:MIS}$=9.67, p=0.014).



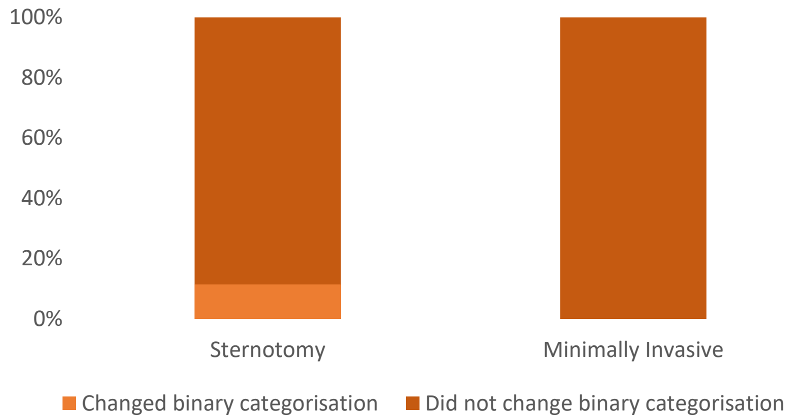
Appendix Figure 83 Re-categorisation of Atelectasis and Surgical Incision.

Of the 70 patients who had a sternotomy, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 24 patients (34.3%); Of the six patients who had a minimally invasive approach, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for one patients (16.7%). See Appendix Figure 84. A minimally invasive approach was found to be non-significant ($OR_{sternotomy:MIS}$=0.38, p=0.394).



Appendix Figure 84 Re-categorisation of Pleural Fluid and Surgical Incision.

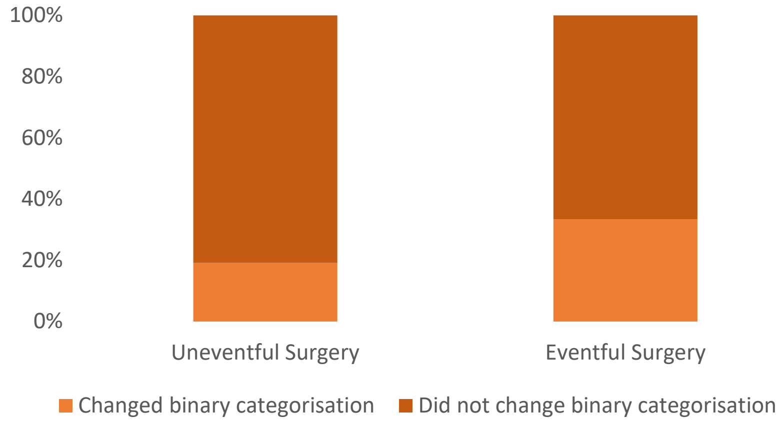
Of the 70 patients who had a sternotomy, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for eight patients (11.4%); Of the six patients who had a minimally invasive approach, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for none of the patients (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 85.



Appendix Figure 85 Re-categorisation of Pneumothorax and Surgical Incision.

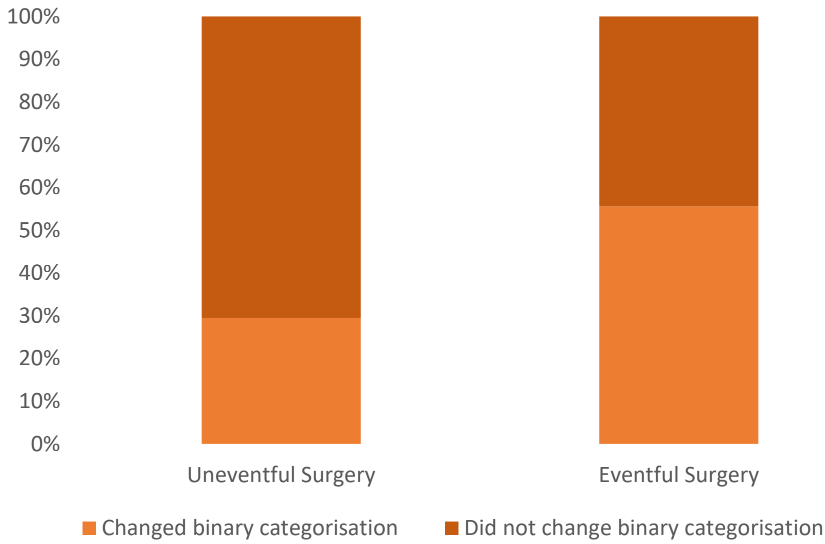
1.5.8 Effects of Eventful Surgery

Of the 68 patients who had uneventful surgery, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for 13 patients (19.1%); Of the nine patients who had eventful surgery, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS for three patients (33.3%). See Appendix Figure 86. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=2.12, p=0.331).



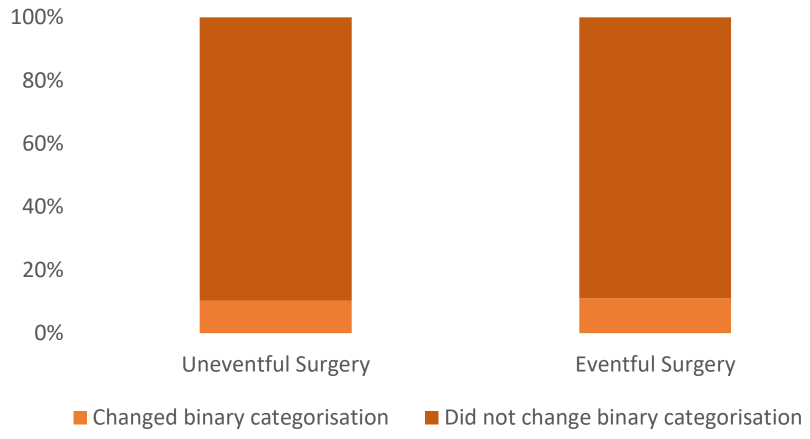
Appendix Figure 86 Re-categorisation of Atelectasis and Eventful Surgery.

Of the 68 patients who had uneventful surgery, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for 20 patients (29.4%); Of the nine patients who had eventful surgery, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS for five patients (55.6%). See Appendix Figure 87. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=3.00, p=0.128).



Appendix Figure 87 Re-categorisation of Pleural Fluid and Eventful Surgery.

Of the 68 patients who had uneventful surgery, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for seven patients (10.3%); Of the nine patients who had eventful surgery, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS for one patient (11.1%). See Appendix Figure 88. Eventful surgery was found to be non-significant ($OR_{uneventful:eventful}$=1.09, p=0.94).



Appendix Figure 88 Re-categorisation of Pneumothorax and Eventful Surgery.

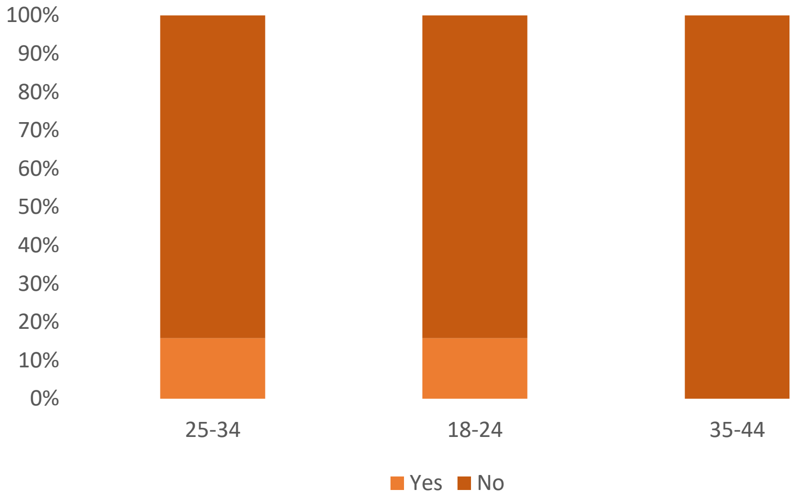
2. Physiotherapist demographics & experience

This next section will present the results of binary linear regressions using the physiotherapist's demographic and experience as the independent variables. There was one physiotherapist who was the only one in the 35-44 age bracket and the only rotational Band 6. Therefore, regressions were not performed using these two variables.

2.1 Management Change

2.1.1 Effects of Age

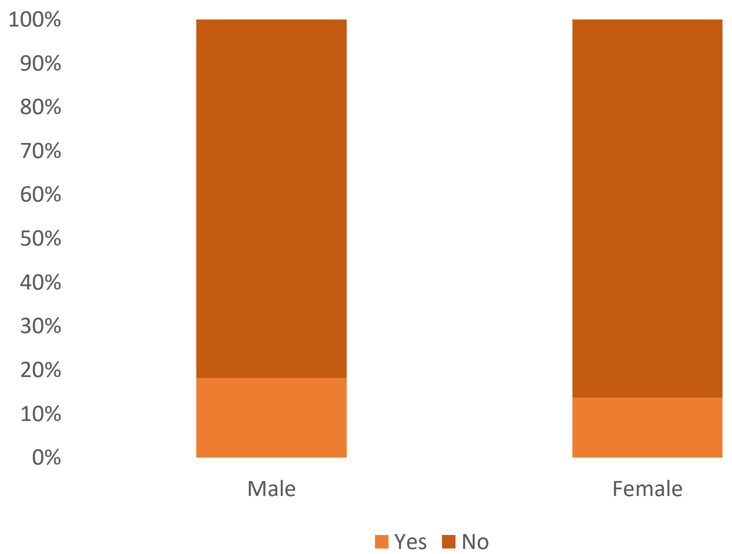
Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, management changed in nine cases (15.8%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, management changed in three cases (15.8%). See Appendix Figure 89. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}$=1.00, p=1.00).



Appendix Figure 89 Management Change and Physiotherapist Age.

2.1.2 Effects of Sex

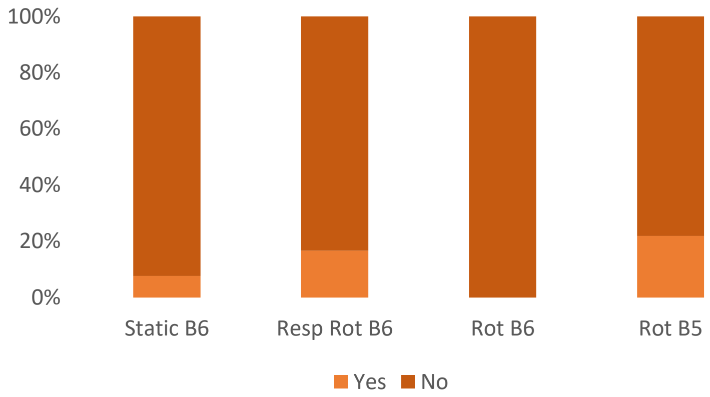
Out of the 33 cases where the physiotherapist was male, management changed in six cases (18.2%); Out of the 44 cases where the physiotherapist was female, management changed in six cases (13.6%). See Appendix Figure 90. Sex was found to be non-significant ($OR_{male:female}$=0.71, p=0.587).



Appendix Figure 90 Management Change and Physiotherapist Sex.

2.1.3 Effects of Band

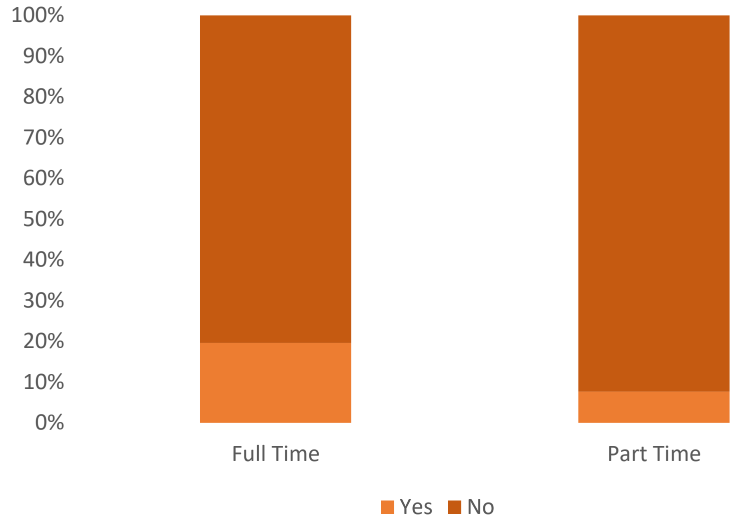
Out of the 26 cases where the physiotherapist was a static band six, management changed in two cases (7.7%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, management changed in three cases (16.7%); Out of the 32 cases where the physiotherapist was a rotational band five, management changed in seven cases (21.9%). See Appendix Figure 91. Band was found to be non-significant ($OR_{SB6:RRB6}$=2.40, p=0.367; $OR_{SB6:RB5}$=3.36, p=0.154).



Appendix Figure 91 Management Change and Job Post.

2.1.4 Effects of Contract

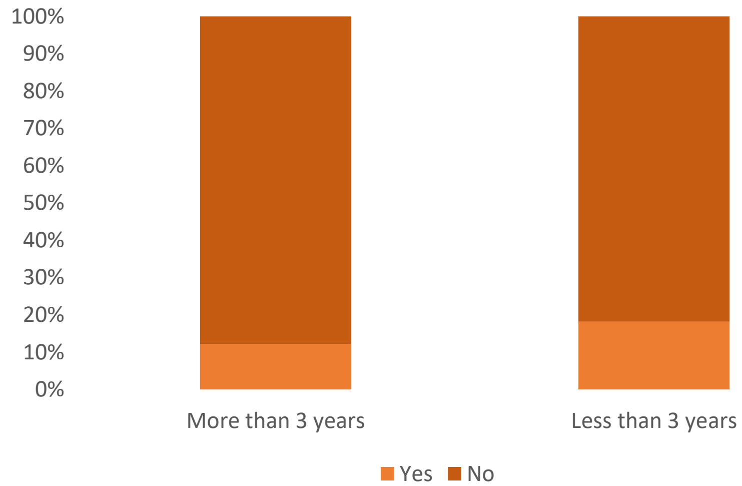
Out of the 51 cases where the physiotherapist was full time, management changed in ten cases (19.6%); Out of the 26 cases where the physiotherapist was part time, management changed in two cases (7.7%). See Appendix Figure 92. Contract was found to be non-significant ($OR_{FT:PT}$=0.34, p=0.188).



Appendix Figure 92 Management Change and Contract.

2.1.5 Effects of Years Qualified

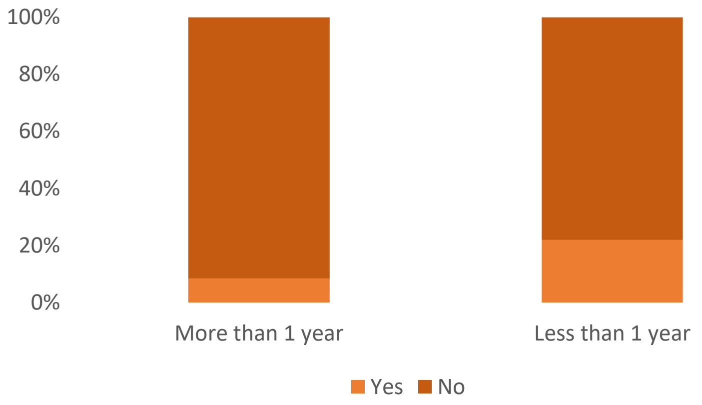
Out of the 33 cases where the physiotherapist had been qualified for more than three years, management changed in four cases (12.1%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, management changed in eight cases (18.2%). See Appendix Figure 93. Years qualified was found to be non-significant ($OR_{>3:<3}$=1.61, p=0.471).



Appendix Figure 93 Management Change and Years Qualified.

2.1.6 Effects of Years Experience with the Cardiac Population

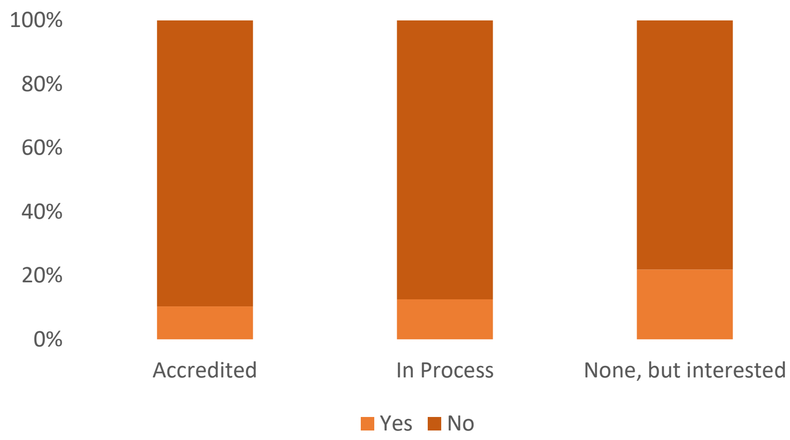
Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, management changed in three cases (8.3%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, management changed in nine cases (22%). See Appendix Figure 94. Years experience with cardiac surgery patients was found to be non-significant ($OR_{>1:<1}$=3.09, p=0.112).



Appendix Figure 94 Management Change and Experience with Cardiac Surgery Patients.

2.1.7 Effects of Lung Ultrasound Experience

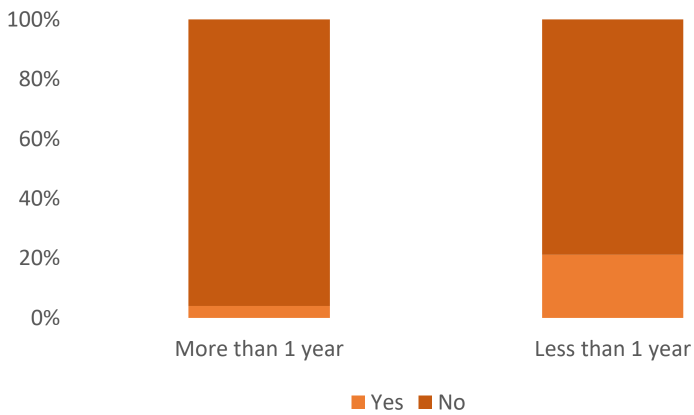
Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, management changed in three cases (10.3%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, management changed in two cases (12.5%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, management changed in seven cases (21.9%). See Appendix Figure 95. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=1.24, p=0.826; $OR_{accredited:none}$=2.43, p=0.234).



Appendix Figure 95 Management Change and LUS Experience.

2.1.8 Effects of Years Accredited in Lung Ultrasound

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, management changed in one case (4%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, management changed in 11 cases (21.2%). See Appendix Figure 96. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=6.44, p=0.083).

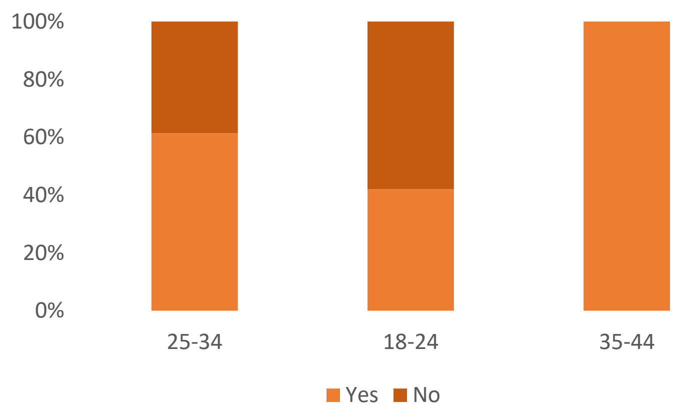


Appendix Figure 96 Management Change and Years Accredited in LUS.

2.2 Matching Impressions

2.2.1 Effects of Age

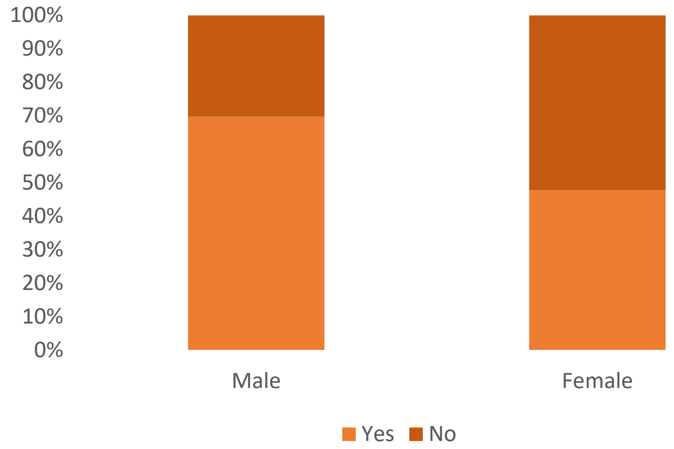
Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 35 cases (61.4%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in eight cases (42.1%). See Appendix Figure 97. Age was found to be non-significant ($OR_{25-34:18-24}$=2.19, p=0.146).



Appendix Figure 97 Matching Impressions and Physiotherapist Age

2.2.2 Effects of Sex

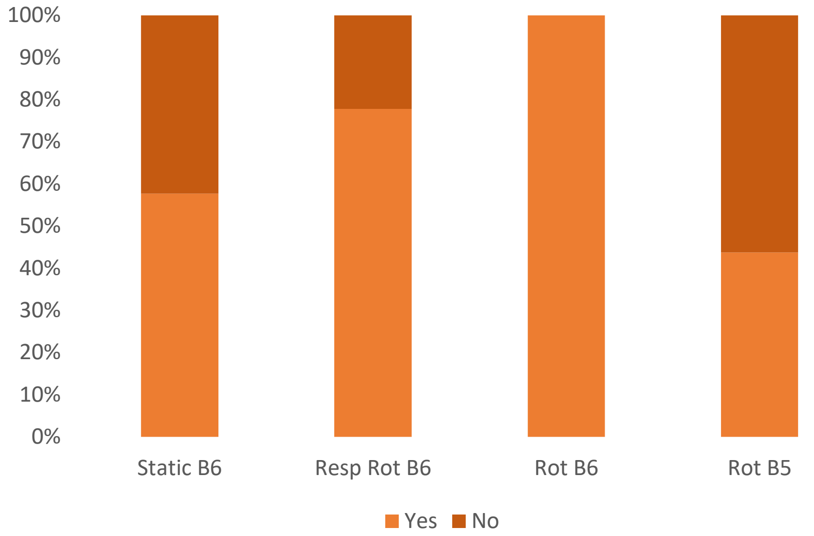
Out of the 33 cases where the physiotherapist was male, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 23 cases (69.7%); Out of the 44 cases where the physiotherapist was female, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 21 cases (47.7%). See Appendix Figure 98. Sex was found to be non-significant ($OR_{male:female}$=2.52, p=0.056).



Appendix Figure 98 Matching Impressions and Physiotherapist Sex

2.2.3 Effects of Job Post

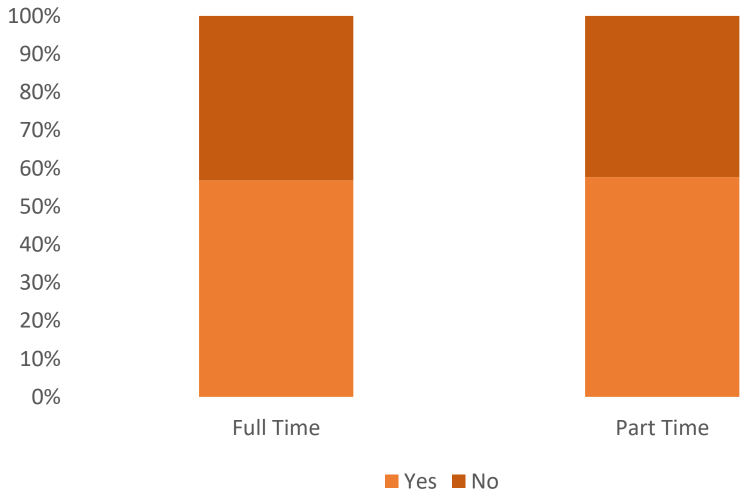
Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 15 cases (57.7%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 14 cases (77.8%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 14 cases (44%). See Appendix Figure 99. Job post was found to be non-significant ($OR_{SB6:RRB6}$=0.39, p=0.173; $OR_{SB6:RB5}$=1.75, p=0.293).



Appendix Figure 99 Matching Impressions and Job Post

2.2.4 Effects of Contract

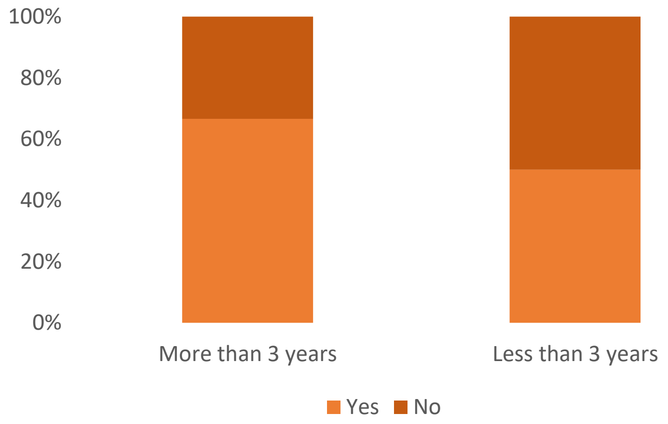
Out of the 51 cases where the physiotherapist was full time, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 29 cases (56.9%); Out of the 26 cases where the physiotherapist was part time, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 15 cases (57.7%). See Appendix Figure 100. Contract was found to be non-significant ($OR_{FT:PT}$=0.97, p=0.945).



Appendix Figure 100 Matching Impressions and Contract

2.2.5 Effects of Years Qualified

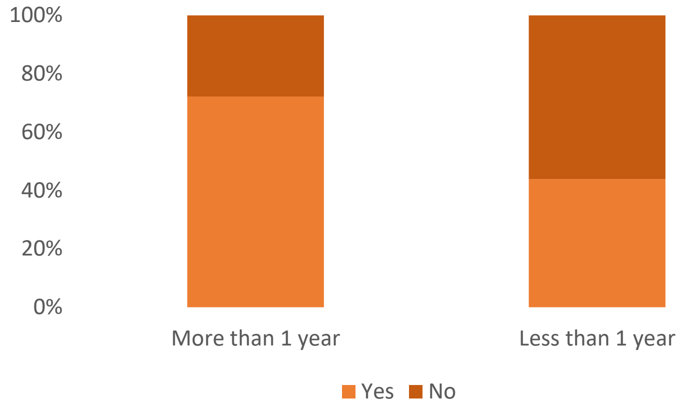
Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 22 cases (66.7%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 22 cases (50%). See Appendix Figure 101. Years qualified was found to be non-significant ($OR_{>3:<3}$=2.00, p=0.146).



Appendix Figure 101 Matching Impressions and Years Qualified

2.2.6 Effects of Years Experience with the Cardiac Population

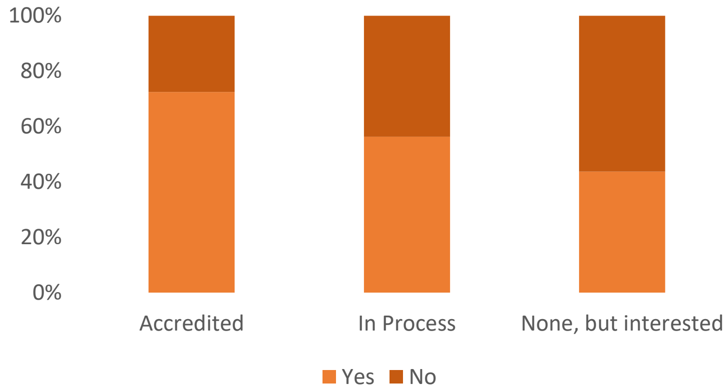
Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 26 cases (72%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 18 cases (43.9%). See Appendix Figure 102. More than a year of experience with cardiac surgery patients was found to be significant ($OR_{>1:<1}$=3.32, p=0.014).



Appendix Figure 102 Matching Impressions and Experience with Cardiac Surgery Patients

2.2.7 Effects of Lung Ultrasound Experience

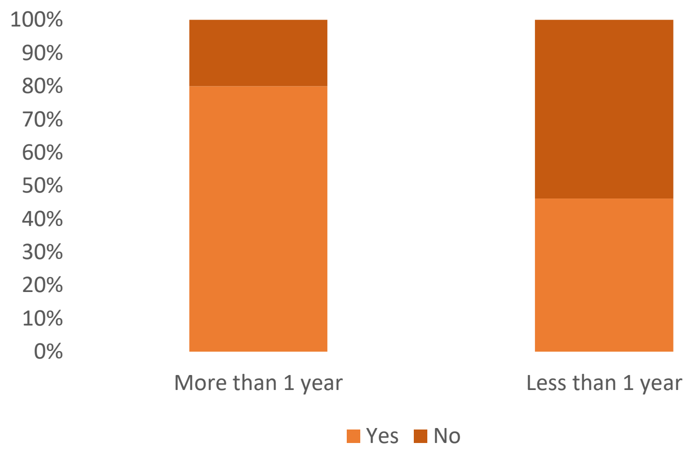
Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 21 cases (72.4%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in nine cases (56.3%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 14 cases (43.8%). See Appendix Figure 103. In process of becoming accredited in lung ultrasound was found to be non-significant ($OR_{accredited:inprogress}$=2.04, p=0.274) No lung ultrasound experience was found to be significant ($OR_{accredited:none}$=3.38, p=0.026).



Appendix Figure 103 Matching Impressions and Lung Ultrasound Experience

2.2.8 Effects of Years Accredited in Lung Ultrasound

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 20 cases (80%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist perceived their clinical impression of the patient matched that of the LUS Scanner in 24 cases (46.2%). See Appendix Figure 104. Less than a year accredited or absence of accreditation was found to be significant ($OR_{>1:<1}$=4.67, p=0.007).

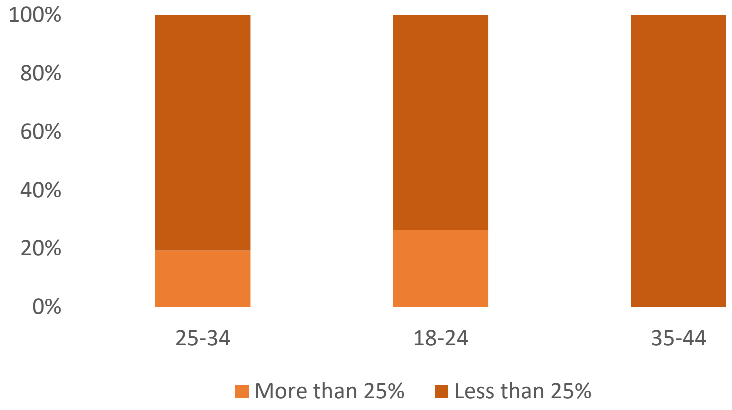


Appendix Figure 104 Matching Impressions and Years Accredited in LUS

2.3 Shift in Probability

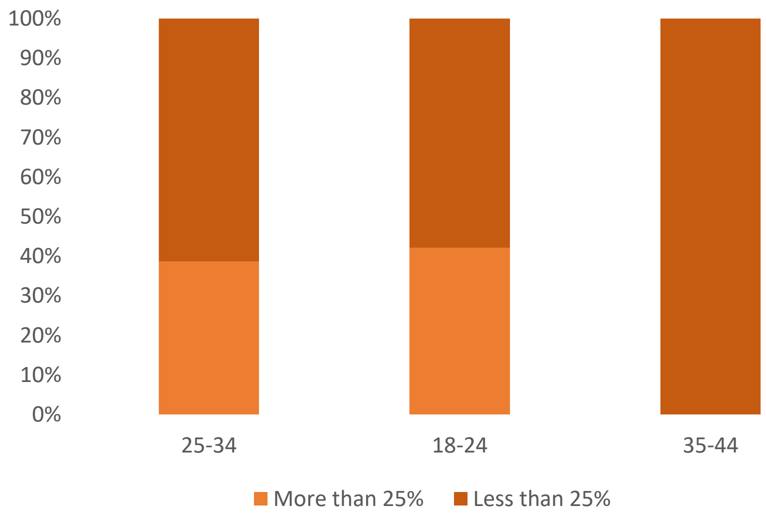
2.3.1 Effects of Age

Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in 11 cases (19.3%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in five cases (26.3%). See Appendix Figure 105. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}$=1.49, p=0.517).



Appendix Figure 105 Shift in Probability of Atelectasis and Physiotherapist Age

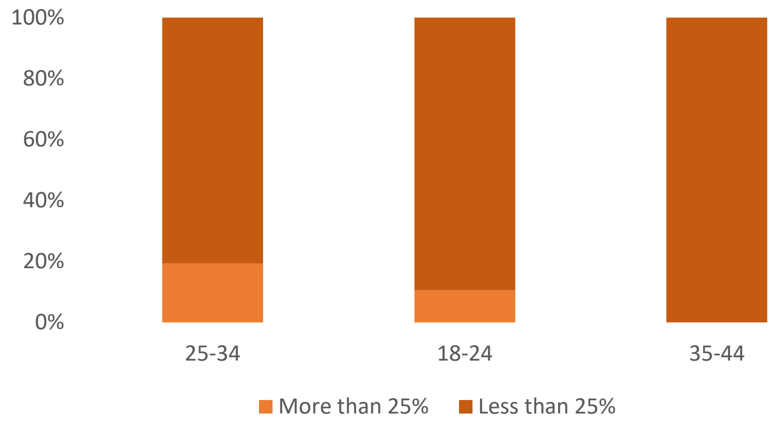
Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 22 cases (38.6%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in eight cases (42.1%). See Appendix Figure 106. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}=1.16$, p=0.786).



Appendix Figure 106 Shift in Probability of Pleural Fluid and Physiotherapist Age

Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in

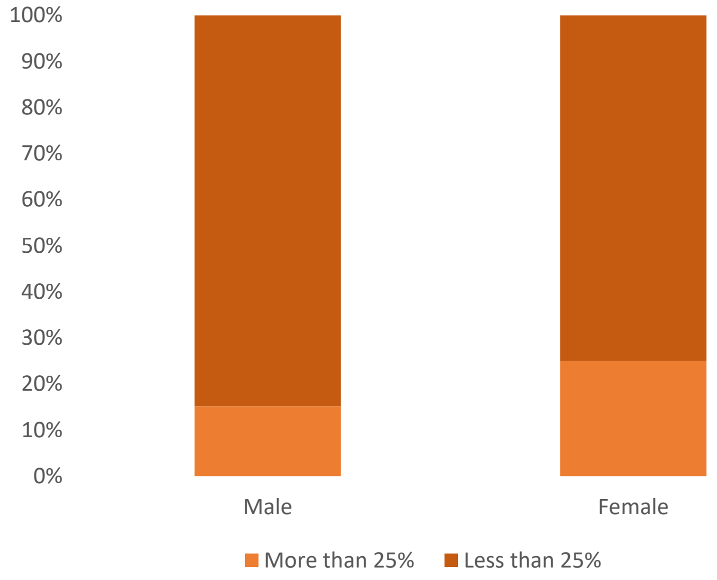
11 cases (19.3%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in two cases (10.5%). See Appendix Figure 107. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}$=0.49, p=0.387).



Appendix Figure 107 Shift in Probability of Pneumothorax and Physiotherapist Age

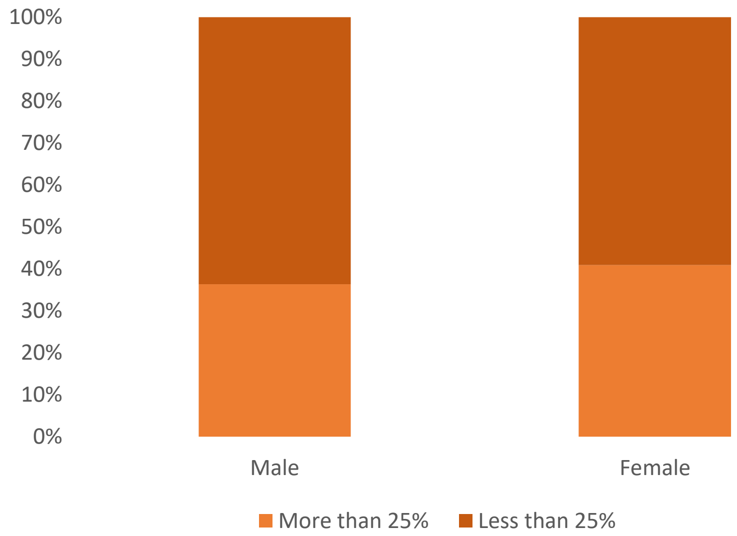
2.3.2 Effects of Sex

Out of the 33 cases where the physiotherapist was male, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in five cases (15.2%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in 11 cases (25%). See Appendix Figure 108. Sex was found to be non-significant ($OR_{male:female}$=1.87, p=0.296).



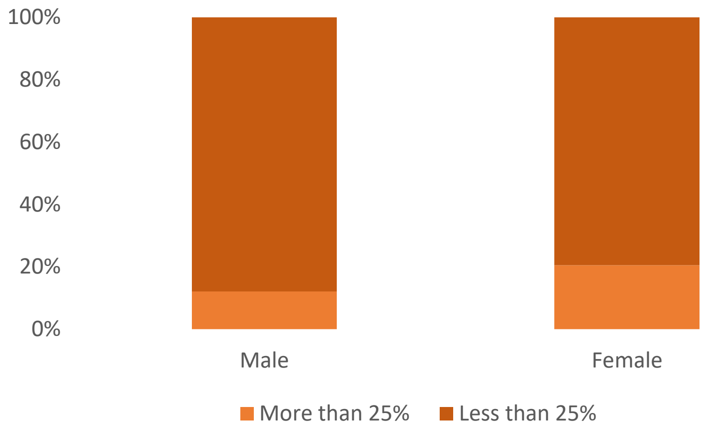
Appendix Figure 108 Shift in Probability of Atelectasis and Physiotherapist Sex

Out of the 33 cases where the physiotherapist was male, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 12 cases (36.4%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 18 cases (40.9%). See Appendix Figure 109. Sex was found to be non-significant ($OR_{male:female}$=1.21, p=0.686).



Appendix Figure 109 Shift in Probability of Pleural Fluid and Physiotherapist Sex

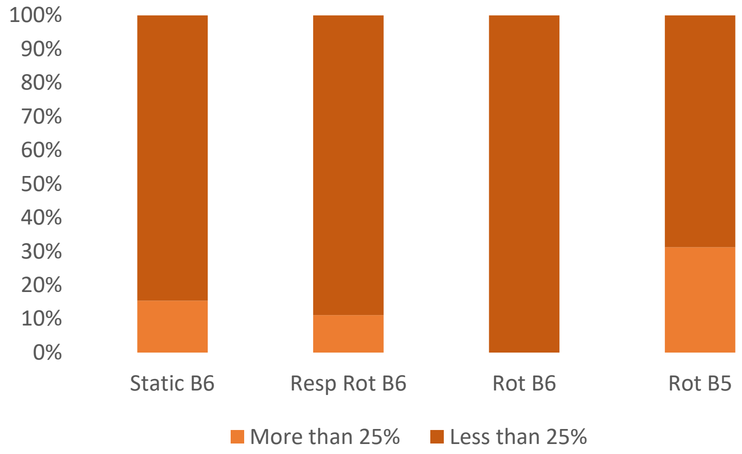
Out of the 33 cases where the physiotherapist was male, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in four cases (12.1%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in nine cases (20.5%). See Appendix Figure 110. Sex was found to be non-significant ($OR_{male:female}$=1.86, p=0.339).



Appendix Figure 110 Shift in Probability of Pneumothorax and Physiotherapist Sex

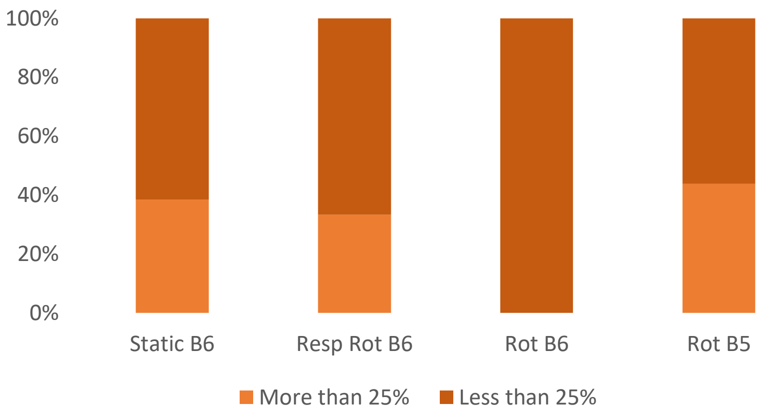
2.3.3 Effects of Job Post

Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in four cases (15.4%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in two cases (11.1%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in ten cases (31.3%). See Appendix Figure 111. Job post was found to be non-significant ($OR_{SB6:RRB6}$=0.69, p=0.686; $OR_{SB6:RB5}$=2.50, p=0.168).



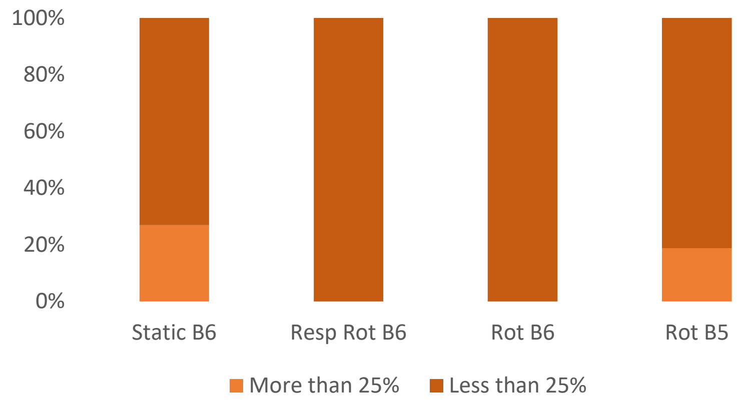
Appendix Figure 111 Shift in Probability of Atelectasis and Job Post

Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in ten cases (38.5%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in six cases (33.3%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 14 cases (43.8%). See Appendix Figure 112. Band was found to be non-significant ($OR_{SB6:RRB6}$=0.80, p=0.728; $OR_{SB6:RB5}$=1.24, p=0.684).



Appendix Figure 112 Shift in Probability of Pleural Fluid and Job Post

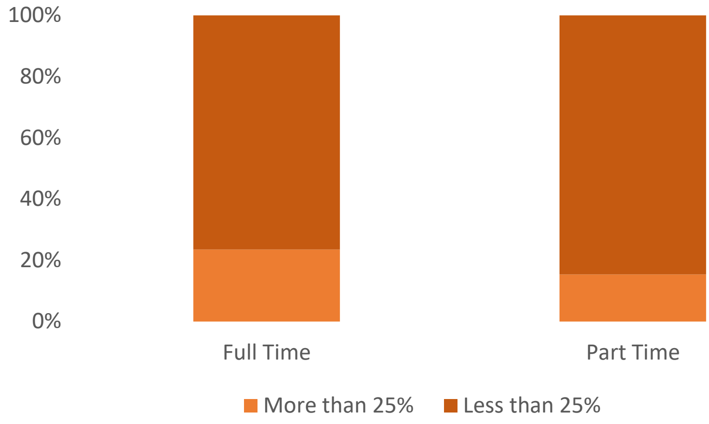
Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in seven cases (26.9%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in none of the cases (0%), therefore no regression analysis was done on this category; Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in six cases (18.8%). See Appendix Figure 113. Band was found to be non-significant ($OR_{SB6:RB5}$=0.63, p=0.460).



Appendix Figure 113 Shift in Probability of Pneumothorax and Job Post

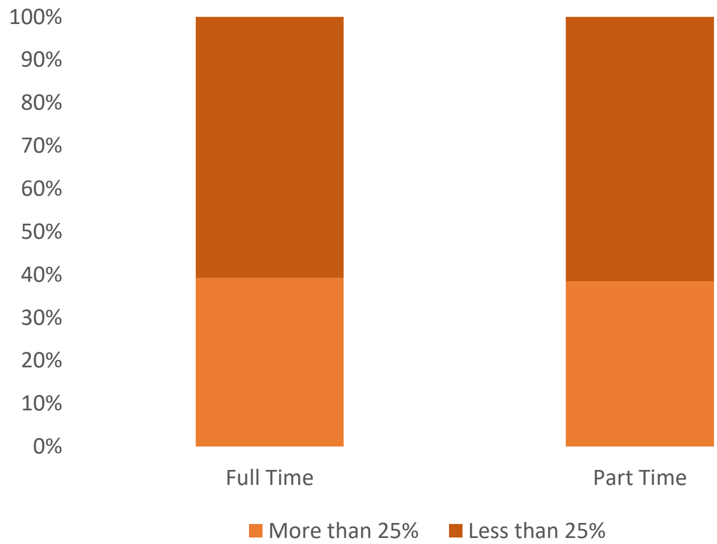
2.3.4 Effects of Contract

Out of the 51 cases where the physiotherapist was full time, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in 12 cases (23.5%); Out of the 26 cases where the physiotherapist was part time, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in four cases (15.4%). See Appendix Figure 114. Contract was found to be non-significant ($OR_{FT:PT}$=0.59, p=0.408).



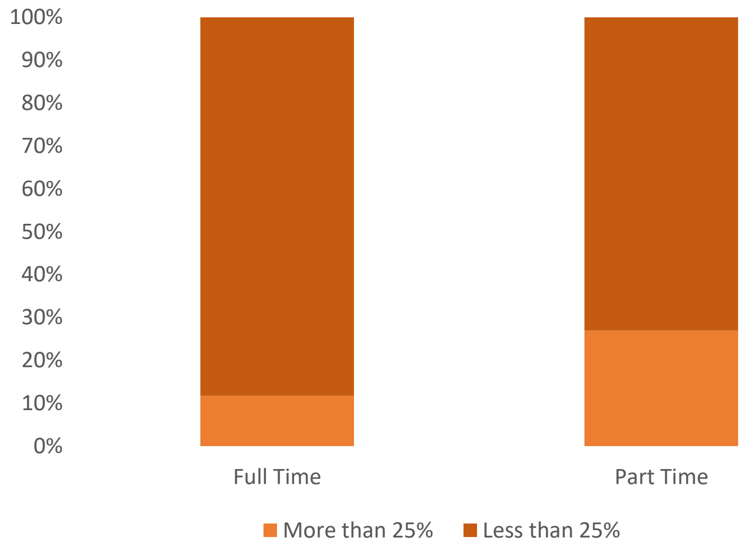
Appendix Figure 114 Shift in Probability of Atelectasis and Contract

Out of the 51 cases where the physiotherapist was full-time, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 20 cases (39.2%); Out of the 26 cases where the physiotherapist was part-time, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in ten cases (38.5%). See Appendix Figure 115. Contract was found to be non-significant ($OR_{FT:PT}$=0.97, p=0.949).



Appendix Figure 115 Shift in Probability of Pleural Fluid and Contract

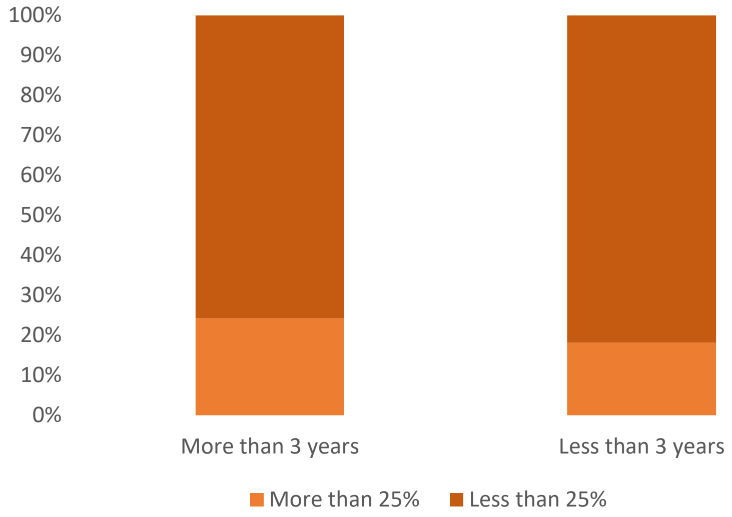
Out of the 51 cases where the physiotherapist was full time, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in six cases (11.8%); Out of the 26 cases where the physiotherapist was part time, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in seven cases (26.9%). See Appendix Figure 116. Contract was found to be non-significant ($OR_{FT:PT}$=2.76, p=0.101).



Appendix Figure 116 Shift in Probability of Pneumothorax and Contract

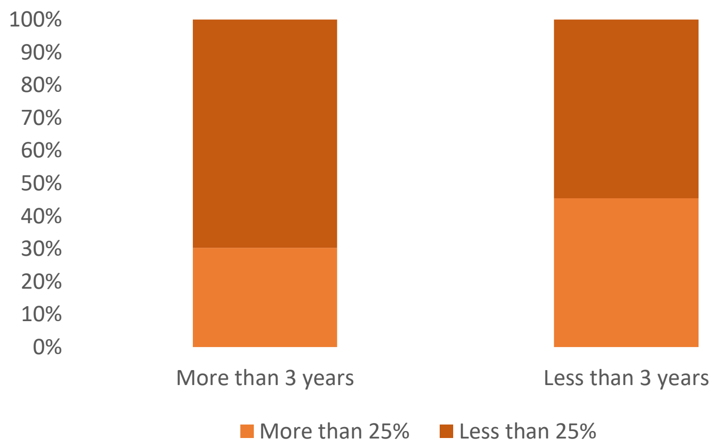
2.3.5 Effects of Years Qualified

Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in eight cases (24.2%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in eight cases (18.2%). See Appendix Figure 117. Years qualified was found to be non-significant ($OR_{>3:<3}$=0.69, p=0.518).



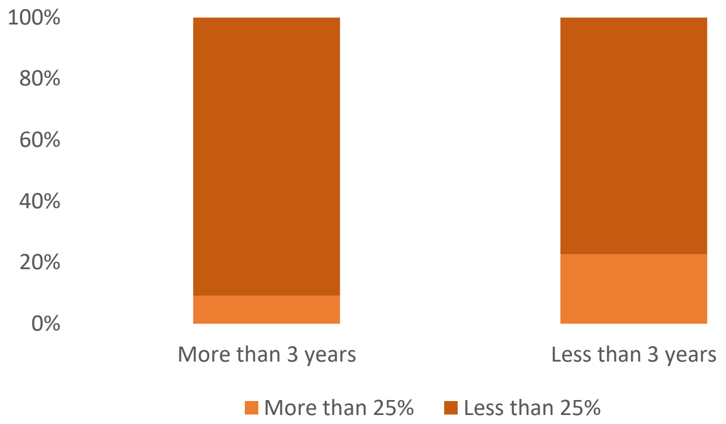
Appendix Figure 117 Shift in Probability of Atelectasis and Years Qualified

Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in ten cases (30.3%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 20 cases (45.5%). See Appendix Figure 118. Years qualified was found to be non-significant ($OR_{>3:<3}$=1.92, p=0.180).



Appendix Figure 118 Shift in Probability of Pleural Fluid and Years Qualified

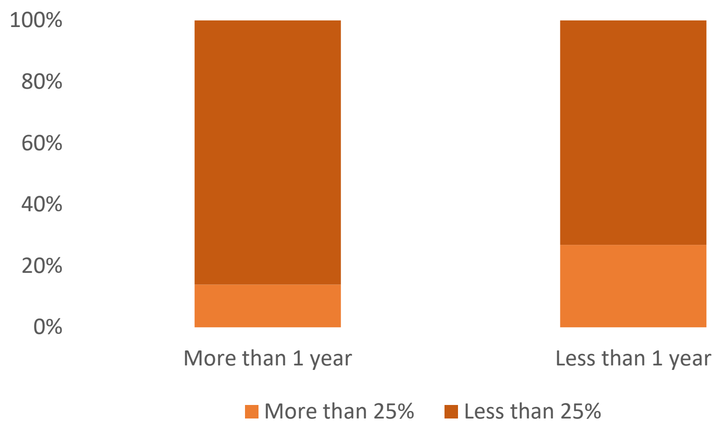
Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in three cases (9.1%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in ten cases (22.7%). See Appendix Figure 119. Years qualified was found to be non-significant ($OR_{>3:<3}$=2.94, p=0.126).



Appendix Figure 119 Shift in Probability of Pneumothorax and Years Qualified

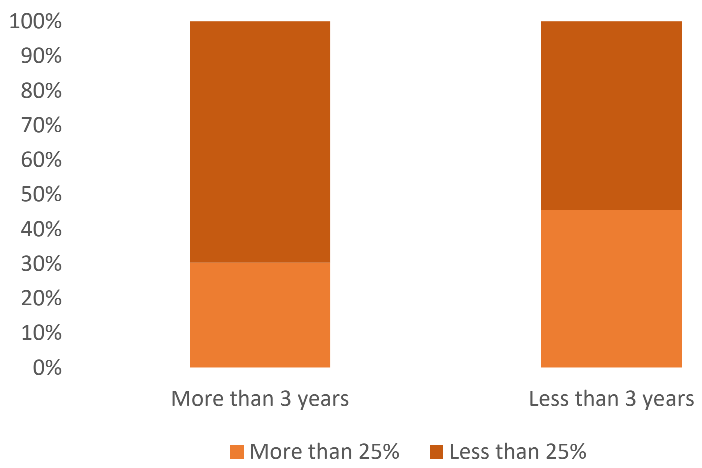
2.3.6 Effects of Years Experience with the Cardiac Population

Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in five cases (13.9%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in 11 cases (26.8%). See Appendix Figure 120. Years experience with cardiac surgery patients was found to be non-significant ($OR_{>1:<1}$=2.27, p=0.169).



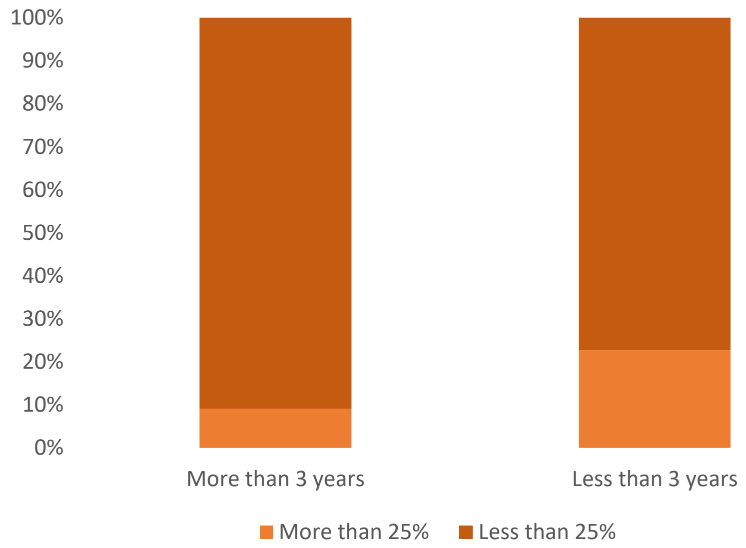
Appendix Figure 120 Shift in Probability of Atelectasis and Experience with Cardiac Surgery Patients

Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 13 cases (36.1%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 17 cases (41.5%). See Appendix Figure 121. Years experience with cardiac surgery patients was found to be non-significant ($OR_{>1:<1}$=1.25, p=0.631).



Appendix Figure 121 Shift in Probability of Pleural Fluid and Experience with Cardiac Surgery Patients

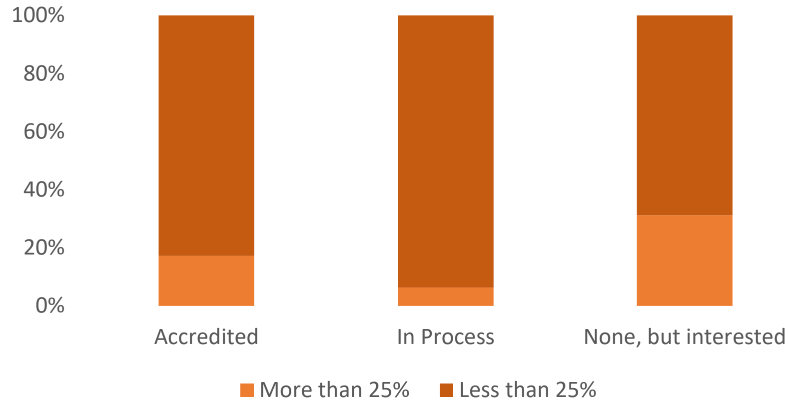
Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in seven cases (19.4%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in six cases (14.6%). See Appendix Figure 122. Years experience with cardiac surgery patients was found to be non-significant ($OR_{>1:<1}$=0.71, p=0.575).



Appendix Figure 122 Shift in Probability of Pneumothorax and Experience with Cardiac Surgery Patients

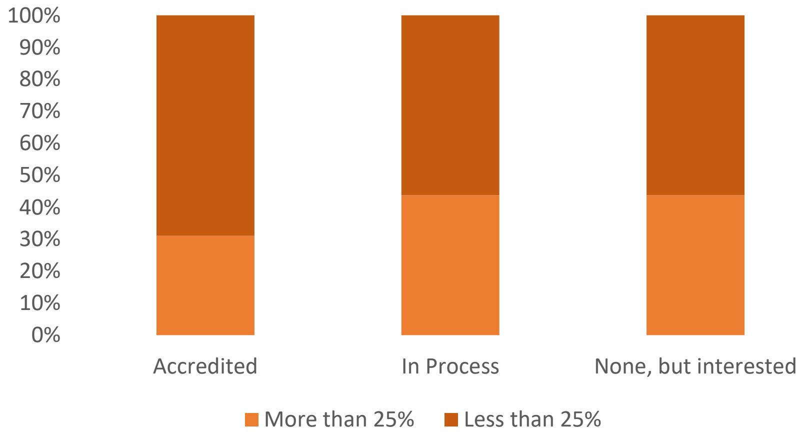
2.3.7 Effects of Lung Ultrasound Experience

Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in five cases (17.2%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in one case (6.3%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in ten cases (31.3%). See Appendix Figure 123. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=0.32, p=0.319; $OR_{accredited:none}$=2.18, p=0.210).



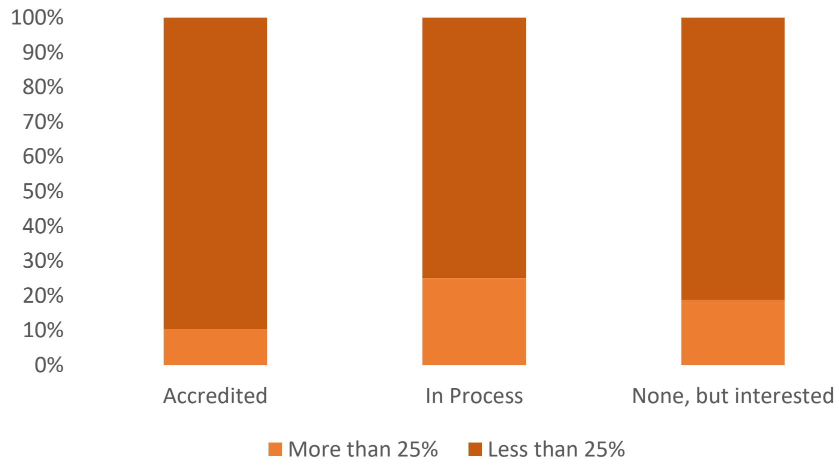
Appendix Figure 123 Shift in Probability of Atelectasis and LUS Experience

Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in nine cases (31%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in seven cases (43.8%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 14 cases (43.8%). See Appendix Figure 124. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=1.73, p=0.396; $OR_{accredited:none}$=1.73, p=0.308).



Appendix Figure 124 Shift in Probability of Pleural Fluid and LUS Experience

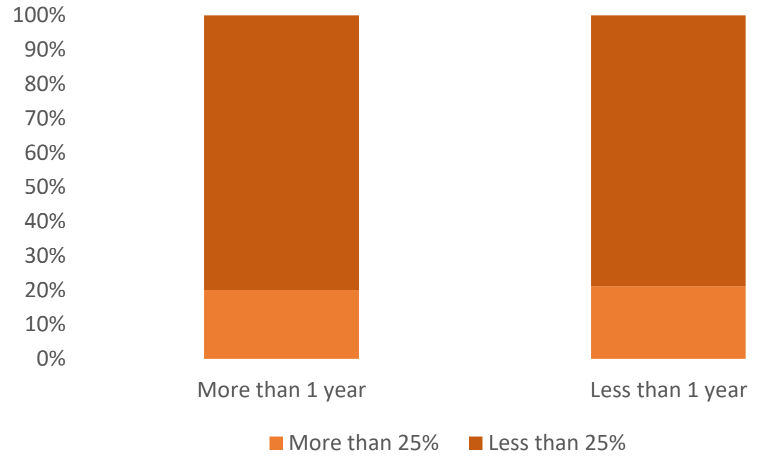
Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in three cases (10.3%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in four cases (25%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in six cases (18.8%). See Appendix Figure 125. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=2.89, p=0.206; $OR_{accredited:none}$=2.00, p=0.361).



Appendix Figure 125 Shift in Probability of Pneumothorax and LUS Experience

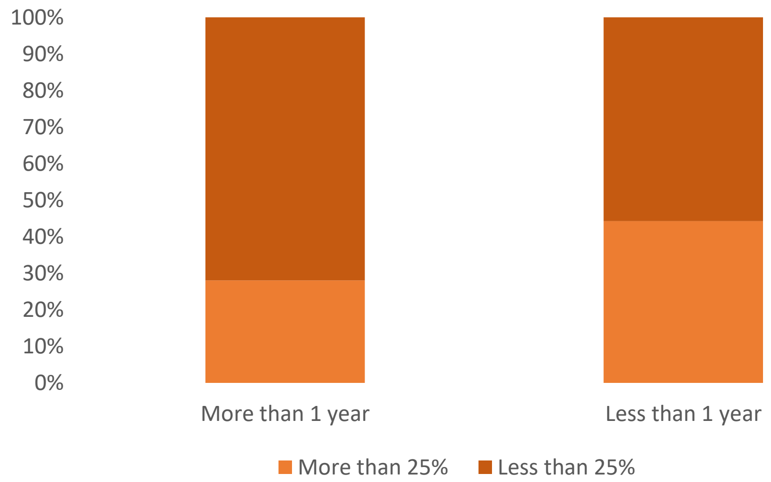
2.3.8 Effects of Years Accredited in Lung Ultrasound

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in five cases (20%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's perceived probability of atelectasis shifted by more than 25% following LUS in 11 cases (21.2%). See Appendix Figure 126. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=1.07, p=0.907).



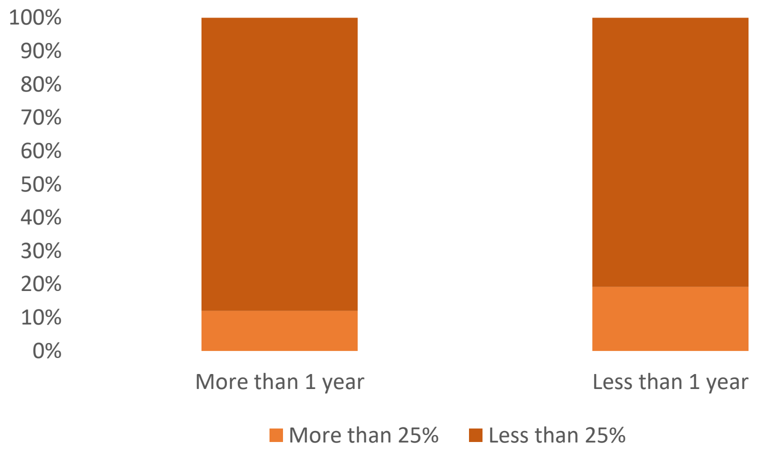
Appendix Figure 126 Shift in Probability of Atelectasis and Years Accredited in LUS

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in seven cases (28%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's perceived probability of pleural fluid shifted by more than 25% following LUS in 23 cases (44.2%). See Appendix Figure 127. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=2.04, p=0.175).



Appendix Figure 127 Shift in Probability of Pleural Fluid and Years Accredited in LUS

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in three cases (12%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's perceived probability of pneumothorax shifted by more than 25% following LUS in ten cases (19.2%). See Appendix Figure 128. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=1.75, p=0.432).

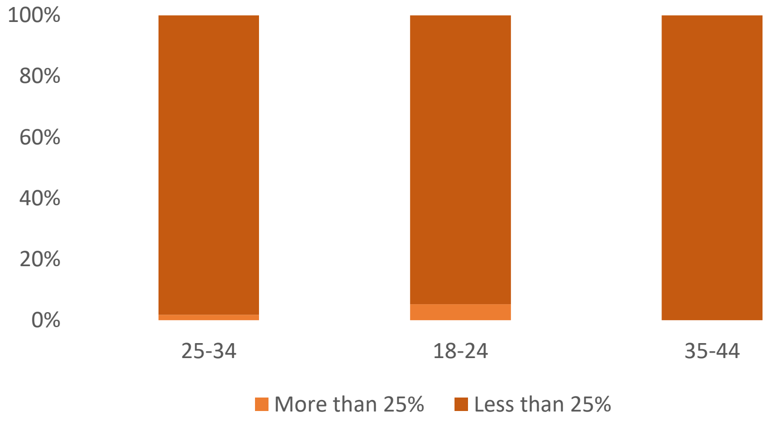


Appendix Figure 128 Shift in Probability of Pneumothorax and Years Accredited in LUS

2.4 Change in Uncertainty

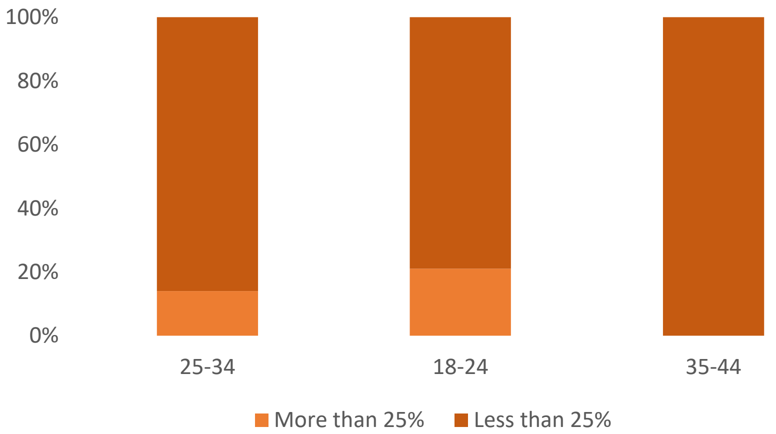
2.4.1 Effects of Age

Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in one case (1.8%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in one case (5.3%). See Appendix Figure 129. Age was found to be non-significant ($OR_{25-34:18-24}$=3.11, p=0.431).



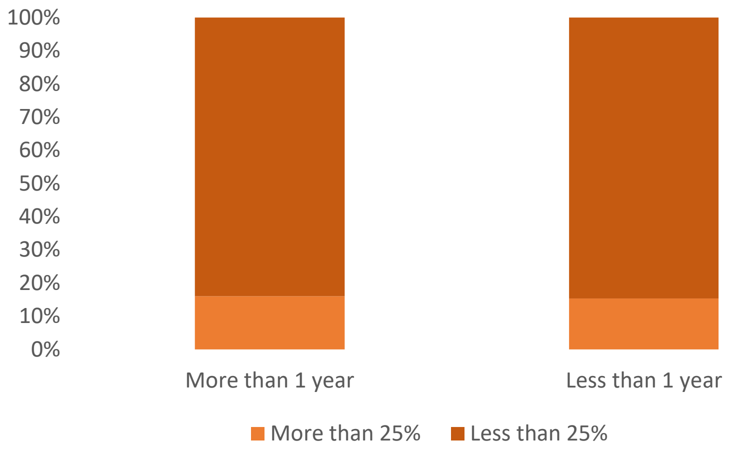
Appendix Figure 129 Change in Uncertainty of Atelectasis and Physiotherapist Age

Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in eight cases (14%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in four cases (21.1%). See Appendix Figure 130. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}$=1.63, p=0.470).



Appendix Figure 130 Change in Uncertainty of Pleural Fluid and Physiotherapist Age

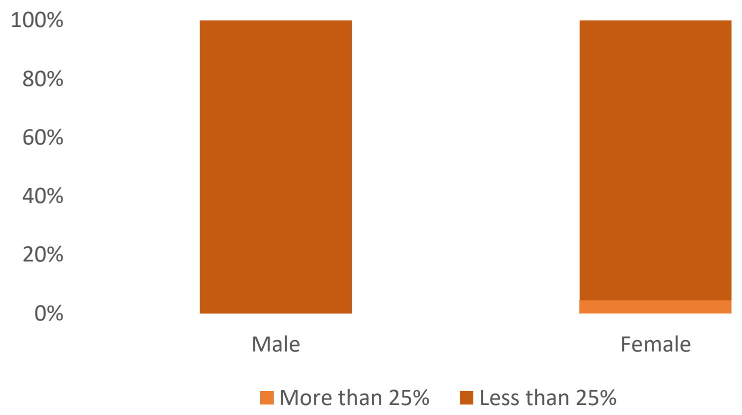
Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in two cases (3.5%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in none of the cases (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 131.



Appendix Figure 131 Change in Uncertainty of Pneumothorax and Physiotherapist Age

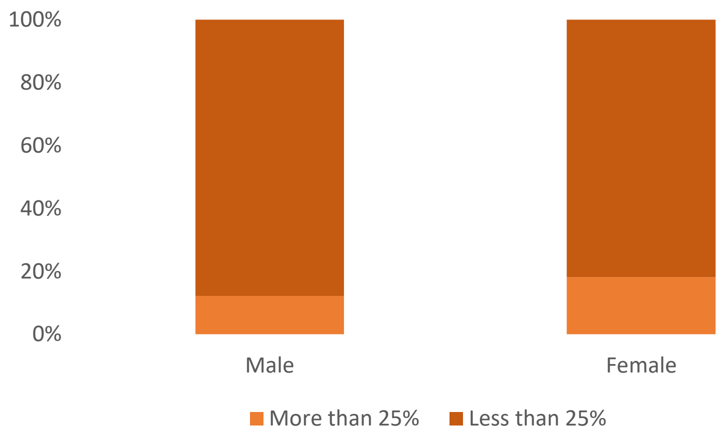
2.4.2 Effects of Sex

Out of the 33 cases where the physiotherapist was male, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in two cases (4.5%). No regression analysis was done in this category due to low variability. See Appendix Figure 132.



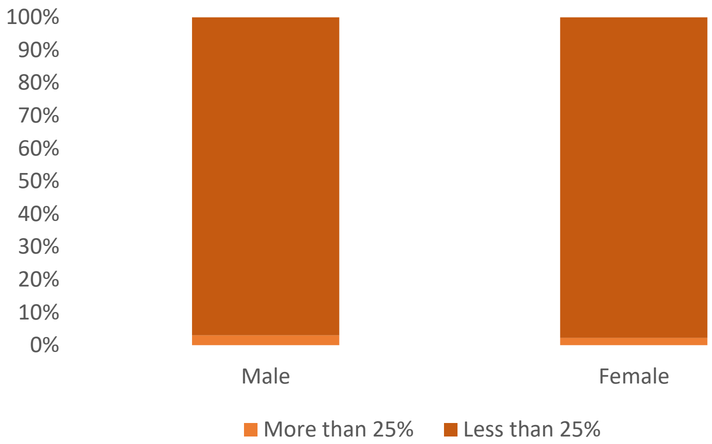
Appendix Figure 132 Change in Uncertainty of Atelectasis and Physiotherapist Sex

Out of the 33 cases where the physiotherapist was male, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in four cases (12.1%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in eight cases (18.2%). See Appendix Figure 133. Sex was found to be non-significant ($OR_{male:female}$=1.61, p=0.471).



Appendix Figure 133 Change in Uncertainty of Pleural Fluid and Physiotherapist Sex

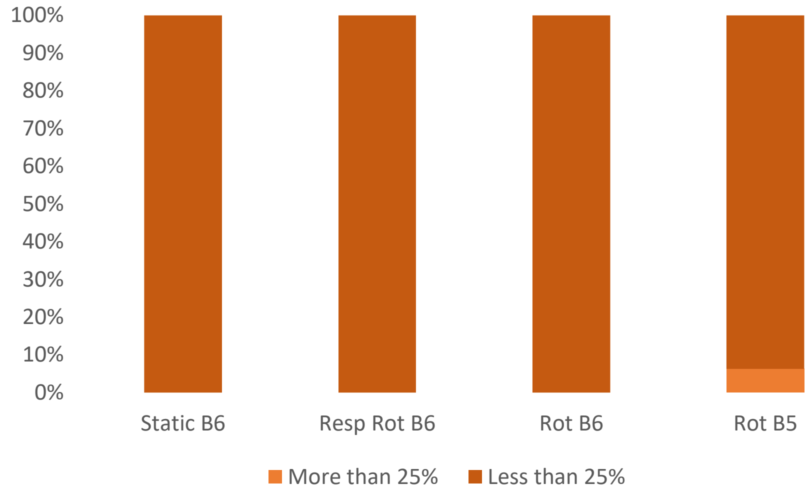
Out of the 33 cases where the physiotherapist was male, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (3%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (2.3%). See Appendix Figure 134. Sex was found to be non-significant ($OR_{male:female}$=0.74, p=0.837).



Appendix Figure 134 Change in Uncertainty of Pneumothorax and Physiotherapist Sex

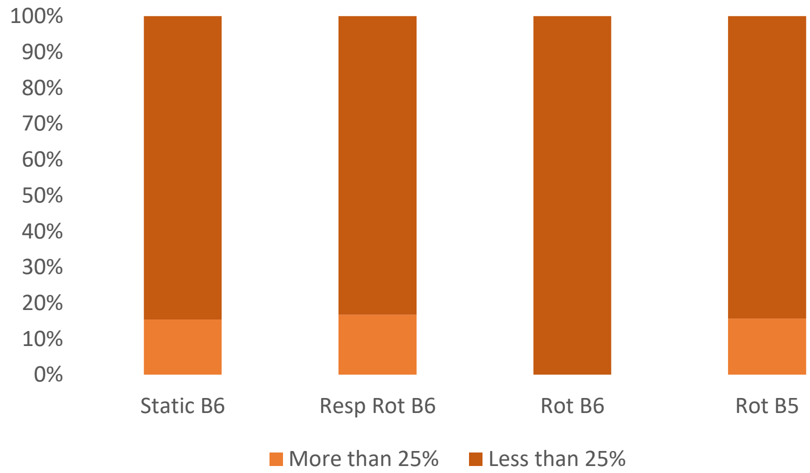
2.4.3 Effects of Job Post

Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in two cases (6.3%). No regression analysis was done in this category due to low variability. See Appendix Figure 135.



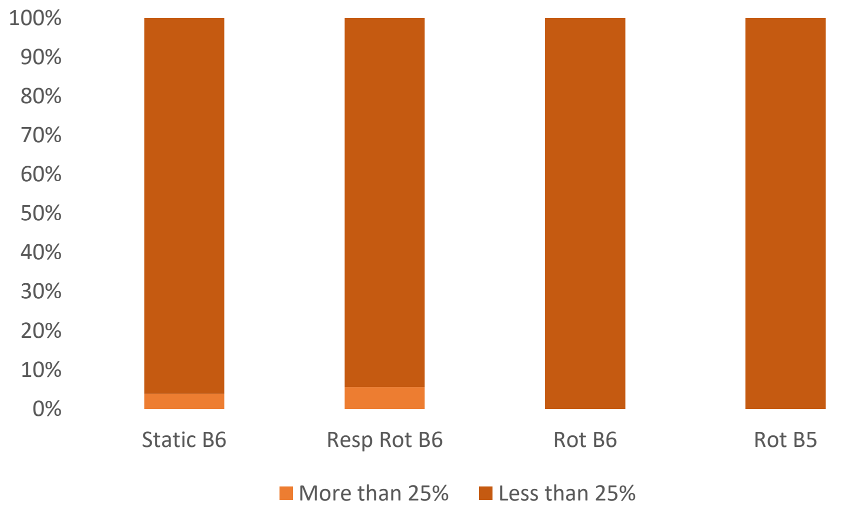
Appendix Figure 135 Change in Uncertainty of Atelectasis and Job Post

Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in four cases (15.4%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in three cases (16.7%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in five cases (15.6%). See Appendix Figure 136. Band was found to be non-significant ($OR_{SB6:RRB6}$=1.10, p=0.909; $OR_{SB6:RB5}$=1.02, p=0.980).



Appendix Figure 136 Change in Uncertainty of Pleural Fluid and Job Post

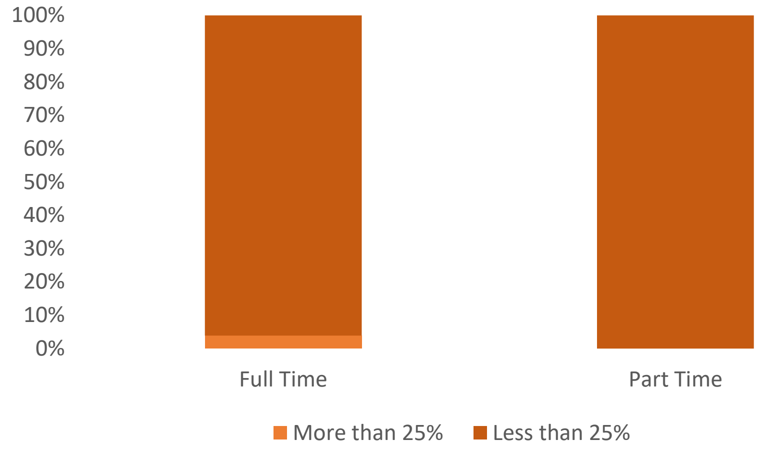
Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (3.8%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (5.6%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in none of the cases (0%), therefore no regression analysis was done on this category. See Appendix Figure 137. Band was found to be non-significant ($OR_{SB6:RRB6}$=1.47, p=0.790).



Appendix Figure 137 Change in Uncertainty of Pneumothorax and Job Post

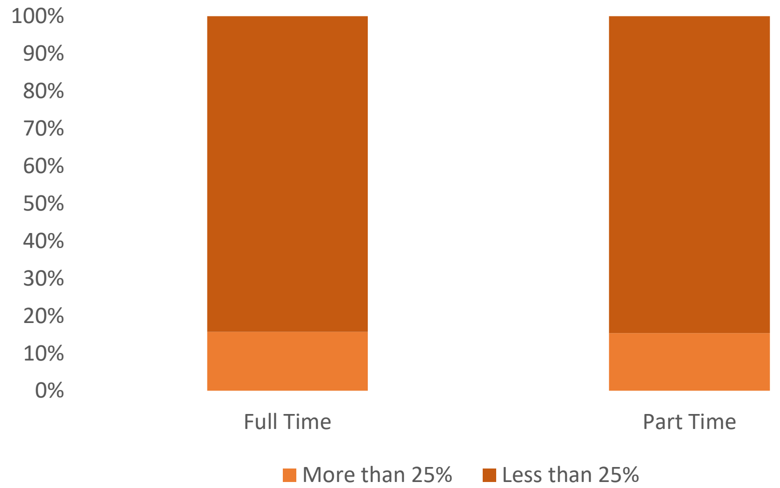
2.4.4 Effects of Contract

Out of the 51 cases where the physiotherapist was full-time, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in two cases (3.9%); Out of the 26 cases where the physiotherapist was part-time, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 138.



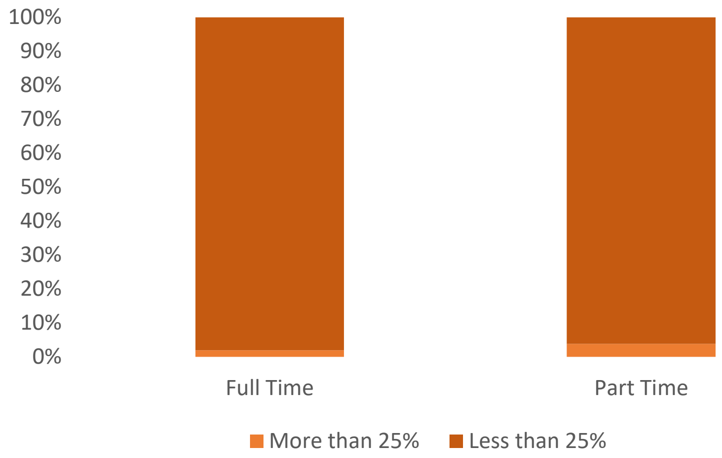
Appendix Figure 138 Change in Uncertainty of Atelectasis and Contract

Out of the 51 cases where the physiotherapist was full-time, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in eight cases (15.7%); Out of the 26 cases where the physiotherapist was part-time, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in four cases (15.4%). See Appendix Figure 139. Contract was found to be non-significant ($OR_{FT:PT}$=0.98, p=0.972).



Appendix Figure 139 Change in Uncertainty of Pleural Fluid and Contract

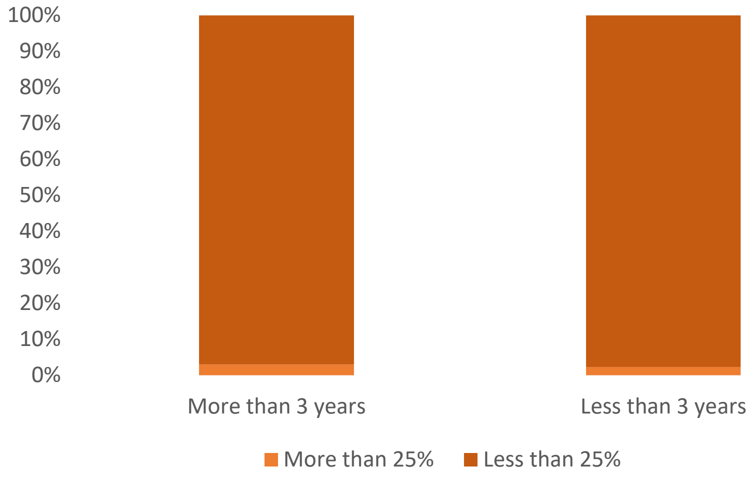
Out of the 51 cases where the physiotherapist was full time, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (2%); Out of the 26 cases where the physiotherapist was part time, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (3.8%). See Appendix Figure 140. Contract was found to be non-significant ($OR_{FT:PT}$=2.00, p=0.629).



Appendix Figure 140 Change in Uncertainty of Pneumothorax and Contract

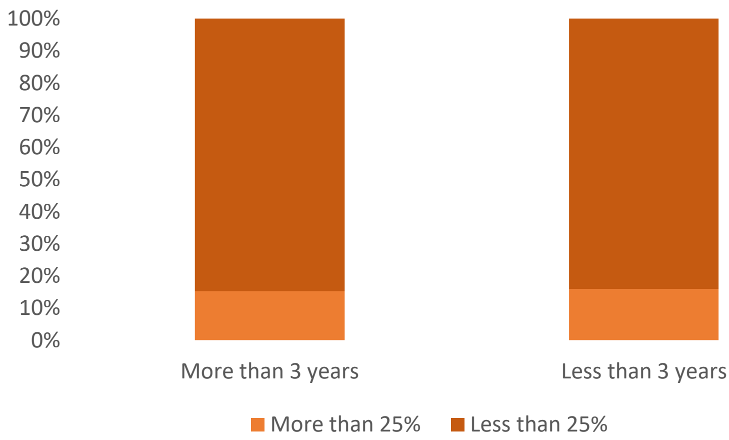
2.4.5 Effects of Years Qualified

Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in one case (3%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in one case (2.3%). See Appendix Figure 141. Years qualified was found to be non-significant ($OR_{>3:<3}$=0.74, p=0.837).



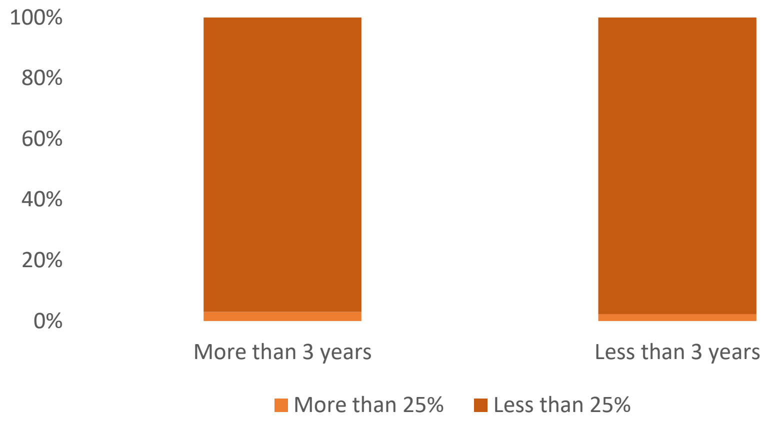
Appendix Figure 141 Change in Uncertainty of Atelectasis and Years Qualified

Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in five cases (15.2%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in seven cases (15.9%). See Appendix Figure 142. Years qualified was found to be non-significant ($OR_{>3:<3}$=1.06, p=0.928).



Appendix Figure 142 Change in Uncertainty of Pleural Fluid and Years Qualified

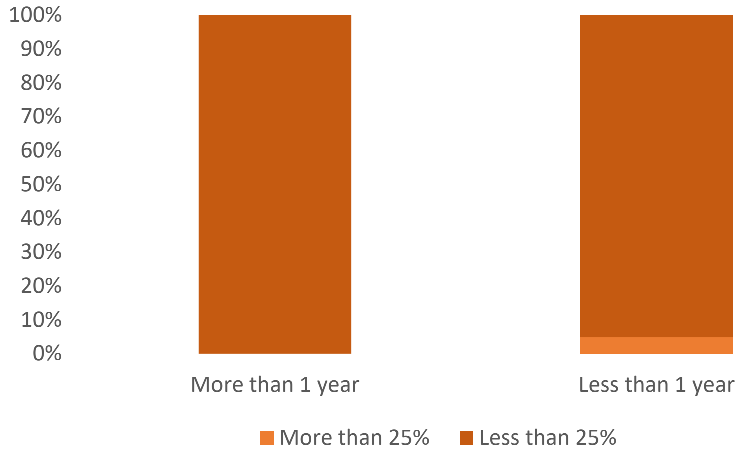
Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (3%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (2.3%). See Appendix Figure 143. Years qualified was found to be non-significant ($OR_{>3:<3}$=0.74, p=0.837).



Appendix Figure 143 Change in Uncertainty of Pneumothorax and Years Qualified

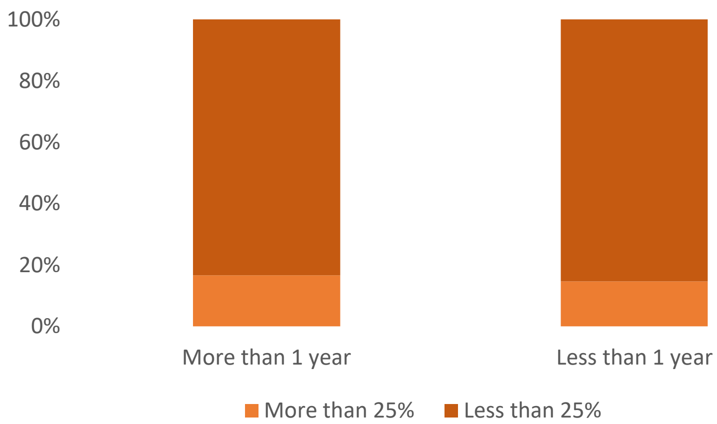
2.4.6 Effects of Years Experience with the Cardiac Population

Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in two cases (4.9%). No regression analysis was done in this category due to low variability. See Appendix Figure 144.



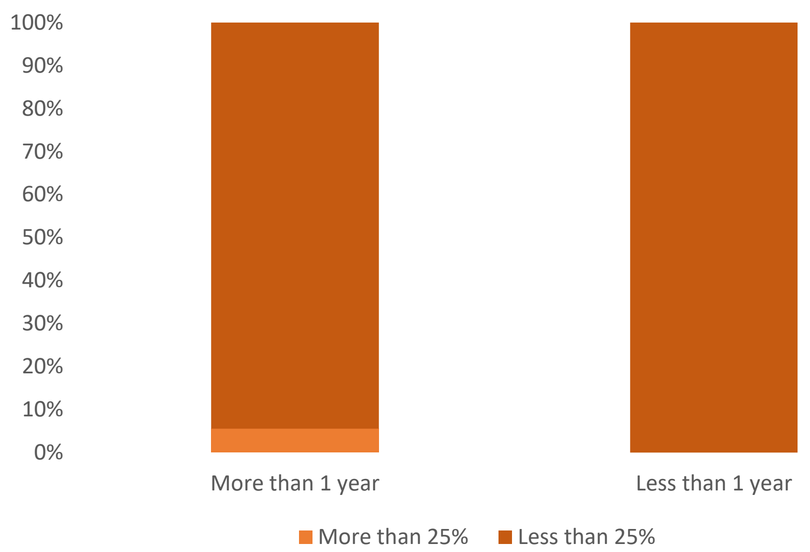
Appendix Figure 144 Change in Uncertainty of Atelectasis and Experience with Cardiac Surgery Patients

Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in six cases (16.7%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in six cases (14.6%). See Appendix Figure 145. Years experience with cardiac surgery patients was found to be non-significant ($OR_{>1:<1}$=0.86, p=0.806).



Appendix Figure 145 Change in Uncertainty of Pleural Fluid and Experience with Cardiac Surgery Patients

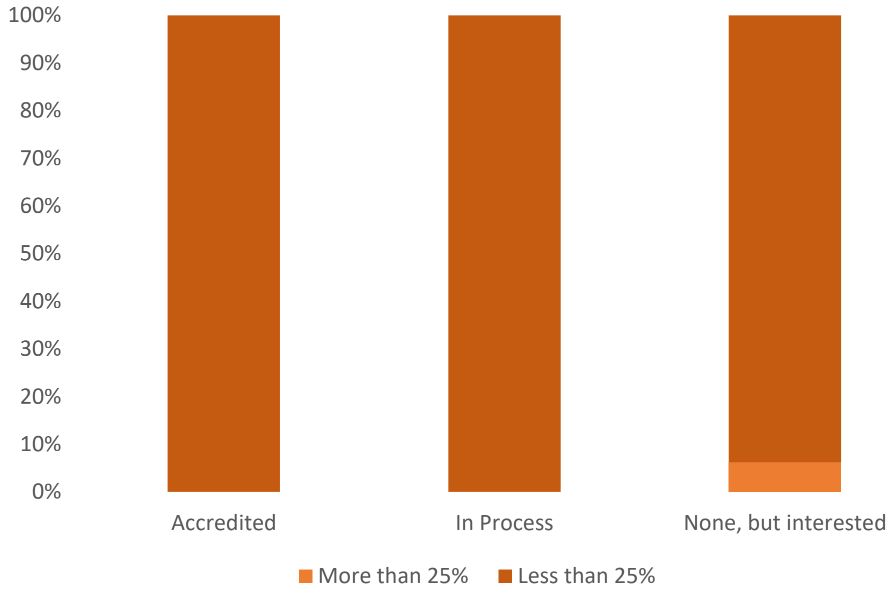
Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in two cases (5.6%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in none of the cases (0%). No regression analysis was done in this category due to low variability. See Appendix Figure 146.



Appendix Figure 146 Change in Uncertainty of Pneumothorax and Experience with Cardiac Surgery Patients

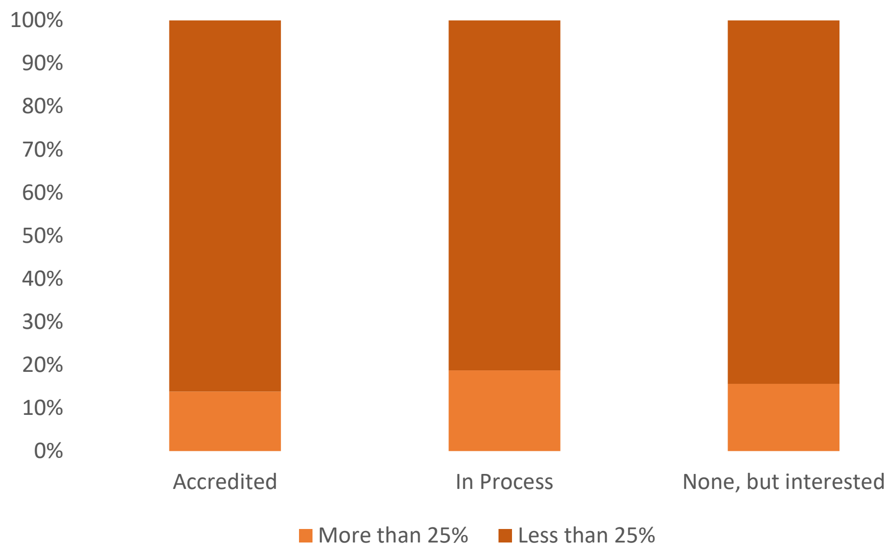
2.4.7 Effects of Lung Ultrasound Experience

Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in two cases (6.3%). No regression analysis was done in this category due to low variability. See Appendix Figure 147.



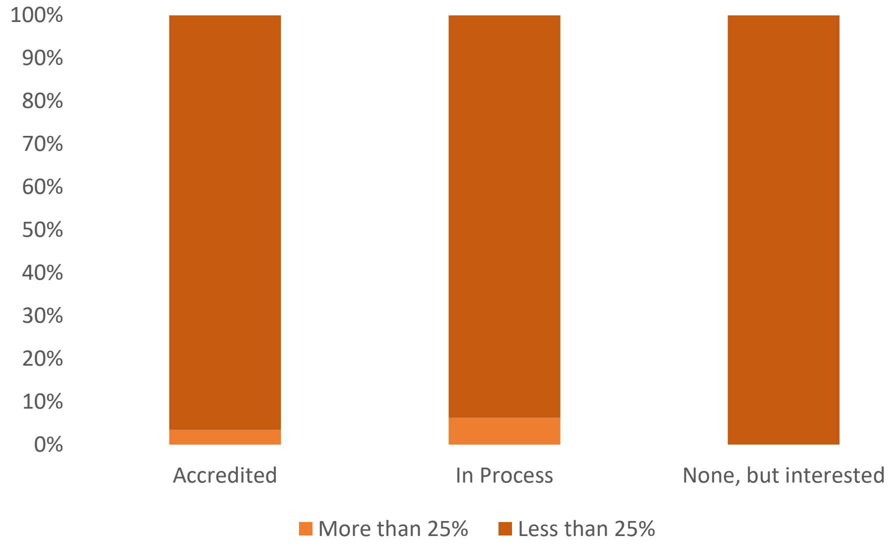
Appendix Figure 147 Change in Uncertainty of Atelectasis and LUS Experience

Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in four cases (13.8%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in three cases (18.8%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in five cases (15.6%). See Appendix Figure 148. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=1.44, p=0.662; $OR_{accredited:none}$=1.16, p=0.840).



Appendix Figure 148 Change in Uncertainty of Pleural Fluid and LUS Experience

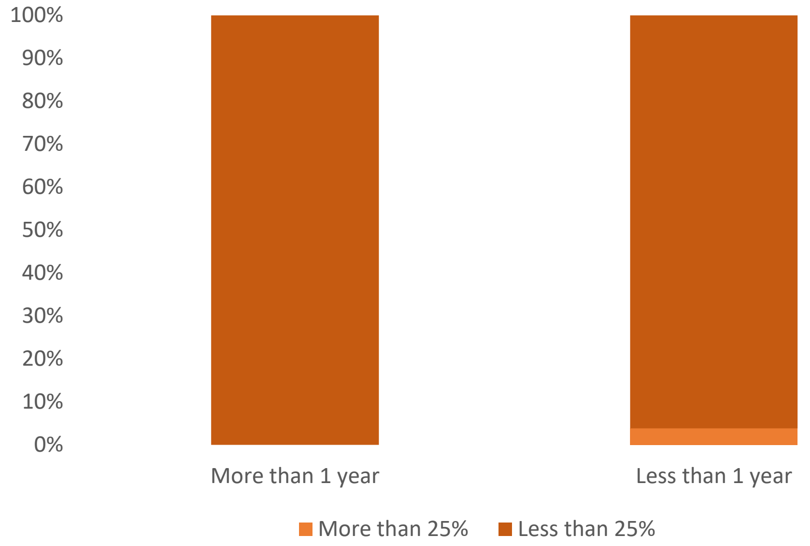
Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (3.4%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (6.3%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in none of the cases (0%). See Appendix Figure 149. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=1.87, p=0.667).



Appendix Figure 149 Change in Uncertainty of Pneumothorax and LUS Experience

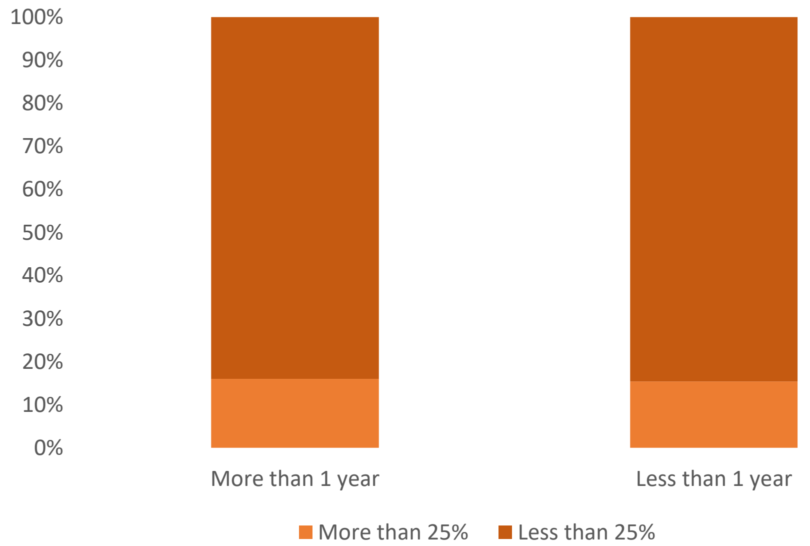
2.4.8 Effects of Years Accredited in Lung Ultrasound

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in none of the cases (0%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's uncertainty in atelectasis reduced by more than 25% following LUS in two cases (3.8%). No regression analysis was done in this category due to low variability. See Appendix Figure 150.



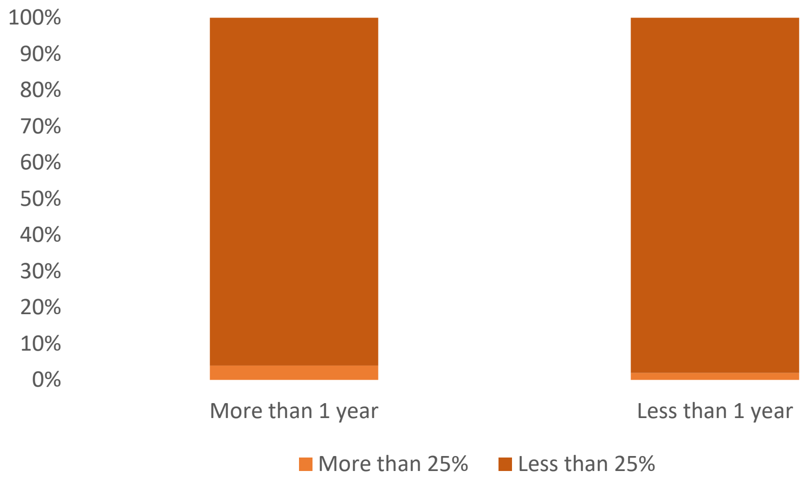
Appendix Figure 150 Change in Uncertainty of Atelectasis and Years Accredited in LUS

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in four cases (16%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's uncertainty in pleural fluid reduced by more than 25% following LUS in eight cases (15.4%). See Appendix Figure 151. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=0.96, p=0.944).



Appendix Figure 151 Change in Uncertainty of Pleural Fluid and Years Accredited in LUS

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (4%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's uncertainty in pneumothorax reduced by more than 25% following LUS in one case (1.9%). See Appendix Figure 152. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=0.47, p=0.600).

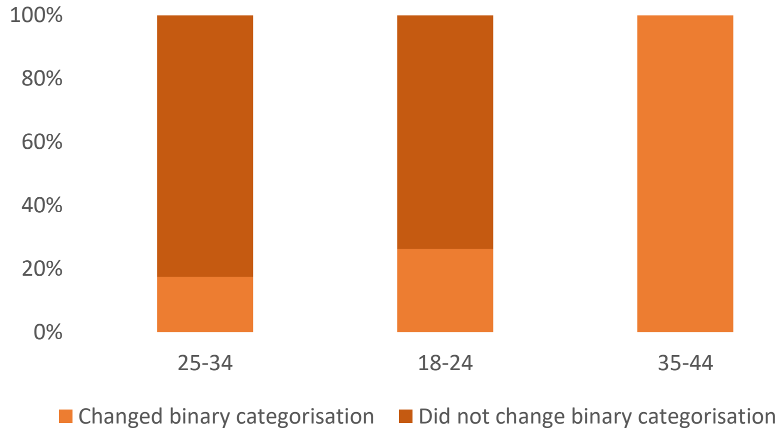


Appendix Figure 152 Change in Uncertainty of Pneumothorax and Years Accredited in LUS

2.5 Change in Overall Identification

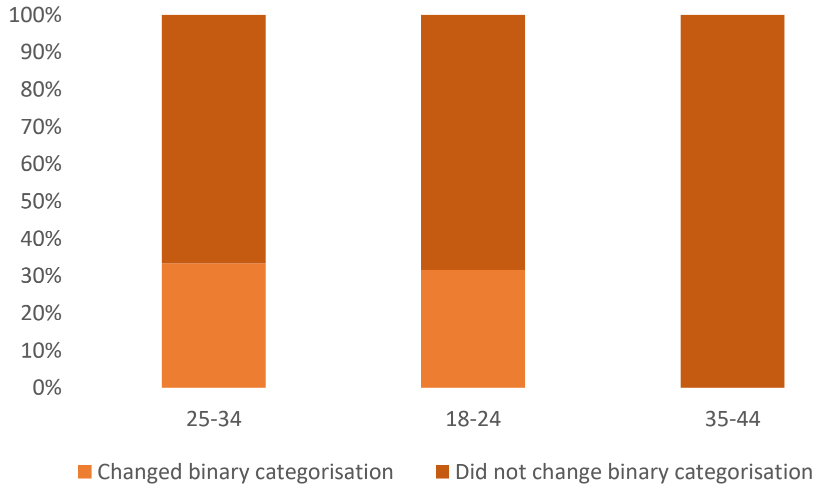
2.5.1 Effects of Age

Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in ten cases (17.5%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in five cases (26.3%). See Appendix Figure 153. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}$=1.68, p=0.409).



Appendix Figure 153 Re-categorisation of Atelectasis and Physiotherapist Age

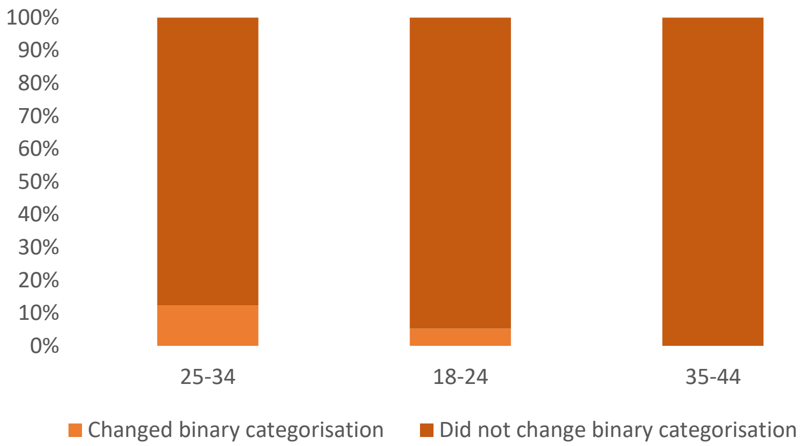
Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 19 cases (33.3%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in six cases (31.6%). See Appendix Figure 154. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}$=0.92, p=0.888).



Appendix Figure 154 Re-categorisation of Pleural Fluid and Physiotherapist Age

Out of the 57 cases where the physiotherapist was between 25 and 34 years of age, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following

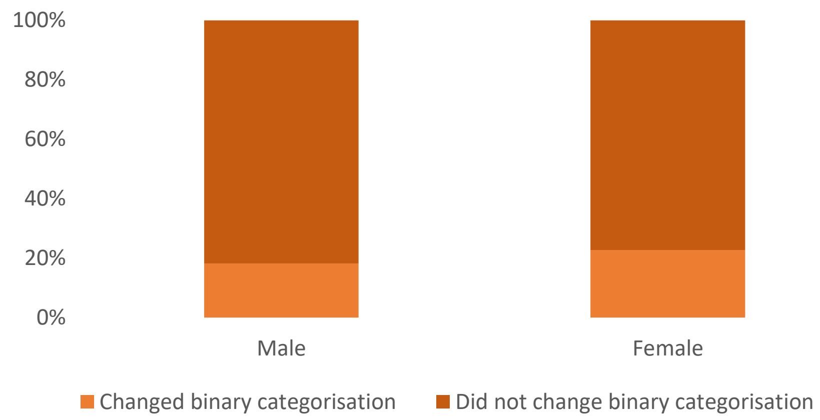
LUS in seven cases (12.3%); Out of the 19 cases where the physiotherapist was between 18 and 24 years of age, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in one case (5.3%). See Appendix Figure 155. Age was found to be non-significant ($OR_{25\text{-}34:18\text{-}24}$=0.40, p=0.402).



Appendix Figure 155 Re-categorisation of Pneumothorax and Physiotherapist Age

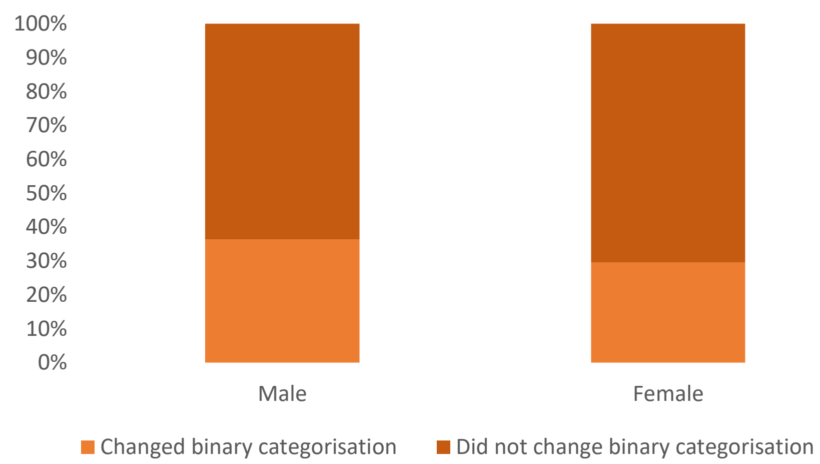
2.5.2 Effects of Sex

Out of the 33 cases where the physiotherapist was male, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in six cases (18.2%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in ten cases (22.7%). See Appendix Figure 156. Sex was found to be non-significant ($OR_{male:female}$=1.32, p=0.627).



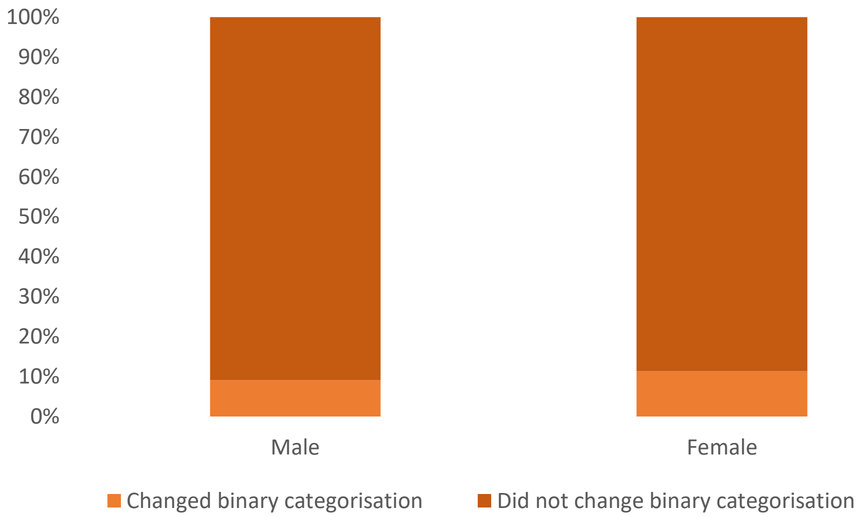
Appendix Figure 156 Re-categorisation of Atelectasis and Physiotherapist Sex

Out of the 33 cases where the physiotherapist was male, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 12 cases (36.4%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 13 cases (29.5%). See Appendix Figure 157. Sex was found to be non-significant ($OR_{male:female}$=0.73, p=0.528).



Appendix Figure 157 Re-categorisation of Pleural Fluid and Physiotherapist Sex

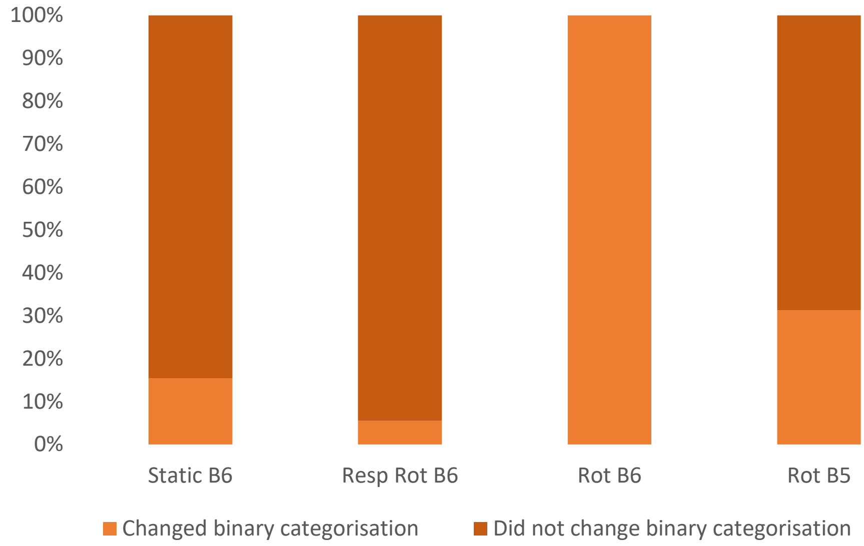
Out of the 33 cases where the physiotherapist was male, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in three cases (9.1%); Out of the 44 cases where the physiotherapist was female, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in five cases (11.4%). See Appendix Figure 158. Sex was found to be non-significant ($OR_{male:female}$=1.28, p=0.747).



Appendix Figure 158 Re-categorisation of Pneumothorax and Physiotherapist Sex

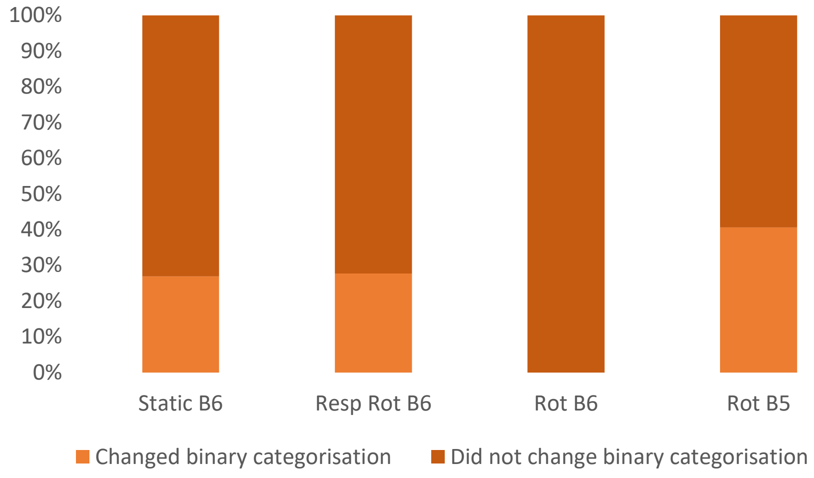
2.5.3 Effects of Band

Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in four cases (15.4%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in one case (5.6%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in ten cases (31.3%). See Appendix Figure 159. Band was found to be non-significant ($OR_{SB6:RRB6}$=0.32, p=0.332; $OR_{SB6:RB5}$=2.50, p=0.168).



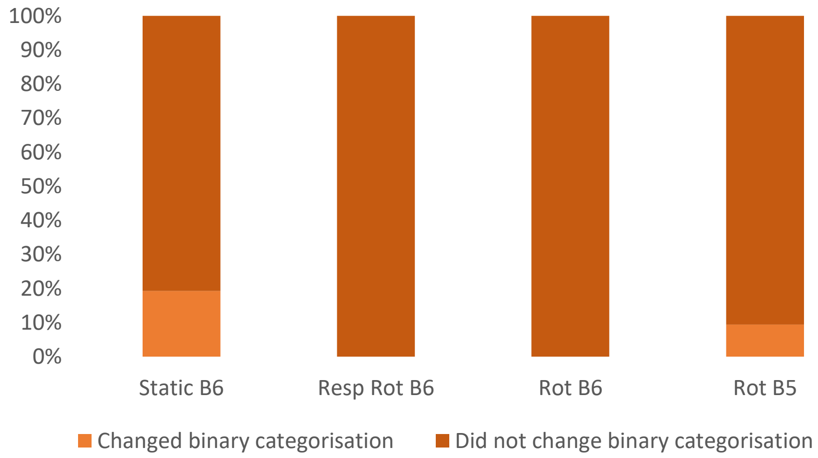
Appendix Figure 159 Re-categorisation of Atelectasis and Job Post

Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in seven cases (26.9%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in five cases (27.8%); Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 13 cases (40.6%). See Appendix Figure 160. Band was found to be non-significant ($OR_{SB6:RRB6}$=1.04, p=0.950; $OR_{SB6:RB5}$=1.86, p=0.278).



Appendix Figure 160 Re-categorisation of Pleural Fluid and Job Post

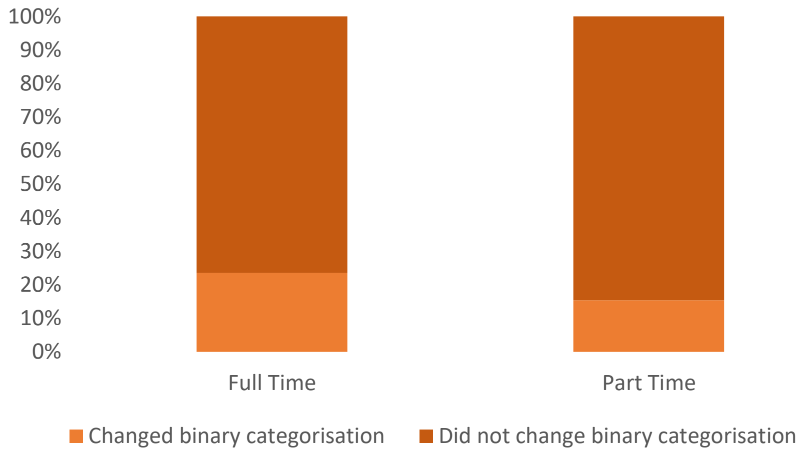
Out of the 26 cases where the physiotherapist was a static band six, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in five cases (19.2%); Out of the 18 cases where the physiotherapist was a respiratory rotational band six, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in none of the cases (0%), therefore no regression analysis was done on this category; Out of the 32 cases where the physiotherapist was a rotational band five, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in three cases (9.4%). See Appendix Figure 161. Band was found to be non-significant ($OR_{SB6:RB5}$=0.43, p=0.288).



Appendix Figure 161 Re-categorisation of Pneumothorax and Job Post

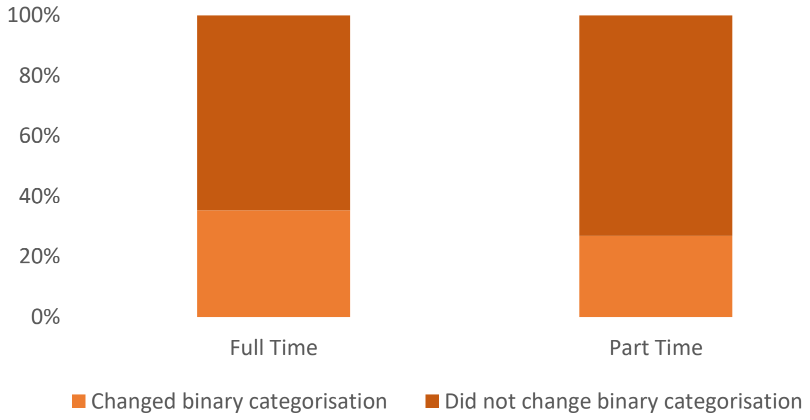
2.5.4 Effects of Contract

Out of the 51 cases where the physiotherapist was full-time, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in 12 cases (23.5%); Out of the 26 cases where the physiotherapist was part-time, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in four cases (15.4%). See Appendix Figure 162. Contract was found to be non-significant ($OR_{FT:PT}$=0.59, p=0.408).



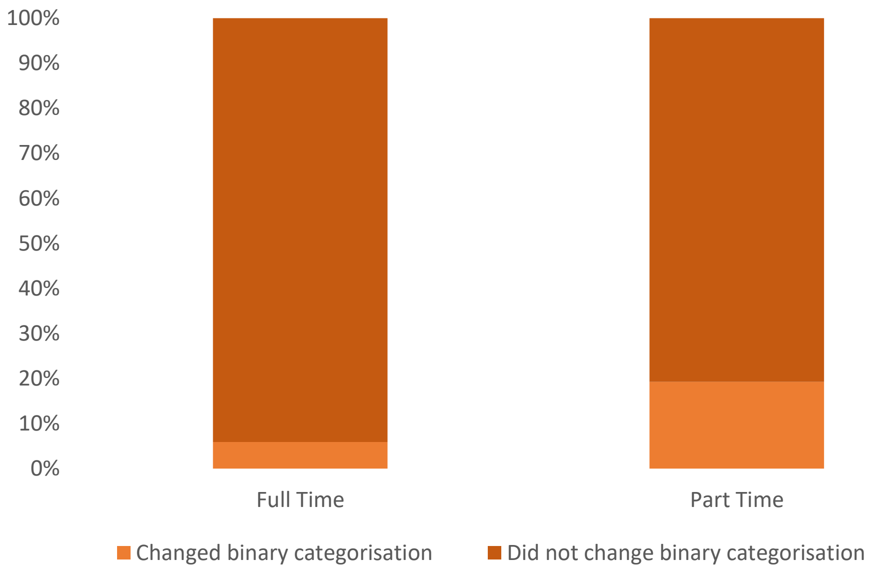
Appendix Figure 162 Re-categorisation of Atelectasis and Contract

Out of the 51 cases where the physiotherapist was full-time, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 18 cases (35.3%); Out of the 26 cases where the physiotherapist was part-time, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in seven cases (26.9%). See Appendix Figure 163. Contract was found to be non-significant ($OR_{FT:PT}$=0.68, p=0.459).



Appendix Figure 163 Re-categorisation of Pleural Fluid and Contract

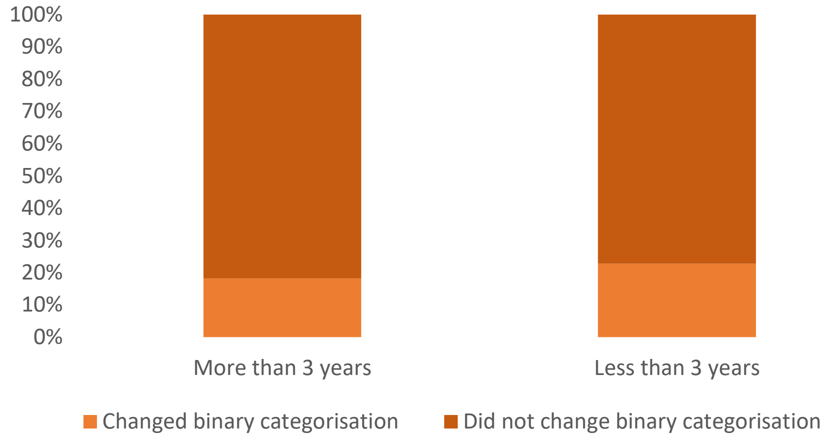
Out of the 51 cases where the physiotherapist was full time, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in three cases (5.9%); Out of the 26 cases where the physiotherapist was part time, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in five cases (19.2%). See Appendix Figure 164. Contract was found to be non-significant ($OR_{FT:PT}$=3.81, p=0.085).



Appendix Figure 164 Re-categorisation of Pneumothorax and Contract

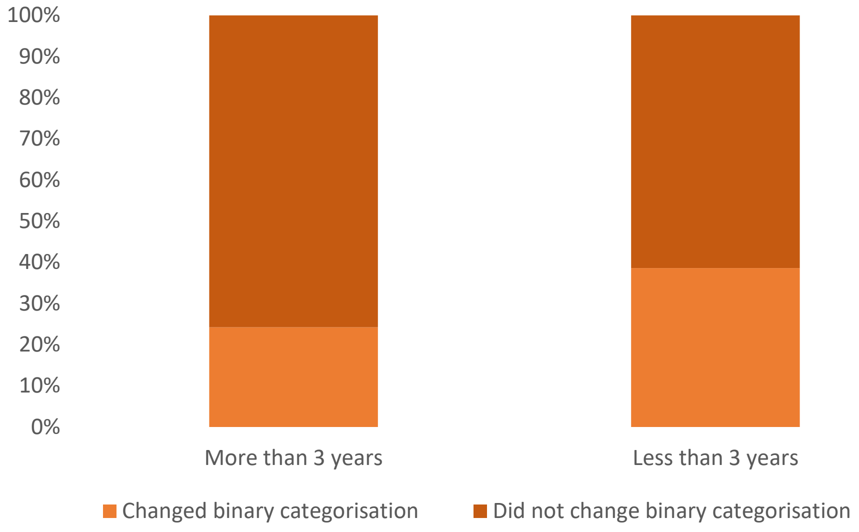
2.5.5 Effects of Years Qualified

Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in six cases (18.2%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in ten cases (22.7%). See Appendix Figure 165. Years qualified was found to be non-significant ($OR_{>3:<3}$=1.32, p=0.627).



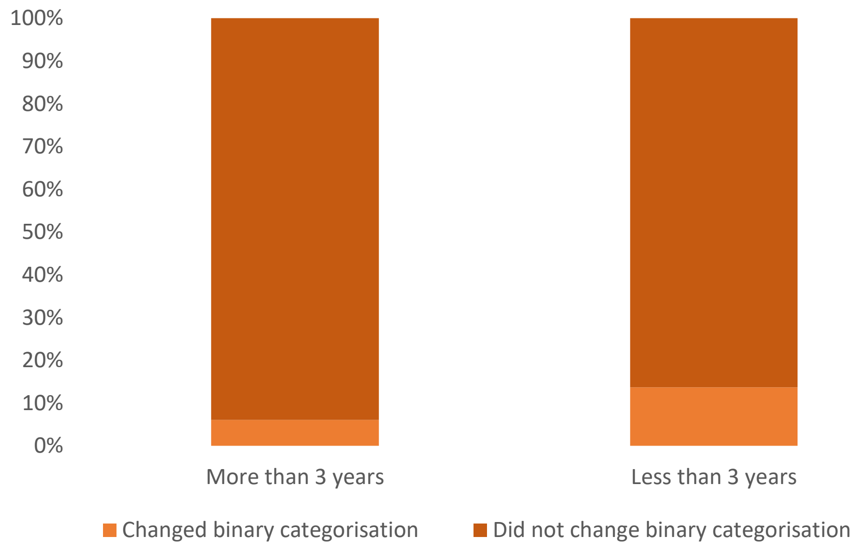
Appendix Figure 165 Re-categorisation of Atelectasis and Years Qualified

Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in eight cases (24.2%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 17 cases (38.6%). See Appendix Figure 166. Years qualified was found to be non-significant ($OR_{>3:<3}$=1.97, p=0.185).



Appendix Figure 166 Re-categorisation of Pleural Fluid and Years Qualified

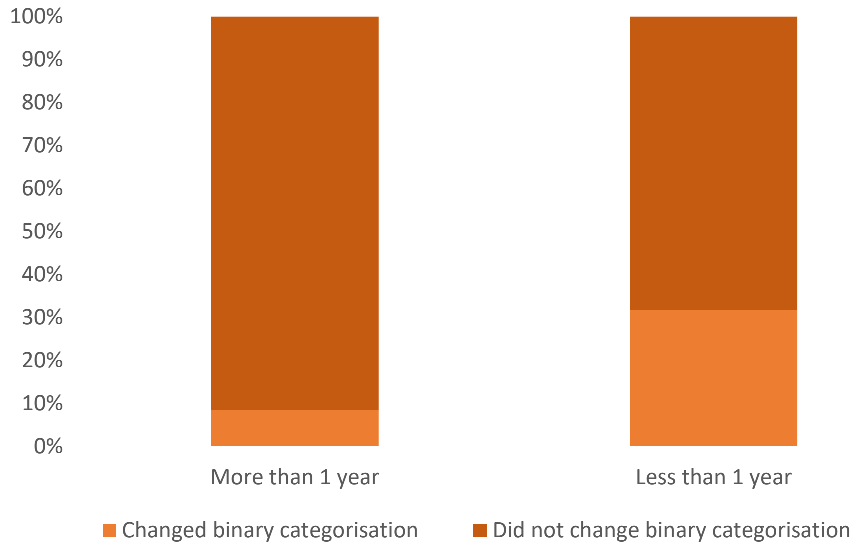
Out of the 33 cases where the physiotherapist had been qualified for more than three years, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in two cases (6.1%); Out of the 44 cases where the physiotherapist had been qualified for less than three years, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in six cases (13.6%). See Appendix Figure 167. Years qualified was found to be non-significant ($OR_{>3:<3}$=2.45, p=0.293).



Appendix Figure 167 Re-categorisation of Pneumothorax and Years Qualified

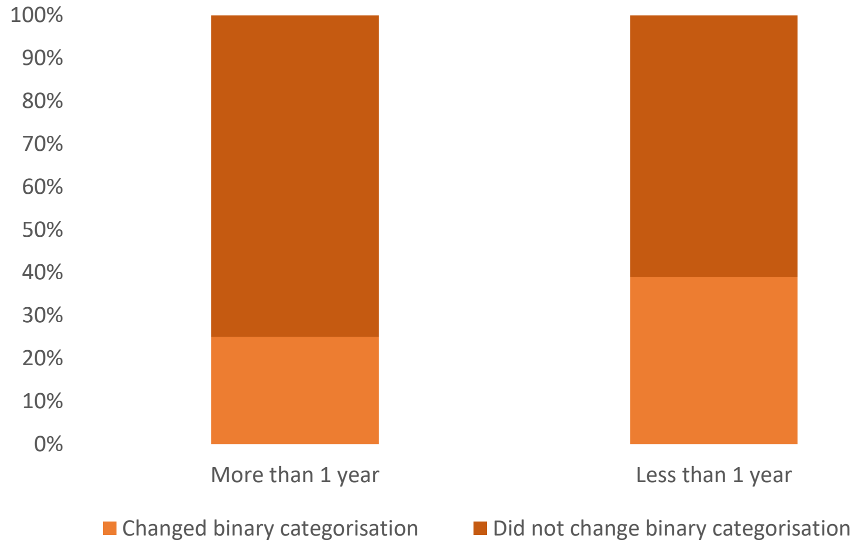
2.5.6 Effects of Years Experience with the Cardiac Population

Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in three cases (8.3%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in 13 cases (31.7%). See Appendix Figure 168. Years experience with cardiac surgery patients was found to be significant ($OR_{>1:<1}$=5.11, p=0.018).



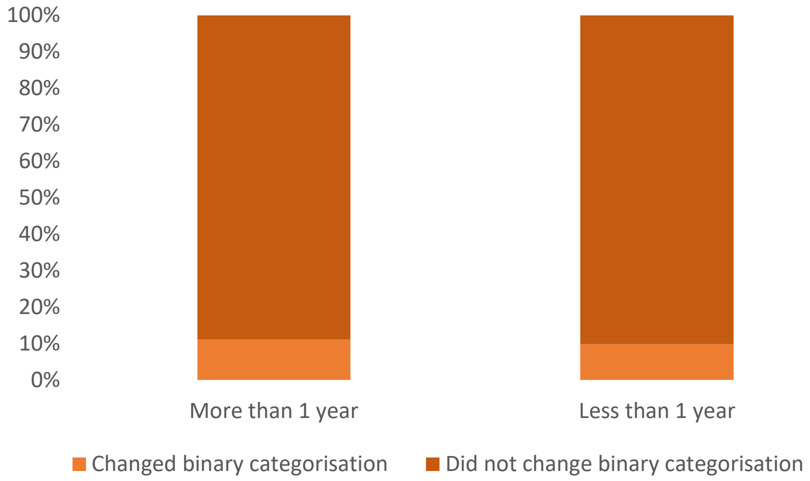
Appendix Figure 168 Re-categorisation of Atelectasis and Experience with Cardiac Surgery Patients

Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in nine cases (25%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 16 cases (39%). See Appendix Figure 169. Years experience with cardiac surgery patients was found to be non-significant ($OR_{>1:<1}$=1.92, p=0.193).



Appendix Figure 169 Re-categorisation of Pleural Fluid and Experience with Cardiac Surgery Patients

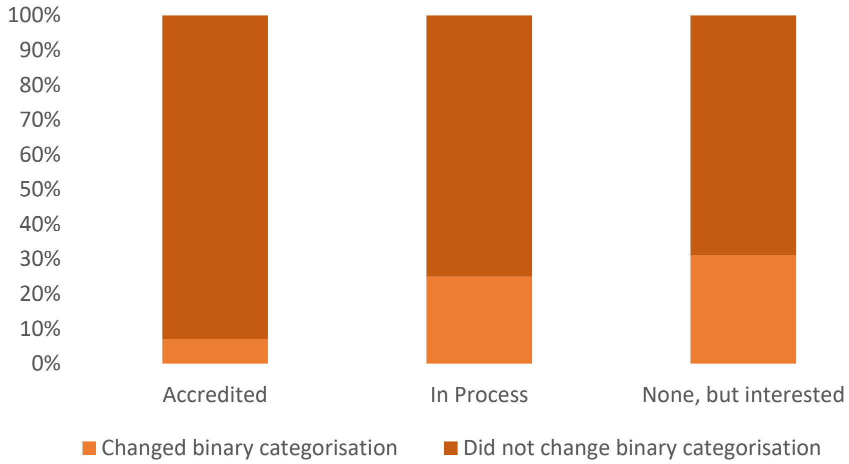
Out of the 36 cases where the physiotherapist had more than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in four cases (11.1%); Out of the 41 cases where the physiotherapist had less than one year experience with cardiac surgery patients, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in four cases (9.8%). See Appendix Figure 170. Years experience with cardiac surgery patients was found to be non-significant ($OR_{>1:<1}$=0.87, p=0.846).



Appendix Figure 170 Re-categorisation of Pneumothorax and Experience with Cardiac Surgery Patients

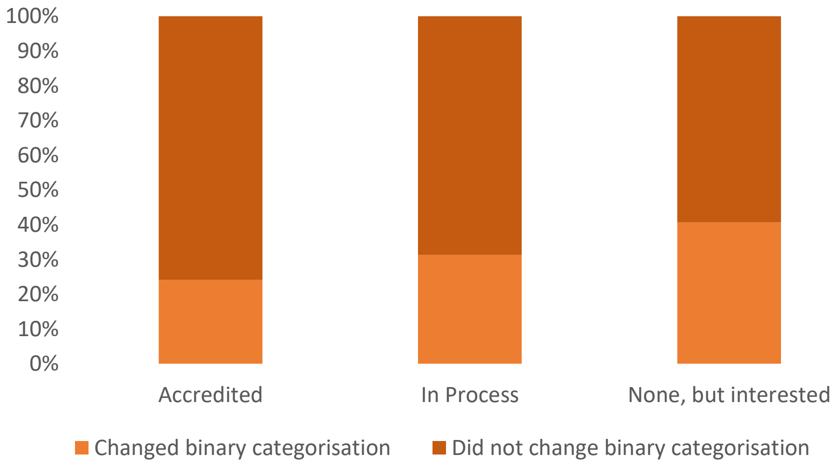
2.5.7 Effects of Lung Ultrasound Experience

Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in two cases (6.9%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in four case (25%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in ten cases (31.3%). See Appendix Figure 171. In process of becoming accredited in lung ultrasound was found to be non-significant ($OR_{accredited:inprogress}$=4.50, p=0.107). No lung ultrasound experience was found to be significant ($OR_{accredited:none}$=6.14, p=0.028).



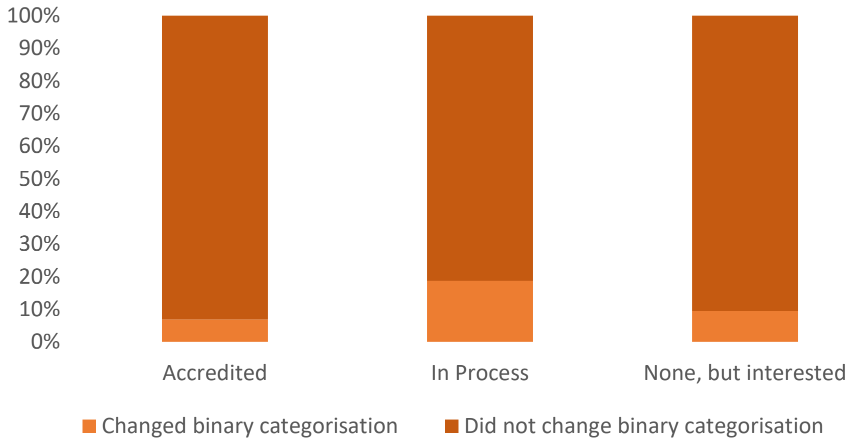
Appendix Figure 171 Re-categorisation of Atelectasis and LUS Experience

Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in seven cases (24.1%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in five cases (31.3%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 13 cases (40.6%). See Appendix Figure 172. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=1.43, p=0.606; $OR_{accredited:none}$=2.15, p=0.174).



Appendix Figure 172 Re-categorisation of Pleural Fluid and LUS Experience

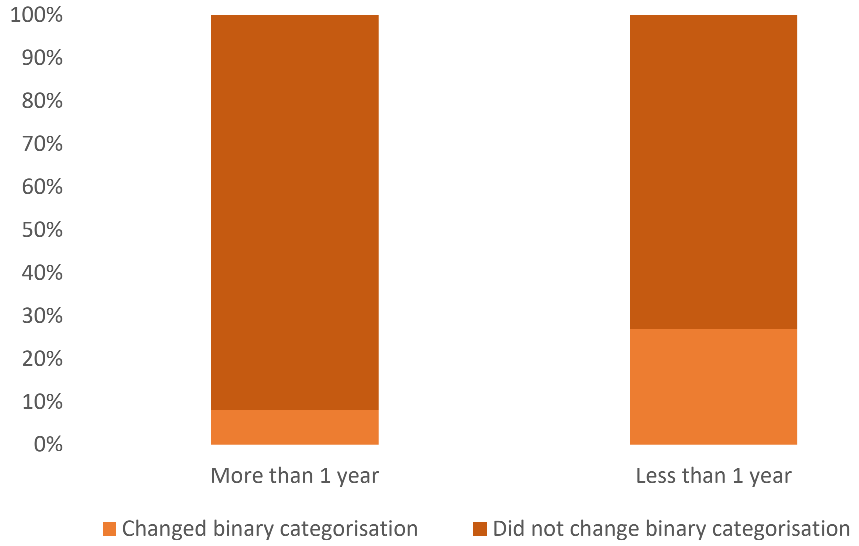
Out of the 29 cases where the physiotherapist was accredited in lung ultrasound, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in two cases (6.9%); Out of the 16 cases where the physiotherapist was in the process of becoming accredited, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in three case (18.8%); Out of the 32 cases where the physiotherapist had no experience using lung ultrasound, but was interested, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in three cases (9.4%). See Appendix Figure 173. Lung ultrasound experience was found to be non-significant ($OR_{accredited:inprogress}$=3.12, p=0.243; $OR_{accredited:none}$=1.40, p=0.725).



Appendix Figure 173 Re-categorisation of Pneumothorax and LUS Experience

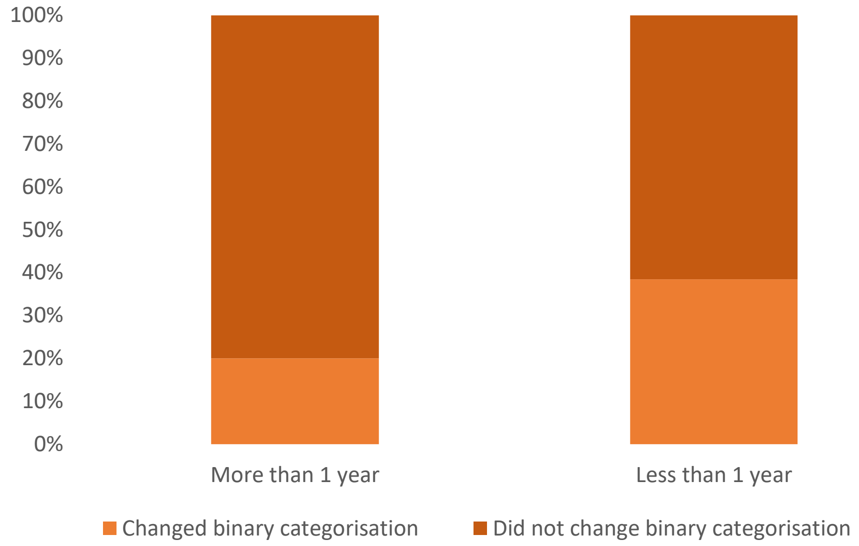
2.5.8 Effects of Years Accredited in Lung Ultrasound

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in two cases (8%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's perceived probability of atelectasis changed binary categorisation following LUS in 14 cases (26.9%). See Appendix Figure 174. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=4.24, p=0.071).



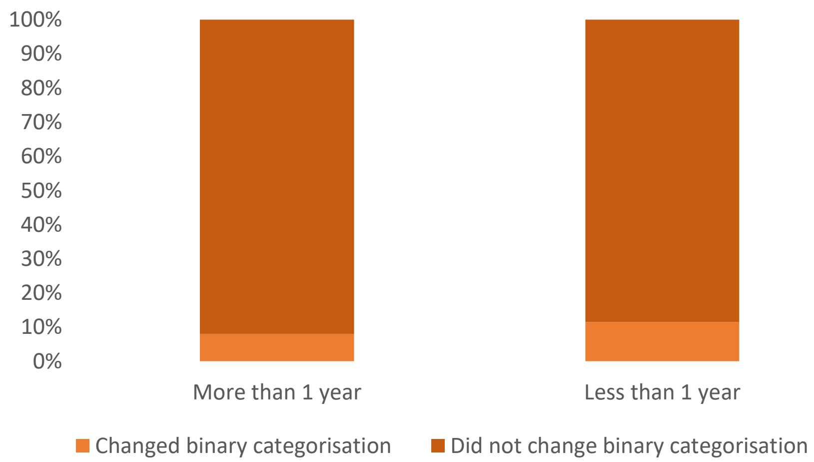
Appendix Figure 174 Re-categorisation of Atelectasis and Years Accredited in LUS

Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in five cases (20%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's perceived probability of pleural fluid changed binary categorisation following LUS in 20 cases (38.5%). See Appendix Figure 175. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=2.50, p=0.111).



Appendix Figure 175 Re-categorisation of Pleural Fluid and Years Accredited in LUS

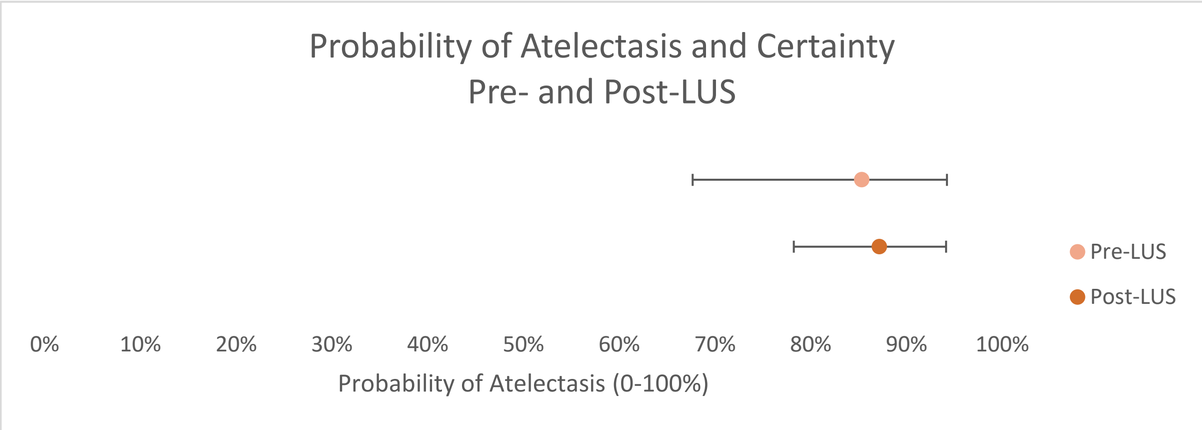
Out of the 25 cases where the physiotherapist had more than one year of lung ultrasound accreditation, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in two cases (8%); Out of the 52 cases where the physiotherapist had less than one year of lung ultrasound accreditation or not accredited, the physiotherapist's perceived probability of pneumothorax changed binary categorisation following LUS in six cases (11.5%). See Appendix Figure 176. Less than a year accredited or absence of accreditation was found to be non-significant ($OR_{>1:<1}$=1.50, p=0.636).

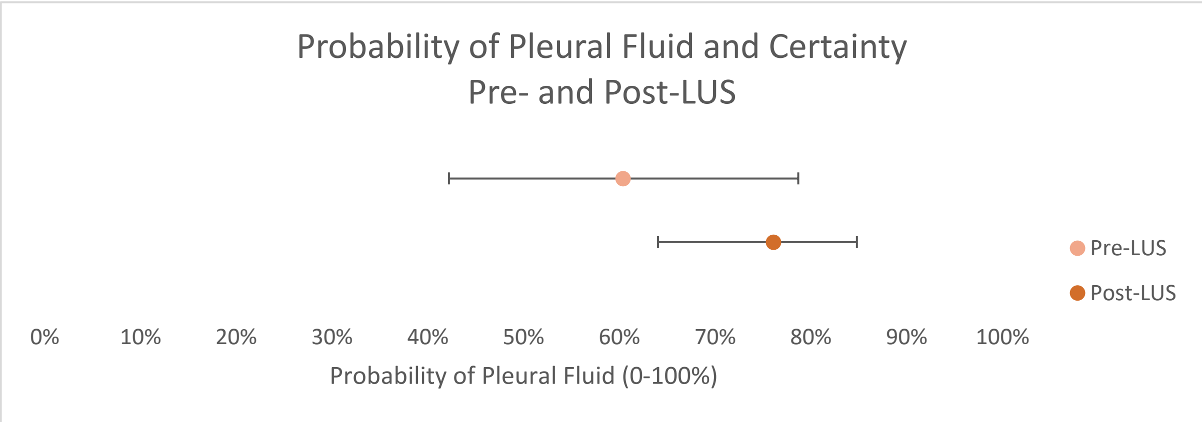


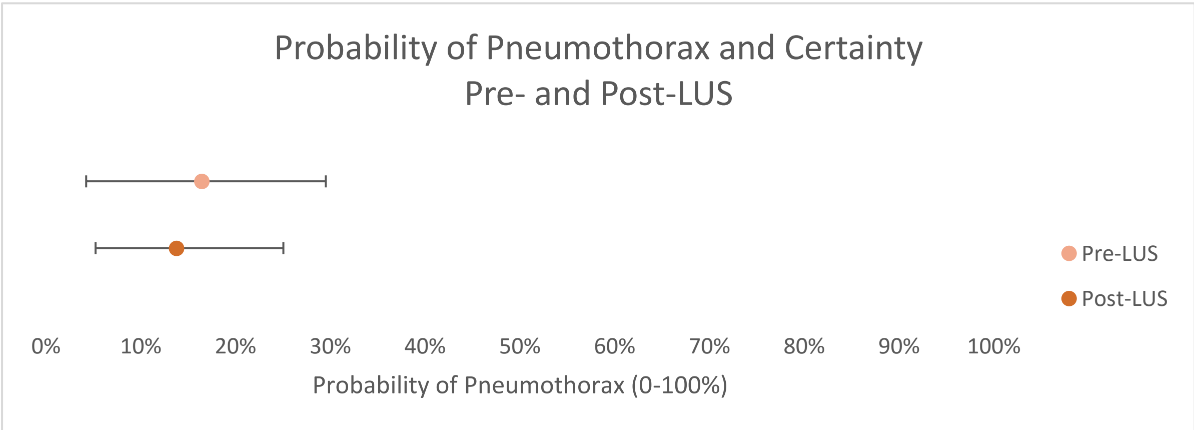
Appendix Figure 176 Re-categorisation of Pneumothorax and Years Accredited in LUS

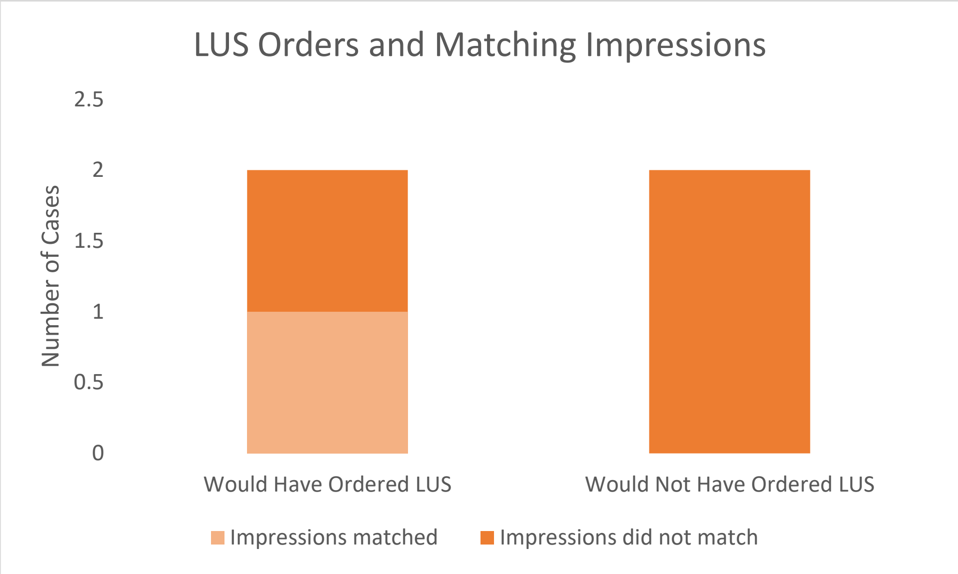
APPENDIX 19 – Example of Participant Preliminary Data for Interviews

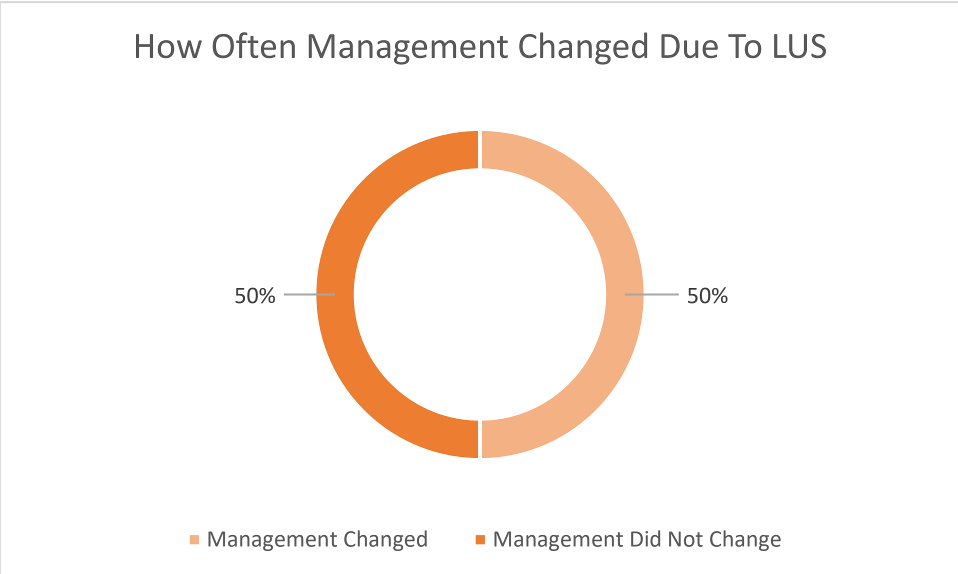
PT3








LUS Orders and Matching Impressions
Number of Cases
2.5
2
1.5
1
0.5
0
Would Have Ordered LUS
Would Not Have Ordered LUS
Impressions matched
Impressions did not match


How Often Management Changed Due To LUS
50%
50%
Management Changed
Management Did Not Change

APPENDIX 20 – Example of Key Dimensions to Categories

BARRIERS & FACILITATORS TO IMPLEMENTING LUS

Key Dimensions	Categories
Interest in LUS due to interest in respiratory physiotherapy (1,10) Interest in LUS due to LUS being an advanced skill requiring experience (1,3,6,7,9,10) Interest in LUS for personal & professional skill development (3,5,6,7) LUS increasing interest in respiratory physiotherapy (3) Barrier – Inexperience & Incompetency (10,9) Interest in LUS to add to the toolbox (1,5) Interest in LUS due to the impact on physiotherapy practice (3,5,6,7)	Views on initial LUS interest and advancing respiratory physiotherapy practice (1,3,5,6,7,9,10)
Barrier – Inexperience & Incompetency (10,9) Barrier – Lack of LUS awareness (3,6)	Lack of experience and exposure to LUS as a barrier (3,6,9,10)
Interest in LUS through exposure (1,7) Facilitator – Exposure: university, work, social media (1,3,7,6,10,9)	Exposure to LUS as a facilitator (1,3,6,7,9,10)
Barrier – Availability of Mentors (3,7) Barrier – Access to training: funding, location, band restrictions (3,5,6,10,9) Barrier – Lack of training opportunities (1) Barrier – Upkeeping skills after accreditation (3,9) Barrier – Time to become accredited (1,5,7,9)	Accessing and maintaining accreditation as a barrier (1,3,5,6,7,9,10)
Barrier – Hesitancy to do LUS if unsure anything would change (1,7,10) Barrier – Appropriateness for patients (6,10) Barrier – Time (6,9,10) Barrier – Time to do LUS: Staffing, pressures, taking away clinical time (1,3,6,7,9,10) Barrier – Lack of staff support (5,7) Barrier – Accessing accredited staff if not accredited (7,9,10) Barrier – Equipment (6) Barrier – Equipment: Availability (1,3,6,7,10) Barrier – Equipment: Quality (1,6,7)	Service-level barriers (1,3,5,6,7,9,10)
Facilitator – Availability of accredited staff (1,3,5,7,9) Facilitator – Staff support (1,3,5,6,7) Facilitator – Not requiring supervision to scan (7) Facilitator – Availability of equipment (3,5,7,9) Facilitator – LUS can be quick (1) Facilitator – Availability of Training (5,7)	Service-level facilitators (1,3,5,6,7,9)