Evaluation of medium-term consequences of implementing commercial computerized physician order entry and clinical decision support prescribing system in two 'early adopter' hospitals.

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A collective case study-based evaluation of routinely used commercial computerized physician order entry and clinical decision support systems in two "early adopter" hospitals

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Abstract

Objective: To understand the medium-term consequences of implementing commercially procured computerized physician order entry (CPOE) and clinical decision support (CDS) systems in "early adopter" hospitals.

Materials and Methods: Two in-depth case studies in hospitals that had been using CPOE and CDS systems for at least two years. Both hospitals implemented commercially-available systems: Hospital A implemented a CPOE system (with basic decision support) whereas Hospital B implemented a system that facilitated order entry, but which was integrated with electronic health records and therefore offered more advanced CDS. We employed a combination of documentary analysis of the implementation plans, audio-recorded semi-structured interviews with system users, and observations of strategic meetings and systems usage.

Results: We collected 11 documents, conducted 43 interviews with system users, and conducted a total of 21.5 hours of observations. We identified three major themes: 1) realizing organizational benefits through secondary uses of data; 2) impacts on individual users including greater legibility of prescriptions, but some accounts of increased workloads; and 3) the introduction of new safety risks relating to accessibility and usability of hardware and software, with users expressing concerns that some problems such as duplicate prescribing were more likely to occur.

Conclusion: We identified few differences between systems over the medium-term. Given the substantial investments and major differences in costs between CPOE and CDS software, it is important that the evidence-base in relation to longer-term consequences in a wider range of hospitals is better established.

Keywords: CPOE, CDS, implementation, adoption

Background and significance

Computerized Physician Order Entry (CPOE) and Clinical Decision Support (CDS) systems are increasingly being implemented in high- and middle-income countries with the aim of improving the quality, safety and efficiency of healthcare.(1) These systems can reduce the substantial disease burden associated with prescribing and medication administration errors and also offer the potential to enhance the quality and efficiency of prescribing decisions.(1-4)

In the United Kingdom (U.K.), such systems are more commonly considered under the general heading of electronic prescribing systems, which have been defined as: "*The utilisation of electronic systems to facilitate and enhance the communication of a prescription or medicine order, aiding the choice, administration and supply of a medicine through knowledge and decision support and providing a robust audit trail for the entire medicines use process*".(2) In the United States (U.S.), basic CPOE functionalities are sometimes defined more narrowly as including "*computerized ordering of specific medication regimens for individual patients*".(5)

CPOE and CDS systems share common features in that CPOE systems typically incorporate basic decision support and CDS systems can impact on order entry. That said, they also have important distinctive features in that CPOE systems are primarily concerned with facilitating medication ordering, whereas the main focus of CDS is to draw on patient specific information held within electronic health records (e.g. allergy history and laboratory test results) and use this to provide more tailored decision support.

Much of the published literature emanates from evaluations of "home-grown" hospital systems, which have been developed over many years.(1,3,4) The empirical evidence indicates that such systems can result in improvements in care processes and health outcomes,(3,4,6-8) but extrapolating from this work to other contexts is problematic, as systems have tended to be developed and evaluated in the same institutions. Locally developed systems are also often extensively customized, which limits the potential transferability of findings to more generic commercial applications that are increasingly being used internationally.(9,10)

Commercially available systems offer the potential for multiple linkages between applications (e.g. pathology test results and discharge letters),(9,10) and may be cheaper to procure and maintain than "home-grown" systems.(10) However, knowledge about the impact of different commercial applications on care processes is still limited.(1,11,12,13) The available evidence has highlighted major challenges associated with changes to long-established organizational and professional practices over relatively short periods of time and integration with different systems (interoperability).(2,5,8,10,11) Substantial organizational benefits are however expected to accrue once the initial hurdles associated with implementation are overcome and systems are adopted and routinely used across the healthcare organization.(11) There are also significant differences between commercial systems in terms of functionality and a 10-20 fold variation in costs.

Current commercially-available applications in the U.K. can either be stand-alone order entry systems (which is comparable to basic CPOE functionality) or part of an integrated hospital information system offering sophisticated CDS functionality.(12,14) In England, the implementation of systems is further complicated by the relative immaturity of the commercial CPOE/CDS market, the limited number of systems tailored to the U.K. context, variable levels of expertise in implementing information technology (IT) systems in hospitals,

and the recent change in national political context from advocating a centralized, standardized implementation model to an emphasis on local autonomy in systems choice for healthcare providers.(14,15)

In order to inform on-going national strategic developments, we conducted an in-depth case-study based evaluation of routinely used commercially available CPOE and CDS systems linked with medicines administration functionalities in two of the first U.K. hospitals to implement these.(16) We aimed to study the local consequences of systems once organizations have overcome the initial, now well-recognized, major challenges associated with introducing disruptive technologies. We were interested in answering the question: What are the consequences of introducing CPOE/CDS over the medium-term in early adopter hospitals? This work is timely as it has the potential to inform policy and clinical deliberations in relation to the imminent substantial U.K. and international investments being made in procuring such systems.(17,18)

Materials and methods

Design

We undertook a theoretically-informed,(19-21) collective case study (22,23) of the processes surrounding system optimization in two hospitals. The case study-based approach is a formal naturalistic research design that involves an in-depth exploration of a complex issue or phenomenon in its everyday real-life context. It typically involves drawing on multiple sources of evidence with the aim to shed light on local processes and extrapolate potentially transferable lessons to other contexts.(22,23) For the purposes of our study, the 'case' was defined as a hospital that had implemented CPOE/CDS systems with a minimum of two years' systems utilization, an approach which thus offered insights into the medium-term consequences of moving to these systems. We investigated similarities and differences between hospitals and systems, which enabled us to theorize surrounding potential medium-term impacts across a wider range of hospitals.

Ethics and permissions

This work was classed as a service evaluation by a National Health Service (NHS) Research Ethics Committee and gained Institutional Review Board permission by The University of Edinburgh. We obtained all necessary organizational approvals from hospitals prior to commencing this work, and participants gave informed consent to taking part. In order to protect anonymity, we removed any potential identifiers of locations and individuals.

Sampling and recruitment

It takes time for systems to embed and to manifest a range of potential benefits,(15) but many of the risks associated with complex systems are evident relatively early on.(15) Few hospitals in the U.K. currently have CPOE/CDS systems,(24) and very few have any history of using commercial systems. Our sampling strategy was therefore designed to identify "early adopters". Though these were not necessarily representative of other hospitals in England, studying their experiences would provide important insights into the processes associated with more routine use of systems with different functionalities, which policymakers, hospitals and clinicians may need to be aware of. We used our recent surveys of the national landscape and on-going monitoring of the situation to develop a sampling frame of early adopter hospitals that had implemented commercial CPOE and CDS systems.(14) We employed a purposive sampling strategy to ensure sampling by duration of system usage (measured from commencement of implementation) and by system functionality (CPOE and CDS). We specified that hospitals should have had a minimum of two years' systems utilization to

ensure sufficient time for the system to become routinely used.(12,25-28) The ensuing sample of two hospitals allowed assessing routine use and comparison of CPOE and CDS functionality (see Table 1 for more specific characteristics).

Table 1: Characteristics of case study hospitals, system description and data collection progress

Hospital characteristics	System characteristics	System description	Data collected	Data collection period
Hospital A: urban, acute care	CPOE system (not part of a wider hospital-wide information system)	- Have a separate patient administration system which is used for other clinical information including pathology results, clinic letters, discharge summaries, certain scoring and assessments etc. - Limited decision support for drug-drug interactions and allergies, including order sets. - Now live in all inpatient wards with the exception of outpatients and critical care. - System not used for certain types of medications such as infusions and warfarin. - Have a "home-grown" reporting system that draws on data from CPOE.	- 23 interviews with users (pharmacists, nurses, doctors) and implementers - Eight observations (12.5 hours) of strategic meetings and system use - Notes from recruitment meeting - Eight documents relating to anticipated changes (e.g. work process maps, implementation plan, business case)	December 2011 - August 2012 Planning to return in August 2014
Hospital B:	CDS modules	- Implemented in	- 20 interviews	May 2012 –

urban, acute care, teaching	within an integrated hospital information system	all inpatient wards except pediatrics. - Clinical noting not yet implemented, but ability to see laboratory and pathology results on the system. - The system includes prescribing of all medicines except: variable dose insulin, patient controlled analgesia, intravenous hydration fluids. Some other medications such as warfarin are only partially supported. - They have not switched on drug-drug interactions, duplicates, or contra-indications. - CDS – They use order sentences, order sets, allergy checking, and some locally customized pop-up warnings.	with users (pharmacists, nurses, doctors) and implementers - Four observations (nine hours) of strategic meetings and system use - Notes from recruitment meeting - Three documents relating to anticipated changes (e.g. work process maps, implementation plan, business case)	June 2013 Planning to return in August 2014

Within each of the two included hospitals, we used purposive maximum diversity sampling to identify a range of stakeholders who had been involved in the deployment and use of its CPOE/CDS system.(29) We started with local chief pharmacists and project managers, who were asked to recommend other relevant colleagues, including ward managers, lead pharmacists, and information technology (IT) professionals. Snowball sampling was then

used for initial contacts to identify system users, including doctors, pharmacists, and nurses (at varying levels of seniority). Throughout this process, we actively searched for different viewpoints and experiences. No individual approached explicitly refused participation, but several (8/51) did not reply to our initial invitation.

Data collection

Data collected at the two case study hospitals included a combination of semi-structured audio-recorded interviews, observations of strategic meetings and system use by different professions, and documents providing information on implementation plans (Table 1). This combination of data sources allowed us to investigate: 1) perspectives on the design, uptake, implementation process and evolution of systems (documents); 2) the nature of everyday use and consequences for practices and processes (observations), and 3) reported experiences and expectations of individuals relating to different implementation stages (interviews).

Data were collected by a university employed research fellow (KC), between two and three years after implementation. Interviews were semi-structured and guided by topic schedules (Table 2), which were tailored to individual roles and updated in light of emerging findings. Issues explored included perspectives on the development, implementation and maintenance of systems, as well as associated lessons learned and suggestions for the future. The average duration of interviews was approximately 30 minutes. Data were digitally audio-recorded and professionally transcribed, and transcripts were checked by the lead researcher (KC). Non-participant observations were facilitated by a recording sheet (Table 2), and accompanied by field notes. This involved the researcher following individual healthcare professionals during their morning work rounds and sitting in on strategic meetings, whilst taking notes. Specific aspects recorded included: setting, participants, interactions, activities (focusing on those that were medication/computer-related), and the sequence of events. We also recorded emerging thoughts and reflections in a research journal.

Table 2: Indicative interview topic guides and observation recording sheet

Sample interview topic guide
- Interviewee's background including current position in the organization and specific role in relation to the system;
- Details of the system and status;
- Views on development of the system: design, uptake, implementation, evolution;
- Important local considerations for example timelines, resources, infrastructure;
- Training and support provided (initial and on-going);
- Collaboration with the software developer (configurability, management process);
- Data quality and systems reliability issues;
- How are data produced by the system utilized?
- Lessons learned;
- Perceived/anticipated consequences of the system on the quality of care, information flow, patient experience, roles and practices of healthcare professionals, the organization, the local community;

- Views on how systems will integrate with existing local and national systems;

- Expectations and perceptions (the future, benefits realized or to be realized);

- Perceived changes over time;

- Integration with other hospital systems.

Observation recording sheet

- Description of the setting – layout: positioning of computers, beds etc.;

- Description of the participants – the roles of individuals on the ward (names not recorded);

- Activities – focus on healthcare professionals and what they are doing (with a focus on activities surrounding the use of computers such as responses to alerts being generated);

- Events – recording of particular events e.g. speaking to a patient, recording information, speaking to other healthcare professionals;

- Time – recording the sequence of events;

- Goals – recording what the participants want to accomplish;

- Feelings – the researcher's own impressions/feelings in relation to the observation.

We continued data collection in each hospital until no new themes were identified and we judged that different data sources did not provide any significant new insights (saturation).(30) Documents, observation field notes and interview transcripts were uploaded to NVivo9 software. In keeping with case study-based approach, we analyzed data within each case first.(22,23)

Data analysis

We employed a thematic approach to analysis,(31) utilizing both deductive and inductive approaches.(32-34) Deductive components involved coding of data along categories developed as part of an analytical framework based on a review of the literature and other on-going work (summarized in Table 3).(35)

Table 3: The coding framework focusing on system optimization (35)

Adoption and use

Changes in work practices

Usability of hardware and software

Benefits

Organizational

Individual

Unintended consequences and risks
Impact on staff time
Safety risks
Continuing development and customization

This framework helped to guide the research, facilitate comparison of findings between cases, helped to identify potentially transferable lessons to other hospitals yet to implement, and helped to integrate the findings with the existing literature. Major categories related to systems optimization and included adoption and use, benefits, unintended consequences and risks, and continuing development and customization. We however also remained open to issues emerging from the data and the inductive component thus involved identifying these additional insights. Integration of findings was achieved by combining the framework categories with new emerging findings.

Data collection and analysis were iterative, allowing emerging themes to be explored in depth and contradictory evidence to be investigated. Initially, data were analyzed within the two cases allowing triangulation of evidence and exploration of tensions/common themes within hospitals.

Data from interviews in each case were analyzed first with relevant data extracts being indexed against the framework categories relating to the different stages of system implementation (see Table 3). This involved exploring particular challenges surrounding implementation and maintenance from different viewpoints (e.g. users and implementation teams) by identifying common themes as well as conflicting evidence. We integrated this with data from observation field notes and organizational documents within each case study site before integration across sites. Data were coded along the same framework being examined for complementary and contradictory evidence.

To identify over-arching themes across the two case studies, and to minimize potential researcher bias, we had frequent discussions amongst the extended research team. Disagreements about emerging findings were resolved by discussion. This allowed similarities/tensions and negative cases to be explored and interpreted. It also helped to place the findings in a wider context and explore different possible explanations for observed outcomes and the potential transferability of findings.

Results

We identified a range of issues and outline how these fit with the existing literature in Table 4.

Table 4: Range of other issues identified in our work which were in line with the existing literature

Limited evidence on clinical patient outcomes (e.g. adverse drug events) and cost effectiveness (36-40)
Benefits

- CPOE and CDSS can improve practitioner performance by supporting prescribing (e.g. helping with inappropriate drug selection, optimizing drug dosage, improved adherence to prescribing guidelines) and reducing medication errors (38,41-44)

- Reduced length of patients' hospital stay (41)

- CDSS and CPOE improving time efficiency and working practices (e.g. quicker prescribing, quicker drug turnaround time) (45,46,47)

- Changes in pharmacist work practices – reduced time spent on direct clinical care (38)

- Improved adherence to guidelines (36,43,44)

- Less time spend by users looking for drug charts (48)

- Positive effects on resource utilization, provider productivity, and care efficiency (39,48)

- Reduction in transcribing errors (49)

Risks

- Adverse impact on patients: delaying care and treatment due to issues with computer system (50,51)

- Implementation process e.g. lack of training (50,52)

- Medication errors introduced by systems due to: information errors associated with failure to integrate with other information systems, and failure of systems to integrate with human work processes (issues in human-system interface) (53,54)

- Wide variability in the degree of system usage (e.g. consultants tend to delegate to juniors) (43)

- Increase in time spent on patient care and increase in ordering time (48,55-57)

- Use of central station desktops increases time (58)

- Alert fatigue (59,60)

- Reduction in team-wide discussions (61)

- Users following idiosyncratic practices (62)

The following key themes emerged from our analysis:

- Realizing organizational benefits through secondary uses of data;
- Understanding the impact on healthcare professionals and support staff;
- The introduction of new unanticipated risks to patient safety.

We found a high degree of commonality in terms of perceived benefits and risks, and perceived usefulness and usability between CPOE (Hospital A) and CDS (Hospital B) solutions, but have outlined differences where relevant.

Realizing organizational benefits through secondary uses of data

Refining organizational processes

Participants valued opportunities to refine organizational processes surrounding quality improvement. These related to organizational capacity building around internal implementation expertise; increasing productivity by reducing medical and pharmacy time on certain activities such as prescribing and generating discharge summaries, enabling more rapid turnaround of patients; allowing recorded audit trails of organizational activity; stimulating the implementation of and adherence to guidelines; and exploiting generated data through secondary uses. For example, institutions could run reports, such as on missed doses, and use data within systems to target specific areas of concerns.

"...in terms of...general improvement in clinical care we can monitor now medications not given, so whereas in the past you might have to...do a one week audit if a ward drug is not given...we've got that data for the whole hospital...hundreds of patients..." Hospital B, Implementation Team, Interview 39

Optimizing organizational performance

Senior managers that had implemented the more sophisticated CDS system also gave examples of how systems improved organizational performance through the implementation of new guidelines and by ensuring associated adherence of users:

"...there was a manufacturing problem with Tinzaparin and we had to change to a different drug. Previously we would have had to go round every single ward, tell the doctor get them to change it. And we just put a little pop up to prompt them to do that and we knew every single patient who was on the drug so the pharmacist targeted them and within one day the whole of the hospital was changed over and normally that would have taken about a month to kick in." Hospital B, Implementation Team, Interview 14

Quality improvement

The use of data held within systems was seen as fundamental to achieving some key quality improvements for different professional groups. For example, pharmacists could draw on targeted searches for high-risk medications and/or patients and then priorities these. The following observation notes at Hospital A with a CPOE system and a locally developed reporting system utilizing CPOE data, illustrate this:

He says that the reports are helpful as they help him to priorities his workload as they help him to identify high-risk medications and missed doses. The information in the reporting system [which is locally developed] is pulled out from [name of patient administration system] and [name of system]. The reporting system also highlights new patients which are regarded as high risk and which therefore need to be seen first by the pharmacist.... He does the searches for his ward about three to four times a day. In addition to this, centralized searches for high-risk medications are done hospital wide by "someone centrally". Hospital A, Pharmacist, Observation notes

Understanding the impact on healthcare professionals and support staff

Benefits for individual users

There were some accounts of systems saving time by, for example: less time spent trying to decipher hand-writing due to improved legibility; quicker generation of discharge summaries, as forms were created automatically (although the overall discharge process was perceived to be slower as discussed below); faster prescribing e.g. through order sets; the ability to

prescribe remotely; less time spent re-writing drug-charts by junior doctors; speedier drug-ordering processes; and faster information transfer through improved communication between members of the multi-disciplinary team.

"...the biggest benefit I would say, is we can actually read things. That has got to be the biggest benefit ever. We can actually read what we're giving now." Hospital B, Nurse, Interview 31

"I think once you get used to it, I mean it saves time because you don't have to go and look for the Kardex, you know where it is, it's on the computer system which is good because you've spent many a happy hour looking for Kardexes on wards so it's good from that point of view." Hospital B, Registrar, Interview 42

Negative consequences for individual workloads

However, most users also reported negative consequences for individual workloads, with some tasks perceived as having become more time-consuming for all professions. This contrasted heavily with organizational expectations of time savings for clinical staff.

Increased workloads were reported to be related to poor software usability, with users complaining about the time-consuming nature of searching for and sifting through the increased amount of information held within systems, and the associated activity of scrolling and switching between screens.

"...when people have got drug allergies sometimes it can take quite a while to actually find the drug to enter it as an allergy that takes a long time...and you can't sort of type in part of the drug and search for it. And they come under headings of drug, drug classes and so then you're searching in that class and it takes quite a while..." Hospital A, Junior Doctor, Interview 10

"Yes it's very long-winded...if you want to say add a drug you'd press 'add' and then you'd start typing the name of the drug and then hopefully you'll find it. And then in terms of say morphine there must be about 30 different morphine types so they all come up, you've got to find the one you want click on that and then it comes down with a whole list of options...in terms of how you actually give stuff." Hospital B, Consultant, Interview 40

However, software usability problems seemed relatively minor when compared to the time-consuming and disruptive consequences of serious shortcomings in the provision of wider technology infrastructure. These included difficulties for users in finding computers, issues with battery life in mobile devices, lengthy log-in times, and slow loading of screens.

"...of course you've got to wait for when you go to it and you have to log on all that takes time...Well because the carts seem to break...quite often you can be waiting there and nothing will happen and then it will just go off and you've got to start all over again, then you have to reboot it. All this is just taking time...." Hospital A, Nurse, Interview 18

"The most frustrating thing as a consultant when you're...doing the ward round you see maybe 20 patients, you've got a computer that you're working on...and...you go away and then someone else has started to use that computer and I start to get quite angry about that." Hospital B, Consultant, Interview 41

The introduction of new unanticipated risks to patient safety

Although some aspects of prescribing and medicines management may have become safer, users also identified a range of potential risks created by the system that had not been anticipated.

Positive impact on safety

In terms of positive consequences, prescribing safety was seen by most to be improved through process-related issues, including:

- Fewer transcribing errors resulting from less duplication of information as it was now *"all in one place"* and immediately accessible (even more so with CDS systems that included access to laboratory and pathology results);
- Improved accessibility and legibility of information;
- Inbuilt order sets and CDS providing information on drugs and doses (which was more sophisticated and customizable in the CDS system).

"...we have comes up with default values and names...if you're not sure how to spell a medicine it will obviously come up with the one you are likely to want..." Hospital A, Consultant, Interview 3

Importantly, nurses reported a reduction in medicines administration errors, with systems helping to reduce ambiguity and ensure that medications were administered on time and enabling users to discover if/why they were not administered. This highlights the benefits of scheduling and reporting of where doses are due, delayed and missed.(63)

"...it's a lot easier to see what you're supposed to be giving and what time you're supposed to be giving it...whereas when you were looking at the old paperwork documentation there was just so much information on it, it would cloud what you...should have been giving at certain times." Hospital A, Nurse, Interview 15

"... it's much more clear on [system] what time something should be given and so I guess overall yeah it does improve care because patients are getting their medications at the right time and it flashes up if they're not given at the right time..." Hospital B, Nurse, Interview 38

Potential negative consequences for safety

Participants also reported a number of new negative unanticipated consequences for safety associated with the introduction of new systems.

Local adaptations of working practices (workarounds) increased potential for error in clinical practice. For example, some clinicians, particularly doctors, tended to take notes on paper and then enter information into the systems in batches once a computer became available (meaning that electronic records were as a result not kept up-to-date for several hours). Others tended not to look at the electronic charts as this was viewed as too time-consuming, which could result in them missing potentially important information.

"I tend to do it in batches just because of the lack of computers on the ward...ward rounds happen so...you've not got time to in-between patients otherwise the rest of the team will have seen five and you won't know what's going on so it tends to be in batches... I have my clipboard, write what I need to prescribe and then go and prescribe it later." Hospital A, Junior Doctor, Interview 10

"...if you're doing a ward round as a consultant in the old school where everyone has got a drug chart at the end of the bed, part of the routine of going round is to take the drug chart and look to see what the patients are on. What becomes sometimes bad practice is because you have to cart the computer round and you have to load it up and it takes time sometimes on some ward rounds...people don't look at the drugs..." Hospital B, Consultant, Interview 43

Users also reported that the additional security measures were at odds with the contingent and highly pressured work routines of healthcare professionals. Repeated logging-in and -out of hardware was viewed as too time consuming, potentially presenting new areas of risk (e.g. with users avoiding having to repeatedly log-in).

"...it takes you longer than it used to just to look at the card and...people don't look at it as often..." Hospital B, Consultant, Interview 43

Participants further referred to particular system properties, relating to user interfaces and system functionality, increasing the risk of specific errors. These included a general lack of system flexibility, which was paradoxically often a symptom of systems attempting to improve safety (e.g. by making certain tasks or viewing of screens compulsory or sequential and thereby resulting in problems obtaining an overview of past activities).

"...your medicines because the times they're due you have to give them at that time otherwise you can't give them, like it won't let you go back. So say if I've missed my eight o'clock medicines and it comes to two o'clock, my list of two o'clock medicines will come up but it won't let me like give the eight o'clock ones now so it's a bit strange but like the old way you could write on your chart what time you give it so it's specifically right..." Hospital A, Nurse, Interview 17

"...when you look at the paper record you can clearly see what patients are on and what they're not on. Sometimes on our system...it will have an antibiotic which will still appear to be [prescribed] but you have to look at the fine print to see that 'oh no it was stopped a week ago', so it doesn't clearly...cross off so there's an error because you might look at that and think 'oh that's OK he's on antibiotics' I'm happy with that, so that's a potential error." Hospital B, Consultant, Interview 43

Users suggested the system could also introduce new risks of selection errors (e.g. when using pull-down menus resulted in users accidentally selecting the wrong drug), automatic allocation of timing and doses (without the user realizing), duplicate prescribing of medications (e.g. through different routes), and through free text prescriptions, which were still possible in systems, designed with the intention of providing flexibility for users. These meant that users could prescribe doses of medications that were not available from the drop-down menu.

"...there is a facility to do a free format prescription. Say for example...a methotrexate dose that is given weekly, you can actually select it weekly but say if the doctor did it in this free format and said methotrexate 10mg weekly and the system doesn't understand that that's weekly, it doesn't attach it to a frequency so it then comes up every single day for admin..." Hospital A, Pharmacist, Interview 4

"The prime example, the only thing I've ever seen is if somebody is taking paracetamol orally as prescribed, then the patient becomes sick, nausea, vomiting and you say can you prescribe

that paracetamol IV [intravenous] and then they'll add that IV prescription and then you've got two prescriptions of the same." Hospital B, Nurse, Interview 38

Discussion

Overview of findings
We found some organizational benefits relating to secondary uses of data, but also reports of some adverse consequences for individual users and patients. Our data however also suggest that improvements in system design and integration could improve productivity and workflow (for example through better user interface design to allow integration of information e.g. by enabling multiple windows to be viewed for the same patient simultaneously). Even greater benefits might result from ensuring adequate availability of computer terminals and underpinning computing and communication facilities. There is also a need to address the log-on time issue as users tended to develop workarounds which in turn could create new risks.

Strengths and limitations
Our study provides important insights into end-user experiences of working with commercial CPOE and CDS systems with different functionalities once the challenging initial implementation phase has been negotiated. Conceptualizing the two hospitals as case studies has helped to explore local processes and consequences of new systems in detail.(20,21) The in-depth nature of this work allowed us to investigate the complex implications of systems for different organizational stakeholders. The diversity of perspectives consulted, drawing on prior theoretical work, facilitated exploring the interplay between technical, organizational and individual dimensions in the on-going implementation journey.(19-21) The study design was further strengthened by consolidating evidence from a range of data types collected from the two case studies with diverse systems (triangulation).

However, as we interviewed direct users and implementers, we did not necessarily capture all benefits, such as those related to organizational performance improvements. Some benefits such as time-savings may be masked by other staff frustrations arising within complex work processes, presenting issues of attribution. Moreover, directly attributable safety issues observed in this work may be limited, partly because we have focused on medication-related areas only.

Due to the overall very limited number of hospitals with routinely used systems in England, we sampled only two hospitals. Our findings may therefore not generalize to other sites in the U.K. or indeed other countries, as the two hospitals investigated were early adopter sites. The two case study hospitals had some important potentially confounding attributes, including strong organizational leadership, receptive contexts for change, and innovative organizational environments. We plan to address this in follow-on work in a greater number of hospitals. That said, we hope that the theoretically driven approach to sampling, analysis and interpretation of data, as well as the richness and depth of data collected should provide important, potentially transferable insights from this work. It is also important to highlight that the hospital that procured the CDS system (Hospital B) still has a wide range of options regarding the local continued development/iteration of functionality, whereas this is more difficult with the CPOE system as its functionality is limited. Similarly, Hospital B has an implementation roadmap for the future, whilst Hospital A is reliant on any supplier developments of the implemented system.

Furthermore, we did not directly measure safety or efficiency, and perceptions around these domains can differ substantially from objective assessments. Qualitative and quantitative

approaches can however provide complementary insights. This essential foundational work has allowed us to understand professional/organizational perspectives and experiences, and will serve as a basis for mixed-methods enquiry in a wider array of hospitals. This should include a more detailed exploration of different functionalities, examining a wider range of perspectives over longer periods of time, and investigating the impacts of systems on healthcare professionals, organizations and patients.(16)

Considering our findings in light of the existing literature

In line with current empirical evidence, our finding suggest that the inadvertent introduction of new often unanticipated risks with new health technology is likely even when organizations move into more routine use of these systems. (15,54,55) As repeatedly highlighted, this appears to reflect the challenges of integrating new systems with existing work processes and difficulties of achieving interoperability between systems.(50-54) Nevertheless, empirical evidence also suggests that CPOE and CDS systems can positively impact on patient outcomes and commercial systems can result in time-savings for healthcare professionals in the medium-term.(1,12,64,65).However, although we observed some system benefits, staff in our study did not report discernible overall time savings. These differences may be due to: 1) international variations in the way healthcare is organized (most existing evidence comes from countries other than the U.K.); 2) the focus on task automation and lack of emphasis on business process transformations in our case study hospitals; 3) specific issues that might be remedied with improvements in system design and integration/work reorganization; and 4) respondents' differential reporting of processes that were made easier or slower/harder.

There is also now increasing recognition within the literature that timelines for realizing benefits are often greatly underestimated.(66) Admittedly, a timeframe of two years after implementation is insufficient to make definitive statements about benefits in the long term, but our findings do highlight medium-term consequences for users and organizations, which has hitherto received far less focus when compared to studies investigating short-term consequences. One recent study by the European Commission of several electronic health record and CPOE/CDS implementations over a period of 12 years has reported that it takes at least four, and more typically up to nine years, before technologies produce returns on investments.(67) Our work suggests that the long time to realize organizational benefits is likely to reflect the later exploitation of data through secondary and innovative uses.(1,66)

This study further builds on the existing literature by providing insights into differences related to organizational, user and safety consequences between CPOE and CDS solutions.(3,4,12,68) The differences between systems observed in our work were minimal, suggesting that CPOE and CDS solutions pose similar challenges with respect to risks and realizing benefits in the medium-term. Any significant differences in post-implementation improvements are more likely to emerge as CDS solutions become more established and more sophisticated functionality is employed, or as CPOE systems become more interoperable and/or integrated – but this will take time, and might occur more rapidly if incentives are aligned, and/or post-implementation testing of decision support is employed.(69)

Implications for policy

Policymakers often fail to appreciate the length of time associated with meaningful secondary uses of data. A recent report by the English Department of Health, for instance, states that estimated financial benefits of CPOE/CDS systems are likely to be in the region of £270 million per annum from year two onwards after implementation.(70) This illustrates the

importance of more realistic estimates in terms of timelines, costs and returns, but also the need to continue tracking emerging benefits through longitudinal evaluations of systems and processes.(71) Such considerations are particularly important in light of the recent announcement of NHS England of investments of £500 million focusing on the implementation of CPOE/CDS systems and associated functionality into hospitals, and subsequent further funding announcements.(17,72) The strategy encourages hospitals to move towards increasing system maturity. CDS and secondary uses are viewed as vital to achieving this but central capital funding must be spent by March 2015, leaving hospitals potentially susceptible to rushing the planning of the complex changes associated with implementation. Policymakers may wish to consider financial incentives for organizations that successfully implement, and post-implementation testing to improve the likelihood that key clinical decision support will be implemented.

Conclusions

Our work highlights how shortcomings in systems design and inadequate provision of devices and computer infrastructure and the consequent use of workarounds, can give rise to new errors and a number of unanticipated safety risks. The lack of clarity surrounding benefits and apparent trade-offs between individual workloads and organizational benefits highlights the need for contemporary rather than retrospective study and for quantitative evaluation.

The perceived differences between CPOE systems with and without more advanced CDS were limited. It remains to be seen whether this trend will continue in the long-term, with implementation of increasing functionality in CDS solutions. This may involve more complex CDS functionality, inclusion of more complex areas and medications, integration with other existing systems (such as laboratory systems), and more sophisticated exploitation of data through secondary uses. We expect that the greater sophistication of CDS systems and more efficient processing of data will result in more substantial long-term benefits when compared to CPOE solutions, but it is as yet unclear whether the same benefits can be realized through incremental implementation and interfacing with CPOE systems.

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