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Interbreed variation in craniometrical parameters in sheep

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SUMMARY

This work is the first investigation to compare craniometrical parameters between different breeds of sheep. Nine breeds or cross-breeds of sheep were studied, with all measurements being carried out on live animals at times of routine animal husbandry. Although a number of the variables were not significantly different between breeds, examples of interbreed differences were found. This was true for both individual measurements of lengths and widths, as well as for indices derived by pair-wise comparisons of individual widths or lengths. In some cases differences indicated that the cross-bred lambs shared a greater similarity to one of the parental breeds relative to the other parental breed; e.g. the width between the ears relative to the length from the nuchal crest to the rostral aspect of the upper lip, where Texel x Wiltshire cross lambs had ratios more similar to the maternal Wiltshire than they had to the paternal Texel line. In other examples the cross-breeds had values which were intermediate between the two parental lines; e.g. the width at the rostral aspect of the diastema relative to the length from the nuchal crest to the rostral aspect of the upper lip, where Texel x Wiltshire cross lambs had ratios intermediate between the maternal Wiltshire and the paternal Texel lines. For one of the ratio values (the length from the nuchal crest to the rostral aspect of the upper lip, relative to the width at the caudal aspect of the diastema) it was particularly interesting to note that this was a trait where the male Suffolk x Brecknock Hill Cheviot cross lambs were more similar to the Suffolks (i.e. the paternal line), but the females cross lambs were more similar to the Brecknock Hill Cheviots (i.e. the maternal line). It is anticipated that this work will provide implications for using craniometrical parameters as a future husbandry tool.

KEY WORDS

Sheep; craniometrical parameters; interbreed comparisons.

INTRODUCTION

Recording data from domesticated animals is a key component of modern husbandry and welfare for both agricultural animals and pets. Examples of measurements routinely taken vary between species but include variables such as: birthweight; weaning weight; withers height, etc.

Craniometry is a long-established discipline in anthropology as evidenced by a book review by Oetteking from over 100 years ago[1]. Although originating in human biology it has been applied to other species. Particularly in dogs, measurements have been made regarding variables in skull shape (e.g.[2]), with skull measurements being used for purposes such as historical breed changes, behavioural traits and general health. For example, studies have shown historical changes to skull shapes of St Bernards[3] as well as links between head measurements and dog trainability[4]. Based on cephalic indices dog breeds can be classified into 3 general groups; brachycephalic (e.g. pugs with relatively flat faces), dolichocephalic (e.g. greyhounds with relatively long faces) or mesaticephalic (e.g. collies with intermediate length faces). However, recently other skull diversity factors have also been studied[5].

There has been interest in skull measurements in ruminants, e.g. Spanish ibex[6], goats[7-9], roe deer[10] and sheep. Interest in sheep heads involved behavioural analysis[11] as well as anatomical abnormalities. There has also been some work carried out on head measurements as part of larger whole-body investigations[12], limited investigations of comparisons between two sheep breeds[13-14], and work on multiple measurement points for skulls[15-17], on single breeds in each paper.

Geographic features of the British Isles have led to numerous breeds of domesticated animals, often based on thriving better on different grounds (e.g. fast-growing animals on lowlands, versus hardier animals on uplands). This has led to over 60 native breeds of sheep within the British Isles[18], together with several breeds imported from mainland Europe and a range of cross-breeds by crossing purebred lines. Initially geographical isolation and establishing flock books led to discrimination between breeds based on morphological characteristics, although more recently they have been distinguished by genetic markers (e.g.[19]). Although breed criteria include morphological characteristics such as body size, there has generally been little consideration of skull shape, as it probably has little impact on major selection criteria e.g. meat production or wool quality.

There are few papers including sheep craniometrical measurements, and with two exceptions using two Turkish sheep breeds[13-14], information on interbreed craniometrical measurements has not underpinned publications. This work investigates head measurements to analyse differences in head morphology in different sheep breeds, and compares measurements in cross lambs relative to parental lines.

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MATERIALS AND METHODS

Animals used and measurements made

Three different groups of animals had craniometrical measurements taken. In each case all animals within a group had measurements determined by a single author at a time of routine husbandry work; prior to livestock being sold at market. Measurements (see Table 1) were made using measuring tapes rather than callipers, as they allowed rapid but accurate measurements with minimal stress to animals which were not used to being handled.

Group 1 - Craniometrical measurements were made using 3 groups of adult ewes (≥ 18 months); 30 Southdown, 30 Ryeland and 30 Suftex (Suffolk x Texel crosses). All measurements, 3 lengths (L1 to L3) and 2 widths (W1 and W2) were recorded by a single author (CEB).

Group 2 - Craniometrical measurements were made using 3 groups of adult ewes (≥ 18 months); 20 Wiltshire Horn (WH), 20 Texel and 20 WH x Texel crosses. All measurements, 3 lengths (L1 to L3) and 4 widths (W1 to W4) were recorded by a single author (RD).

Group 3 - Craniometrical measurements were made using 3 groups of lambs aged around 6 months; 50 Brecknock Hill Cheviot (BHC), 50 Suffolk and 50 BHC x Suffolk crosses - 25 males and 25 females per group. All measurements, 5 lengths (L1 to L5) and 4 widths (W1 to W4) were recorded by a single author (MHO).

Statistical Analysis

Within groups data were checked for normal distribution before interbreed comparisons using F-test supported student T-tests. In addition, a series of indices were derived using one measurement divided by another, and expressed as the first variable as a percentage of the second. This was performed for all length: width and width: width combinations, and the statistical analysis repeated as above.

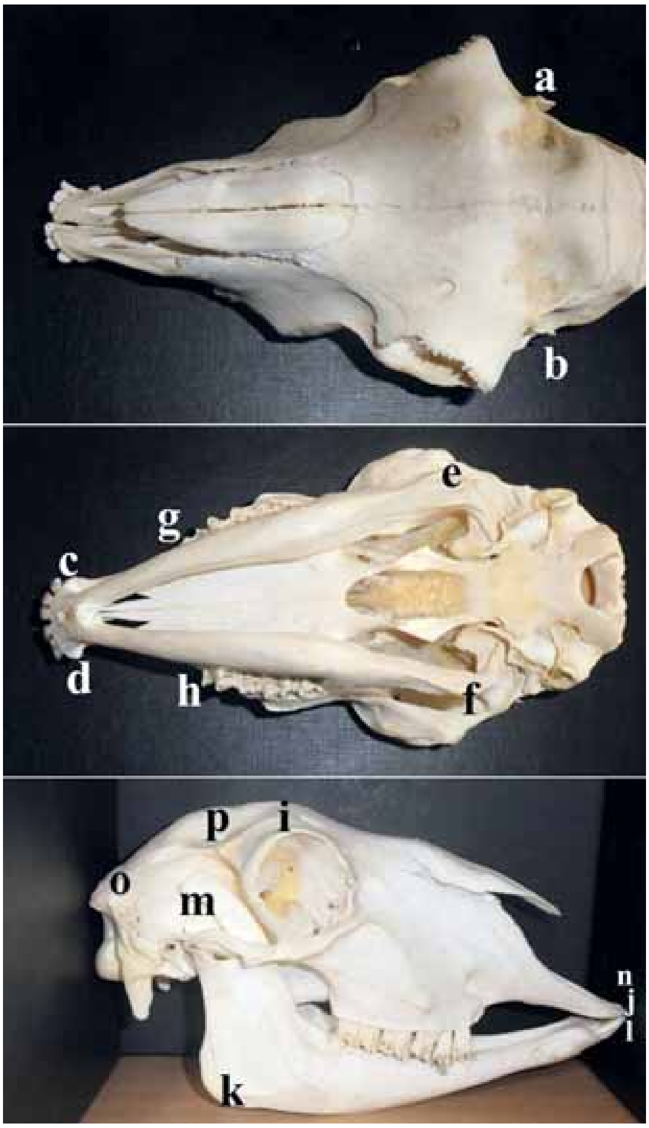

Figure 1 - Positions at which measurements were made on the sheep heads. Note that all measurements were made in live animals but this image uses a skull to make viewing easier.

RESULTS

Group 1

Data for adult Southdown, Ryeland and Suftex ewes are shown in Table 2. This shows that sizes of some features did not vary significantly between breeds. For example, the length from the nuchal crest to the rostral aspect of the upper lip [L1] was not significantly different between breeds. However, other measurements did vary, e.g. width between the ears [W1] was significantly different between breeds. Furthermore, the length from the caudoventral aspect of the

Table 1 - Variables measured within the current work. The symbols denote the position shown on the image in Figure 1.

		Symbol 1	Symbol 2
W1	Width between the ears	a	b
W2	Width at rostral aspect of diastema - between outer incisors (I4) of left and right jaws	c	d
W3	Width between caudal aspects of left and right jaws	e	f
W4	Width at caudal aspect of diastema - between first premolars (P1) of left and right jaws	g	h
L1	Length from nuchal crest to rostral aspect of upper lip	i	j
L2	Length from caudoventral aspect of angle of mandible to rostral aspect of lower lip	k	l
L3	Length from caudal aspect of hinge of lower jaw to nasal tip	m	n
L4	Length from akrokranion to rostral aspect of upper lip	o	j
L5	Poll to the rostral aspect of upper lip	p	j

Table 2 - Five measurements (in mm) recorded for the Ryeland, Southdown and Suftex (Suffolk x Texel) adult ewes (n=30 for each breed), together with the corresponding indices which have been derived by expressing the size of the first variable as a percentage of the second variable. SEM values are shown in parenthesis. Values within rows which are not significantly different (P>0.05) share a superscript.

	Ryeland	Southdown	Suftex
W1	154 [a] (2.4)	143 [b] (1.6)	126 [c] (2.2)
W2	76 [a] (1.5)	84 [b] (2.5)	121 [c] (2.3)
L1	244 [a] (3.5)	239 [a] (5.8)	239 [a] (2.6)
L2	140 [a] (3.9)	149 [ab] (4.1)	158 [b] (2.3)
L3	175 [a] (3.8)	173 [a] (3.4)	208 [b] (2.3)
W1 - L1	63 [a] (1.4)	61 [a] (1.4)	53 [b] (0.9)
W1 - L2	114 [a] (3.4)	99 [b] (2.5)	80 [c] (1.8)
W1 - L3	90 [a] (2.4)	84 [a] (1.8)	61 [b] (1.1)
W2 - L1	31 [a] (0.7)	35 [b] (0.7)	51 [c] (0.9)
W2 - L2	56 [a] (1.9)	57 [a] (1.3)	77 [b] (1.8)
W2 - L3	44 [a] (1.3)	49 [a] (1.1)	58 [b] (1.2)
W1 - W2	206 [a] (4.5)	176 [b] (4.6)	105 [c] (2.3)

Table 3 - Seven measurements (in mm) recorded for the Texel, Wiltshire Horn and Texel x Wiltshire Horn adult ewes (n=30 for each breed), together with the corresponding indices which have been derived by expressing the size of the first variable as a percentage of the second variable. SEM values are shown in parenthesis. Values within rows which are not significantly different (P>0.05) share a superscript.

	Texel	Wiltshire	Texel x Wiltshire
W1	146 [a] (1.4)	151 [a] (2.8)	144 [a] (1.8)
W2	74 [a] (1.6)	73 [a] (1.2)	73 [a] (1.1)
W3	107 [a] (2.3)	107 [a] (2.2)	104 [a] (2.2)
W4	94 [a] (1.7)	94 [a] (1.7)	99 [a] (1.3)
L1	230 [a] (2.0)	259 [a] (1.4)	247 [a] (1.8)
L2	185 [a] (2.5)	172 [a] (2.4)	172 [a] (2.6)
L3	178 [a] (2.9)	178 [a] (4.7)	166 [a] (1.8)
W1 - L1	63 [a] (0.6)	59 [b] (1.1)	58 [b] (0.7)
W1 - L2	79 [a] (0.9)	88 [b] (1.7)	84 [ab] (1.6)
W1 - L3	83 [a] (1.3)	87 [a] (2.3)	87 [a] (1.5)
W2 - L1	32 [a] (0.6)	28 [b] (0.5)	30 [ab] (0.5)
W2 - L2	40 [a] (0.8)	43 [a] (0.9)	43 [a] (1.0)
W2 - L3	42 [a] (1.4)	42 [a] (1.3)	44 [a] (0.7)
W3 - L1	51 [a] (1.0)	41 [b] (0.8)	42 [b] (1.0)
W3 - L2	63 [a] (1.2)	62 [a] (1.5)	61 [a] (1.7)
W3 - L3	66 [a] (1.5)	61 [a] (1.7)	63 [a] (1.1)
W4 - L1	46 [a] (0.8)	37 [b] (0.7)	40 [c] (0.6)
W4 - L2	57 [a] (1.2)	55 [a] (1.2)	58 [a] (1.4)
W4 - L3	60 [a] (1.6)	55 [a] (1.8)	59 [a] (0.8)
W1 - W2	201 [a] (4.2)	213 [a] (6.8)	199 [a] (4.3)
W1 - W3	126 [a] (2.2)	145 [b] (3.9)	140 [b] (3.7)
W1 - W4	140 [a] (2.9)	165 [b] (5.2)	148 [ab] (3.2)
W2 - W3	63 [a] (1.2)	70 [ab] (1.8)	71 [b] (1.2)
W2 - W4	70 [a] (1.1)	78 [b] (1.0)	74 [ab] (0.8)
W3 - W4	112 [a] (2.0)	115 [a] (3.0)	106 [a] (1.8)

mandible angle to the rostral aspect of the lower lip [L2] was significantly longer in Suftexs ($\bar{x}$=158 mm, SEM=2.3) than Ryelands ($\bar{x}$=140 mm, SEM=3.9), but neither differed significantly from that of the intermediate Southdowns ($\bar{x}$=149 mm, SEM=4.1).

Group 2

The data for adult Texel, WH and Texel x WH cross ewes are shown in Table 3. Differences in absolute values for these breeds were not significant (P>0.05).

However indices derived from these measurements showed significant differences. In some indices the parental breeds were significantly different, but cross ewes had intermediate values and were not significantly different from either parent. One such an index was the ratio between L1 (length from nuchal crest to aspect of upper lip) relative to W1 (width between ears).

In other indices, cross ewes were not significantly different from WHs, but both cross ewes and the WHs were significantly different from Texels e.g. L1 (length from nuchal crest to aspect of upper lip) relative to W3 (width between caudoventral aspects jaws).

There were no indices where crosses showed similarity to Texels but not to the WHs.

One index, W4 (width between caudal aspect of diastema) relative to L1 (length from nuchal crest to rostral aspect of upper lip) was significantly different in all 3 breeds, with values for crossbreds intermediate between those for pure breeds.

Finally, there was an example where Texels and WHs were not significantly different, but cross ewes were significantly different from either pure breed. This was seen when comparing W2 (width at rostral aspect of diastema) relative to W3 (width between caudoventral aspects of jaws). It was assumed that this observation was due to proportions of the Texel and WH head shapes being similar, but that proportions in crosses were different.

Group 3

All animals were around 6 months old when measured. At this age some measurements were already different, although this could be due to developmental differences between breeds, rather than interbreed differences in mature animals.

For example the width between the ears [W1] differed based on a combination of breed and gender factors, with male Suffolks having the largest means ($\bar{x}$=154 mm, SEM=2.8) and female BHCs having the smallest mean value ($\bar{x}$=90 mm, SEM=1.3).

Examples were seen where cross lambs had values more similar to those of the BHCs than those of Suffolks. For example the length from the caudal aspect of the hinge of the lower jaw to the nasal tip [L3], where differences were not significant between crosses and BHCs (P>0.05), irrespective of gender (mean lengths ranged from 178-181 mm). However this value was significantly longer in Suffolk females ($\bar{x}$=187 mm, SEM=1.6), and males ($\bar{x}$=206 mm, SEM=3.2).

The opposite was seen in other examples. The index derived by comparing L2 (length from caudoventral aspect of angle of mandible to rostral aspect of lower lip) relative to W2 (width at rostral aspect of diastema) was not significantly different (P>0.05) in Suffolk lambs and cross lambs with males ($\bar{x}$=26 in both breeds) and females ($\bar{x}$=25 in both breeds). However the mean BHC values were significantly shorter (23 and 21 for males and females respectively).

As well as interbreed differences, gender differences were observed. For example the length from the nuchal crest to the rostral aspect of the upper lip [L1]. In this case male BHCs ($\bar{x}$=224 mm, SEM=2.1) and male crosses ($\bar{x}$=218 mm, SEM=2.5) were not significantly different (P>0.05), and female BHCs ($\bar{x}$=208 mm, SEM=2.8) and female crosses ($\bar{x}$=208 mm, SEM=2.3) were not significantly different (P>0.05). However both lengths in males were significantly (P<0.05) longer than in females.

Indices were also observed with differences between breeds and genders. For example the ratio between W4 (width at caudal aspect of diastema) and L1 (length from nuchal crest to rostral aspect of upper lip). Male and female Suffolks, ($\bar{x}$=22, SEM=0.7 and $\bar{x}$=22, SEM=0.7 respectively) did not differ significantly (P<0.05). Likewise male and female BHCs, ($\bar{x}$=20, SEM=0.4 and $\bar{x}$=20, SEM=0.5 respectively)

Table 4 - Nine measurements (in mm) recorded for the Suffolk, Brecknock Hill Cheviot and Suffolk x Brecknock Hill Cheviot lambs (25 males and 25 females for each breed), together with the corresponding indices which have been derived by expressing the size of the first variable as a percentage of the second variable. SEM values are shown in parenthesis. Values within rows which are not significantly different (P>0.05) share a superscript.

	Suffolk		Brecknock Hill Cheviot		Suffolk x Cheviot	
	Male	Female	Male	Female	Male	Female
W1	154 ^{a} (2.8)	131 ^{b} (2.1)	102 ^{c} (1.8)	90 ^{d} (1.3)	138 ^{e} (2.2)	112 ^{f} (2.6)
W2	44 ^{a} (1.12)	39 ^{b} (1.0)	36 ^{c} (0.7)	32 ^{d} (0.6)	41 ^{b} (0.7)	38 ^{c} (0.5)
W3	97 ^{a} (2.0)	87 ^{b} (1.7)	78 ^{c} (1.3)	74 ^{d} (1.2)	84 ^{b} (1.6)	69 ^{e} (1.2)
W4	58 ^{a} (1.2)	55 ^{b} (1.4)	44 ^{c} (0.9)	41 ^{d} (0.8)	49 ^{e} (1.1)	42 ^{cd} (0.7)
L1	266 ^{a} (5.8)	249 ^{b} (3.8)	224 ^{c} (2.1)	208 ^{d} (2.8)	218 ^{c} (2.5)	208 ^{d} (2.3)
L2	176 ^{a} (3.6)	160 ^{bc} (2.4)	160 ^{bc} (1.8)	156 ^{bde} (1.7)	160 ^{cd} (2.1)	151 ^{e} (1.8)
L3	206 ^{a} (3.2)	187 ^{b} (1.6)	178 ^{c} (1.9)	178 ^{c} (1.5)	181 ^{c} (2.4)	178 ^{c} (1.3)
L4	346 ^{a} (4.8)	323 ^{b} (3.2)	273 ^{c} (3.4)	259 ^{d} (3.0)	271 ^{c} (4.1)	273 ^{c} (2.6)
L5	228 ^{a} (2.82)	213 ^{b} (2.3)	191 ^{c} (1.6)	180 ^{d} (1.3)	190 ^{c} (1.6)	187 ^{c} (1.6)
W1 - L1	58^{a} (1.5)	53 ^{b} (1.2)	46 ^{c} (0.9)	44 ^{c} (0.9)	63 ^{d} (1.3)	54 ^{b} (1.4)
W1 - L2	88 ^{a} (2.9)	83 ^{a} (1.9)	64 ^{b} (1.3)	58 ^{c} (1.0)	86 ^{a} (1.7)	74 ^{d} (1.9)
W1 - L3	75 ^{a} (1.7)	70 ^{b} (1.4)	57 ^{c} (1.1)	51 ^{d} (0.9)	77 ^{a} (1.6)	63 ^{e} (1.4)
W1 - L4	45 ^{a} (0.8)	41 ^{b} (0.7)	37 ^{c} (0.6)	35 ^{d} (0.7)	51 ^{e} (1.)	41 ^{b} (1.0)
W1 - L5	68 ^{a} (1.1)	62 ^{b} (1.2)	54 ^{c} (1.2)	50 ^{d} (0.8)	73 ^{e} (1.3)	60 ^{b} (1.4)
W2 - L1	17 ^{ab} (0.6)	16 ^{a} (0.5)	16 ^{a} (0.4)	16 ^{a} (0.4)	19 ^{c} (0.4)	18 ^{bc} (0.3)
W2 - L2	26 ^{a} (1.0)	25 ^{a} (0.6)	23 ^{b} (0.5)	21 ^{c} (0.4)	26 ^{a} (0.5)	25 ^{a} (0.4)
W2 - L3	22 ^{ab} (0.6)	21 ^{a} (0.6)	20 ^{a} (0.4)	18 ^{c} (0.3)	23 ^{b} (0.4)	21 ^{a} (0.3)
W2 - L4	13 ^{a} (0.3)	12 ^{a} (0.4)	13 ^{a} (0.3)	13 ^{ab} (0.3)	15 ^{c} (0.3)	14 ^{b} (0.2)
W2 - L5	19 ^{ab} (0.5)	19 ^{ac} (0.6)	19 ^{ac} (0.4)	18 ^{c} (0.3)	22 ^{d} (0.4)	20 ^{b} (0.3)
W3 - L1	37 ^{ab} (1.2)	35 ^{ac} (0.9)	35 ^{ad} (0.7)	36 ^{a} (0.7)	39 ^{b} (0.8)	33 ^{cd} (0.7)
W3 - L2	55 ^{a} (1.2)	55 ^{a} (1.1)	49 ^{b} (1.0)	48 ^{bc} (0.8)	53 ^{a} (1.1)	46 ^{c} (1.0)
W3 - L3	47 ^{a} (1.0)	47 ^{a} (1.0)	44 ^{b} (0.7)	42 ^{c} (0.7)	47 ^{ab} (1.1)	39 ^{d} (0.7)
W3 - L4	28 ^{a} (0.7)	27 ^{a} (0.6)	29 ^{a} (0.7)	29 ^{a} (0.5)	31 ^{b} (0.7)	25 ^{c} (0.5)
W3 - L5	43 ^{ab} (0.9)	41 ^{a} (1.1)	41 ^{a} (0.7)	41 ^{a} (0.7)	44 ^{b} (0.9)	37 ^{c} (0.6)
W4 - L1	22 ^{a} (0.7)	22 ^{a} (0.7)	20 ^{b} (0.4)	20 ^{b} (0.5)	22 ^{a} (0.5)	20 ^{a} (0.5)
W4 - L2	33 ^{a} (0.9)	35 ^{a} (1.0)	28 ^{bc} (0.6)	26 ^{b} (0.5)	30 ^{d} (0.7)	28 ^{c} (0.5)
W4 - L3	29 ^{ab} (0.7)	30 ^{a} (0.9)	25 ^{c} (0.5)	23 ^{d} (0.4)	27 ^{b} (0.8)	24 ^{cd} (0.5)
W4 - L4	17 ^{abc} (0.5)	17 ^{ac} (0.5)	16 ^{abd} (0.2)	16 ^{be} (0.4)	18 ^{c} (0.5)	16 ^{de} (0.3)
W4 - L5	26 ^{a} (0.6)	26 ^{a} (0.8)	23 ^{b} (0.5)	23 ^{b} (0.4)	26 ^{a} (0.7)	23 (0.4) ^{b}
W1 - W2	266 ^{a} (6.9)	241 ^{b} (5.4)	232 ^{bc} (4.3)	223 ^{c} (5.8)	286 ^{a} (7.6)	266 ^{a} (7.3)
W1 - W3	352 ^{a} (8.6)	337 ^{a} (8.5)	284 ^{b} (5.4)	281 ^{b} (5.3)	337 ^{a} (6.4)	299 ^{b} (8.7)
W1 - W4	161 ^{ab} (4.7)	152 ^{a} (3.5)	131 ^{c} (3.3)	122 ^{d} (2.3)	165 ^{b} (3.8)	162 ^{ab} (4.3)
W2 - W3	47 ^{ab} (1.2)	46 ^{a} (0.8)	47 ^{ab} (0.9)	44 ^{a} (0.6)	50 ^{b} (0.9)	54 ^{c} (0.8)
W2 - W4	77 ^{ab} (1.4)	71 ^{a} (1.3)	81 ^{cd} (1.3)	80 ^{bc} (1.2)	87 ^{de} (1.3)	89 ^{e} (1.3)
W3 - W4	167 ^{ab} (3.7)	160 ^{a} (4.4)	179 ^{c} (4.7)	182 ^{c} (3.9)	174 ^{bc} (3.7)	165 ^{ab} (3.4)

were not significantly (P<0.05) different. However male crosses ($\bar{x}$=22, SEM=0.5) were more similar to Suffolks and female crosses ($\bar{x}$=20, SEM=0.5) were more similar to BHCs. A similar pattern was seen for the index derived from W4 (width at caudal aspect of diastema) relative to L5 (length from poll to top lip); male crosses being more similar to Suffolks and female crosses being more similar to BHCs.

DISCUSSION

Previous studies of sheep craniometrical measurements tend to have concentrated on using skulls without soft tissue. The two exceptions to this[13-14], were part of a wider range of measurements across the body. Therefore, as far as we are aware, this is the first comparison of craniometrical measurements between breeds in a single paper, and the first analysis of multiple head measurements in live sheep. The current work uses data collected by three individuals from different sites. Therefore no comparison has been made between groups, to avoid potential inter-experimenter variation. In addition, groups 1 and 2 involved adult animals, but group 3 used younger animals, again meaning comparisons across all groups were not appropriate. Repeating measurements by a single experimenter could have allowed comparisons between groups, but animals were measured during routine handling after which some animals were sold, meaning they were not available for retrospective measurements.
The work involved measurements with a tape, rather than callipers as these sheep were not used to being handled, and so minimised stress levels with rapid recording of data. However SEM values within groups (Tables 2 to 4) were all relatively low, suggesting low variability within single samples, supporting the assumption that tapes gave adequately reliability.
The first set of analysis were performed primarily to demonstrate that differences (e.g. W1) between breeds could be detected using a measuring tape with low variability. Therefore measurements undertaken were the five which were felt could be made rapidly and would involve minimal stress to the animals. Using these values it was possible to demonstrate that statistically significant (P<0.05) interbreed differences could be detected in terms of absolute values, and also in indices derived from these measurements. Moreover, statistical analysis of these identified statistically significant differences. In this example, two of the breeds were unrelated purebred lines, and the third breed was a cross which was not derived from either of these. Thus no relationship comparisons were performed between the three sets of animals.
The second analysis used two pure breeds; Texels and WHs, and a cross derived by mating Texel rams and WH ewes. A further two measurements were included, again ones which it was felt could be made rapidly and with minimal stress. As above only adult ewes were used. This group was used to examine if particular distances or indices in the crosses were more similar to those seen in specific parents. Two indices were not significantly (P>0.05) different in the WHs and crosses, but significantly different (P<0.05) in Texels relative to the other breeds; ratio of the width between the ears [W1] relative to width between the caudoventral aspects of jaws [W3], and ratio of the width at the rostral aspect of the diastema [W2] relative to width at the caudal aspect of the diastema [W4]. The values in the cross ewes were more similar to those in WH ewes, suggesting these traits may show a genetic bias.
In this group there were also two examples where crosses had intermediate values, which were not significantly different (P>0.05) from either parental breed, but both parental breeds differed significantly (P<0.05) from each other; ratio of the length from the nuchal crest to the rostral aspect of the upper lip [L1] relative to width at the rostral aspect of the diastema [W2], and ratio of width between the ears [W1] relative to width at the caudal aspect of the diastema [W4].
Both of the first two groups used data from adult ewes, meaning potential gender differences were not considered. Primarily this was due to individual farms generally have enough adult ewes available to allow comparisons, but insufficient adult rams to permit this. In mammals males tend to be larger and heavier, a factor which prompted the third study involving males and female from two pure breeds (BHCs and Suffolks), and crosses produced from BHC ewes and Suffolk rams. However, routinely insufficient males are retained for breeding, meaning analysis were restricted to animals at 6 months, rather than adults as above. A further two measurements were included at this point, again ones which could be carried out rapidly and with minimal stress.
The length from the nuchal crest to the rostral aspect of the upper lip [L1] in male BHC lambs ($\bar{x}$=224 mm, SEM=2.1) and male crosses ($\bar{x}$=218 mm, SEM=2.5) were not significantly different, and those in female BHC lambs ($\bar{x}$=208 mm, SEM=2.8) and female cross lambs ($\bar{x}$=208 mm, SEM=2.3) were also not significantly different, suggesting this length in the cross lambs had more in common with the equivalent length in BHC lambs of the same sex.
The length from the caudal aspect of the hinge of the lower jaw to the nasal tip was not significantly different between the BHC and cross lambs; irrespective of gender. Neither of these factors was observed in Group 2 study using Texels, WHs and their cross.
It is worth noting that the mean length from the akrokranion to the rostral aspect [L4] of the upper lip and the mean length from the poll to the top lip [L5], measurements not recorded in the previous two groups, both showed significant similarity in length in cross lambs of both sexes relative to the equivalent distance in male BHC lambs.
Some indices provided interesting comparisons for preliminary comparisons between groups - albeit they were carried out by different individuals. For example the ratio of width between the ears [W1] relative to width between the caudoventral aspects of left and right jaws [W3], where Texel x WH crosses were more similar to WHs (maternal line) than Texels, but BHC x Suffolk crosses (both genders) showed more similarity to male Suffolks (i.e. the paternal lineage).
The ratio between the length from the nuchal crest to the rostral aspect of the upper lip [L1] and width between the ears [W1] was not significantly different (P>0.05) between Suffolk females and female BHC x Suffolk crosses. This pattern was repeated for the length from the poll to the top lip [L5] relative to width between the ears [W1], with similar values between Suffolk females and female BHC x Suffolk crosses, again similarity with the maternal lineage.
In other cases there was similarity between Suffolk males and male BHC x Suffolk crosses. There was no significant difference in ratios between the length from the caudal as-

pect of the hinge of the lower jaw to the nasal tip [L3] relative to width between the ears [W1], and the length from the caudoventral aspect of the angle of the mandible to the rostral aspect of the lower lip [L2] relative to width between the ears [W1].

The ratio of width at the rostral aspect of the diastema to the length from the caudoventral aspect of the angle of the mandible to the rostral aspect of the lower lip was similar in both the Suffolk lambs and BHC x Suffolk crosses. However the values for the BHCs showed significant ($P<0.05$) gender differences. This group identified potential gender differences for one index; ratio of the length from the nuchal crest to the rostral aspect of the upper lip [L1] relative to width at the caudal aspect of the diastema [W4], where male crosses were more similar to Suffolks (both genders), but the female crosses more similar to BHCs (both genders).

The full implications of this work are unclear as this is the first investigation in sheep on this scale. The role of craniometrical parameters in understanding problems in dogs has been clear for some time (e.g.[2]) with more detailed recent studies (e.g.[5]), particularly the role of head shape to health issues such as birthing and respiratory problems in brachycephalic dogs. However factors affecting heads are being implicated as important in understanding pain and stress in sheep[20].

It is in these areas that analysing craniometrical parameters, and estimating what constitutes normal, may have a future impact on sheep breeding. In some sheep breeds head size and shape can pose lambing problems. It has been estimated that dystocia accounts for around half of deaths in lambs in the first 72 hours after birth[21], i.e. around 7% of lambs born. Although lambing difficulties vary between breed and are not restricted to the lamb's head, these pose major problems at lambing time, particularly when numbers are considered at both national and international levels.

Furthermore, some sheep breeds, as with some brachycephalic dogs, are prone to respiratory and breathing problems e.g. laryngeal chondritis. Therefore an exploration of a potential linkage between head morphology and traits such as respiratory problems later in life is worth further exploration.

In conclusion, this work is the first to carry out interbreed comparisons of a range of craniometrical parameters in live sheep. Examples of differences were found between breeds, including some suggesting that some parameters in the cross breeds are more similar to one of the parental breeds than the other, and also examples of intermediate mean values. Moreover, differences within breeds could be seen between male and female lambs, including an example where the male cross lambs showed more similarity to the paternal breed and the ewe lambs showed more similarity to the maternal breed.

Nine breeds, or crosses of breeds were studied in the current work, and up to nine measurements were made for each breed. These data for variation between breeds in terms of head measurements and craniometrical indices derived from them, may argue for head measurements becoming a topic worth investigating in more detail, using more measurements than those used in the current work. Moreover the range of domesticated breeds which exist internationally, coupled with other species in the *Ovis* genus and other genera in the Caprinae Subfamily, argue that there is scope for further craniometric measurements in other animals to understand these relationships.

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