

Research article

Lesions in sheep elbows: Insights from a large-scale study

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ABSTRACT

Objectives: Enthesophytes on sheep elbow joints are commonly reported in archaeological material. Although these lesions are often described as ‘penning elbow’, little is known of their aetiology. In this study, a new method for recording these lesions is presented, and the effect of age, sex and body size is explored to understand their potential for informing upon past human-animal interactions.

Materials: 1133 distal humeri and proximal radii from 16 archaeological sites.

Methods: The presence and severity of enthesophytes were recorded and findings compared with modern data from a group of 17 complete Soay sheep skeletons.

Results: Significant, positive correlations between age and body size and the presence of enthesophytes were demonstrated. Environmental factors and trauma may also play a role in their formation.

Conclusion: The aetiology of enthesophytes on sheep elbows is complex and varied, affected by age, body size and environment.

Significance: This is the first study of enthesophytes on sheep elbows to combine archaeological data with modern animals of known age and sex. Blanket explanations of husbandry methods for the cause of these lesions are dispelled, and use of the term ‘penning elbow’ is redundant.

Limitations: The sample of modern specimens is relatively small and would benefit from the inclusion of older individuals and those raised in different environments.

Future research: The method developed here can be adopted in future studies.

Interpretations should take age, size and environmental factors into consideration, and only when these variables are established can the role of husbandry be evaluated.

1. Introduction

The sheep elbow is a synovial hinge joint comprising the distal humerus, proximal radius and proximal ulna, united by interosseous ligaments. The lateral collateral ligament inserts on the humerus just above the lateral epicondyle, and in the radius just below the articular margin on the lateral tuberosity (Sisson and Grossman, 1975, 221) (Fig. 1). It is at these interfaces between hard and soft connective tissues (enthese) that bony spurs (enthesophytes) can develop in response to repetitive or acute biomechanical stress, or systemic inflammatory processes (Benjamin et al., 2006; Resnick and Niwayama, 1983; Villotte and Knüsel, 2013). Classification of human ligament attachments suggest that the lateral collateral ligament in the sheep elbow is a fibrocartilaginous enthesis as it occurs at the end of the bone and directly attaches to the bone, rather than indirectly via the periosteum (Benjamin et al., 2006). Recent work on reindeer has demonstrated that tendinous

enthesophytes are more likely to be present in large, male animals, on joints subject to repeated activity (i.e. digging for lichen) and in animals used for draught purposes (Niinimäki and Salmi, 2016; Salmi et al., 2020). Similar patterns are reported in the human palaeopathological literature, with enthesophytes precipitated by numerous variables such as age (Rogers et al., 1997; Villotte and Knüsel, 2013), sex, genetics (Rogers et al., 1997), trauma (Villotte and Knüsel, 2013) and high-level and/or repeated activity (al-Oumaoui et al., 2004). Specifically, enthesophytes are more likely to be found in older, larger, male individuals, and in the skeletons of ‘bone formers’: individuals that have elevated abilities to form bone in response to biomechanical stress (Rogers et al., 1997, 90). Enthesophytes resulting from trauma are less commonly referred to (e.g. Redfern and Roberts, 2019), though damage to tendons or ligaments resulting from fractures may precipitate enthesophyte formation (Resnick and Niwayama, 1983, 8).

Zooarchaeological observations of enthesophytes on the lateral

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Fig. 1. Diagram to show anterior and lateral views of the sheep humerus (A) and anterior and lateral views of the sheep radius (B), with points of insertion of the lateral collateral ligament highlighted: 1) on the lateral epicondyle; and 2) on the articular margin of the lateral tuberosity.

aspect of the sheep elbow joint demonstrate consistency in location and progression. They begin as a sharp margin of new bone at the enthesis, growing to a projection of several millimetres in the direction of the connective tissue and, in advanced cases, result in ankylosis of the joint (Baker and Brothwell, 1980, 127; Clark, 2009, 158). This lesion is peculiar to sheep, with no comparable pathology described in other taxa, even though the anatomy of other ruminants (e.g. goat, cattle, deer) is similar (Clark, 2009, 158; Salmi et al., 2020; Upex and Dobney, 2012, 202). The fact that the lesion is reported rarely in veterinary literature suggests that it is not commonly recognised in modern flocks. Exceptionally, Scott (2001) investigated severe lameness in ten sheep from south-east Scotland exhibiting arthropathy of the elbow joint marked by extensive enthesophyte and osteophyte formation. These were adult animals (between 2 and 5 years of age), the majority male, and their mobility was severely impeded. Radiographs and post-mortem examination of the bones revealed enthesophytes on the distal humerus and proximal radius consistent with the most severe lesions observed in archaeological material. Scott (2001) noted that the unusually high number of rams in the sample (50 %) contrasted with the low prevalence of entire males in the UK flock book (just 5 % of all sheep) and suggested that farmers were more likely to seek veterinary advice for expensive male animals than ewes exhibiting the same symptoms. However, Scott (2001) also suggested that rapid growth, and the greater body mass of males may have been predisposing factors in lesion formation.

While enthesophytes on the humeral-radial joint are often recorded in zooarchaeological assemblages, they are rarely discussed in detail (though see Clark, 2009; Dobney et al., 2007). One of the consistently cited causes of these lesions is husbandry, specifically the act of confining sheep, which has resulted in the application of the term ‘penning elbow’ to characterise both the lesion and its cause (e.g. Albarella, 2004; Harman, 1985; O’Connor, 1984; West, 1995). This nomenclature originated from one of the first books describing these lesions, which in turn cites the source as “shepherds who recognise the condition” (Baker and Brothwell, 1980, 127). This interpretation is plausible as the elbow joint is exposed and surrounded by little soft tissue, so it is at risk from penetrating and non-penetrating wounds, which in turn may stimulate ossification at the ligament attachment site (Bartosiewicz and Gál, 2013, 118; Scott and Sargison, 2012, 19). Enthesophytes resulting from a fracture to a sheep elbow joint have been recorded archaeologically (Harman, 1985, 79); however, these lesions are likely to have developed in response to the altered biomechanical loading resulting from the fracture repair.

Increasing diagnostic rigour in zooarchaeological palaeopathology has undermined uni-causal, anthropocentric explanations of several lesions following systematic analysis of known-history populations (e.g. Fabiš and Thomas, 2011; Thomas and Grimm, 2011; Thomas et al., 2018). The only large-scale study of this kind investigating ‘penning elbow’ was conducted by Clark (1994), who recorded lesions from a

Table 1

Summary of the case study sites recorded for the FeedSax project. No.= location number on Fig. 2; Elev.= elevation in metres above ordnance datum; landscapes are taken from the National Character map (Natural England, 2012).

No.	Site	County	Landscape	Elev.	Dates
1	28 Bow Street, London	Middlesex	Alluvial valley	19	600–750
2	Barking Abbey	Middlesex	Alluvial valley	12	500–1500
3	Cadley Road, Collingbourne Ducis	Wiltshire	Chalk down	133	700–900
4	Cook Street, Southampton	Hampshire	Clay vale	3	650–875
5	Eynsham	Oxfordshire	Clay vale	66	500–1330
6	Flaxengate, Lincoln	Lincolnshire	Alluvial vale	65	900–1400
7	French Quarter, Southampton	Hampshire	Clay vale	11	900–1350
8	High Street, Ramsbury	Wiltshire	Chalk down	121	750–1300
9	Ketton	Northamptonshire	Alluvial valley	46	850–1066
10	Lyminge	Kent	Chalk down	101	450–1300
11	Market Lavington	Wiltshire	Clay vale	91	400–1300
12	Quarrington	Lincolnshire	Alluvial vale	27	450–900
13	Stafford	Staffordshire	Alluvial valley	77	1100–1300
14	Stoke Quay, Ipswich	Suffolk	Clay vale	9	700–1500
15	Stratton	Bedfordshire	Alluvial valley	40	400–1350
16	West Parade, Lincoln	Lincolnshire	Alluvial vale	18	1050–1375
17	Flag Fen	Cambridgeshire	Fens	7	Modern
	Orkney sheep	North Ronaldsay	Rocky island	20	Modern
	Hirta Soays	Hirta	Rocky island	430	Modern

sample of 1426 bones of feral adult Orkney sheep living on the island of North Ronaldsay, Scotland. Clark concluded that there was no evidence to suggest that the condition reflected husbandry practices (Clark, 1994, 253). While this conclusion has been echoed in recent publications (Bartosiewicz and Gál, 2013, 118; Clark, 2009; Upex and Dobney, 2012, 203), the term ‘penning elbow’ remains widespread, even in work that acknowledges the lesion is unlikely to be caused by specific husbandry methods (for example Bendrey, 2014, 262; Dobney et al., 2007, 494; Maltby, 2008, 12).

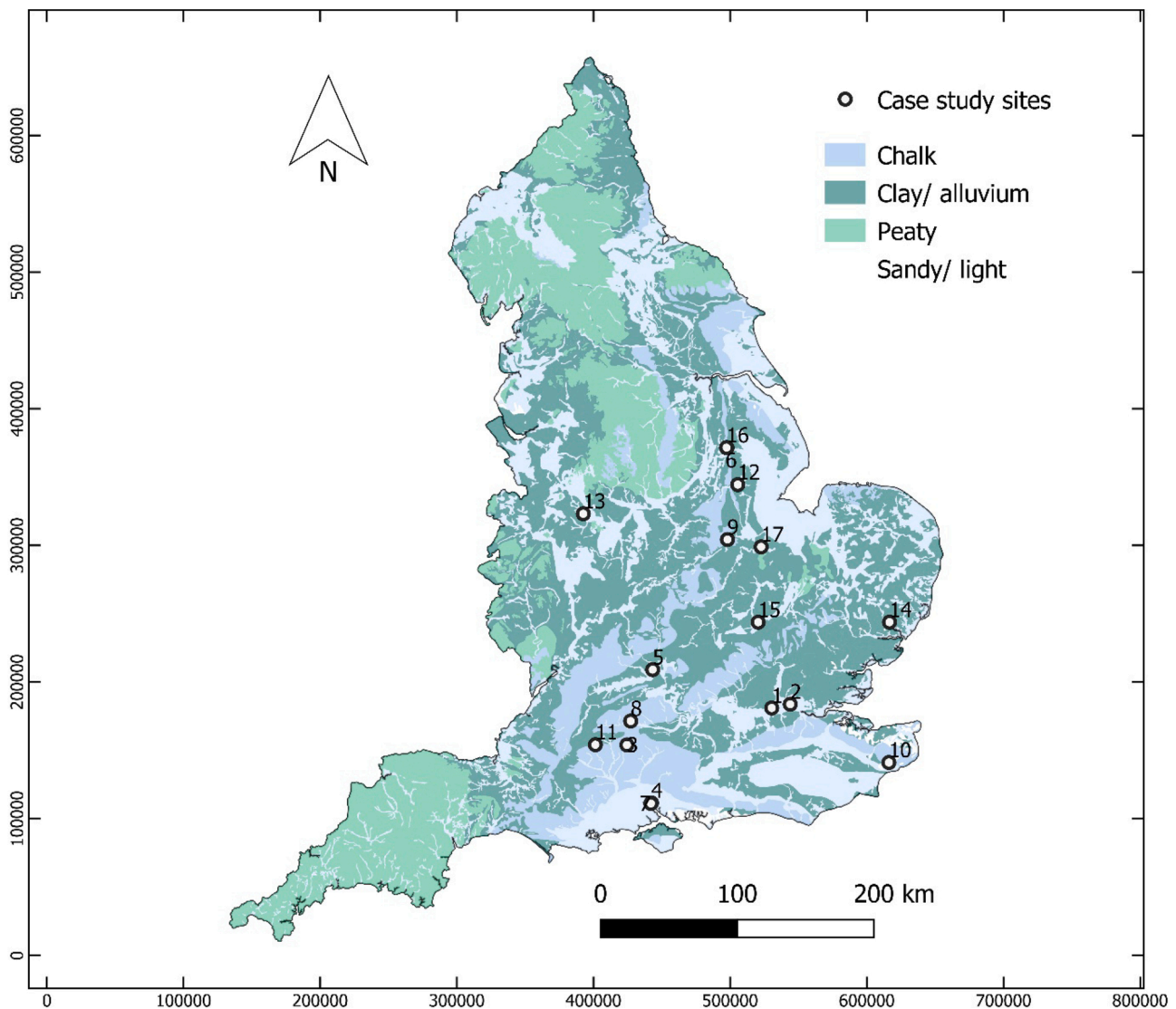


Fig. 2. Basic geological map of England (data from Lowerre et al. 2015) showing the location of case study sites and other sites referred to in the text (see Table 1 for details).

This study aims to provide a comprehensive review of the factors that can lead to the formation of enthesophytes on the elbow joints of sheep, specifically, age, sex/body size, environment and husbandry. Using a combination of modern sheep skeletons and archaeological material, these variables will be considered alongside the prevalence and severity of enthesophytes on the distal humerus and proximal radius. To this end, the following questions will be answered:

- 1 How common are enthesophytes affecting the distal humerus and proximal radius, and does the prevalence vary between the two bones?
- 2 Is it a condition affected by age?
- 3 Is it a condition affected by the size of the individual?
- 4 Is it a condition affected by the sex of the individual?
- 5 Is it a condition affected by environment or husbandry?
- 6 What can the findings add to future studies of animal palaeopathology and sheep husbandry?

2. Materials and methods

2.1. Data

Archaeological sheep radii and humeri were recorded during research for the project *Feeding Anglo-Saxon England: the bioarchaeology of an agricultural revolution* (FeedSax) (Hamerow et al., 2020, 2019). One of the project aims was to investigate changes in animal husbandry in England between CE 450 and 1400, which involved the re-examination of several large animal bone assemblages from archaeological sites. Lesions of the elbow joint were recorded systematically as a possible avenue of evidence for sheep management. The sample under study comprised 1133 elements (roughly split between the distal humerus and proximal radius) from 16 sites (Table 1, Fig. 2).

Modern data were captured from a collection of 17 complete Soay sheep skeletons from the Flag Fen visitor centre, Cambridgeshire (Table 1), curated at the Institute of Archaeology, University College London. The skeletons were recorded and prepared by Hawkes (1998), who noted that the animals were pastured on grass for much of the year. Additional hard feed was provided during the lambing season, summer and autumn as required, and during winter they were kept in a barn and fed hay and hard feed. Six sheep were casualties of a dog attack, six died

Table 2

Demography of the Flag Fen sheep (from [Hawkes, 1998](#)). Male/female distinctions in parentheses have been determined using pelvis morphology.

Specimen	Sex	Age range
10180	(Female)	2–3 years
10181	(Female)	1–2 years
10182	(Female)	2–3 years
10183	(Female)	3–4 years
10184	(Male)	6–12 months
10185	(Female)	3–4 years
10186	Female	2–3 years
10187	Female	2–3 years
10188	Female	2–3 years
10189	Female	6–12 months
10190	Female	6–12 months
10191	Female	6–12 months
10192	Castrate	4–6 years
10193	Male	6–12 months
10194	Castrate	2–3 years
10195	Castrate	6–12 months
10196	Castrate	1–2 years

during lambing and the remaining five were euthanised when they could no longer eat comfortably due to dental problems. The absence of paper records for the Flag Fen sheep means that individual life histories are uncertain, but specimens came from ewes, rams and wethers (castrated males) aged from six months to six years of age ([Table 2](#)).

To contextualise the results, comparisons are drawn from the modern study of Orkney sheep from North Ronaldsay, Scotland ([Clark, 1994](#)) and the description of Soay sheep from Hirta, Scotland ([Clutton-Brock et al., 1990](#)) ([Table 1](#)), which included detailed recording of pathologies.

2.2. Recording

Recording methods were identical for archaeological and modern material, applying the following criteria to each bone.

- Goats were identified in the archaeological sample using the methods of [Zeder and Lapham \(2010\)](#) and excluded.

- Element, side, anatomical zones ([Serjeantson, 1996](#)) and the state of fusion of the epiphyses (fused, fusing, unfused) were recorded.
- The following measurements were taken following [von den Driesch \(1976\)](#): greatest length (GL) of complete, fully fused bones; proximal breadth (Bp) and depth (Dp) and shaft diameter (SD) of radii; breadth of trochlea (BT), and height of the trochlea constriction (HTC) (following [Payne and Bull \(1988\)](#)) of humeri. Humerus Bd and radius Bp were not included as they are often distorted by the presence of enthesophytes.
- Eburnation was recorded as present or absent.
- Enthesophytes were scored on a four-point scale ([Figs. 3 and 4](#)).
 - o Stage 0: the margin of the enthesis is rounded and smooth in the radius, and smooth and regular in the humerus.
 - o Stage 1: the margin of the enthesis develops a distinctly sharp and roughened edge up to 1 mm from the margin
 - o Stage 2: the enthesophyte is well established, forming a projection over 1 mm in length. In the radius the maximum height of the enthesophyte will reach two thirds the height of the caput radii. In the humerus the enthesophyte only projects laterally.
 - o Stage 3: the enthesophyte has grown over two thirds the height of the caput radii, and in the humerus has started to project cranially.

Although the presence or absence of enthesophytes is easy to discern, recording the extent of changes or classifying stages is appreciably subjective ([Clark, 1994, 203](#); [Villotte and Knüsel, 2013, 138](#)). Notwithstanding, the criteria described here can be applied to the elbow joint of any taxon, and are relative to the anatomy of the element, so they are not affected by the size of the individual.

2.3. Ageing

Direct ageing data for archaeological samples of sheep radii and humeri were available in the form of epiphyseal fusion ([Silver, 1969](#)). Three age stages were recorded for complete bones: (1) early-fusing, where the distal epiphysis of the humerus was attached to the metaphysis, but the fusion line was still partly open or visible; (2) early-fused, where the distal humerus or proximal radius was fused and the fusion



Fig. 3. Scoring protocol used to describe enthesophytes on the distal humerus (anterior view). Arrow depicts the beginning stage of enthesophyte formation.



Fig. 4. Scoring protocol used to describe enthesophytes on the proximal radius (anterior view). Arrow depicts the beginning stage of enthesophyte formation.

Table 3

Description of fusion stages. Ages of fusion in the majority of cases given in months from Moran and O'Connor (1984) and Popkin et al (2012). NB: the proximal radius fuses very early, and the fusion line is quickly obliterated, so the early-fusing stage is excluded for this element. Fusing refers to instances where the epiphysis and metaphysis is attached, but the line of fusion is still visible.

Element	Stage	Description	Moran and O'Connor		Popkin et al	
			Male/ female	Castrate	Male/ female	Castrate
Humerus	Early fusing	Proximal unfused, Distal fusing	6–10.5			
Radius	Early fused	Proximal fused, Distal unfused	0–40	0–36	<7–31	<7–40
Humerus	Early fused	Proximal unfused, Distal fused	9–36	11–32	<7–40	<7–43
Radius	Late fused	Proximal fused, Distal fused	>23	>32	>16	>28
Humerus	Late fused	Proximal fused, Distal fused	>36	>42	>16	>28

line was not visible, but the proximal humerus and distal radius remained unfused; and (3) those that were fully fused at both proximal and distal ends (Table 3). Although the range of ages that correlate to these stages in modern sheep varies considerably (Table 3), it permits comparison between animals that died in the first year of life, in the first three to three and a half years, and those over 16 months respectively. This allows some understanding of how animals in the first few years of life are affected by enthesophyte formation, but cannot provide details of the prevalence of lesions in older or elderly animals. While there is overlap in the absolute ages between the early fused and late fused stages (Table 3), the former can provide some insight into the relative proportion of sheep with enthesophytes prior to three years of age.

2.4. Body size

Measurements of fused epiphyses were taken to investigate the effect of body size on the prevalence of enthesophytes on the elbow joint. Non-length measurements are particularly useful because they are reliable proxies for body mass (Scott, 1983, 1990). When using measurements of early-fusing epiphyses (as in this study), the influence of post-fusion growth needs to be addressed (Davis, 2000; Popkin et al., 2012). Measurements of complete bones were compared for early fused and late fused age-stages. There was no correlation between humerus HTC and BT measurements and fusion stage, which is consistent with other findings for HTC (Davis, 2000, 383; and, to some extent Popkin et al., 2012, 1780), although the size of the archaeological sample of complete bones is small and should be treated with caution. Radius Dp measurements were not included in studies of known-age sheep by Popkin et al. (2012), but there was a statistically significant difference in measurements for the two fusion groups ($T = 2.6$; $p = 0.009$), whereby later fused bones were larger than those from younger sheep. The use of Dp in metrical analysis was therefore also excluded, as it is not age independent.

2.5. Analysis

Data were compared using calculations of prevalence (Coggon et al., 2009, 10) and severity to reveal how widespread lesions were within each population, and how advanced their form was:

$$\text{Prevalence} = \frac{\text{number of observations of enthesophytes}}{\text{total number of elements}} \times 100$$

Table 4

Prevalence of enthesophytes on archaeological and modern material.

Sample	Element	Total N	N enthesophytes	Prevalence
Archaeological	Humerus			
	Left	291	78	26.8
	Right	304	68	22.4
	Total	595	146	24.5
	Radius			
Both	Left	276	36	13.0
	Right	264	37	14.0
	Total	540	73	13.5
	Both	1135	219	19.3
Modern	Humerus	34	1	2.9
	Radius	33	2	6.1
Both		67	3	4.5

$$\text{Severity} = \frac{\text{total score of enthesophytes (i.e. 0, 1, 2, 3)}}{\text{total possible score (i.e. number of elements} \times 3)} \times 100$$

Data analysis was undertaken using dedicated software (Coe, 2021; Hammer et al., 2001). Methods to evaluate effect size (quantifying the size of the difference between two groups) and corresponding confidence intervals were used as appropriate (Smith, 2018). Effect sizes were calculated using Hedge's g , because sample sizes were uneven (Durlak, 2009). Problems in absolute interpretations of effect sizes are recognised but, as a starting point, they were considered small at 0.20, medium at 0.50 and large at 0.80, and were then evaluated further using confidence intervals (Durlak, 2009). Odds ratios, a test to quantify the correlation between two groups (Szumilas, 2010), were used in the first instance to assess the association between basic physiological variables, such as the prevalence of enthesophytes recorded on humeri and radii, and between left and right sides.

3. Results

Enthesophytes of the elbow joint were more common in archaeological samples than modern material, presenting as 19 % and 4 % respectively. Within the modern sample, the presence of enthesophytes was unilateral, observed in different specimens on a right radius, left radius, and left humerus. This suggests that the cause was not systemic, but due to localised trauma or uneven biomechanical stress. It was not possible to determine if individuals were affected in both left and right limbs in the archaeological material, due to disarticulation. However, the difference in the proportion of enthesophytes between left and right elements was investigated using odds ratios, which was 0.79, 95 % CI [0.541, 1.144] for humeri, and 1.09 95 % CI [0.663, 1.78] implying little difference between the two (Table 4).

The humerus was almost twice as likely to exhibit enthesophytes as the radius in the archaeological sample, while twice as many radii as humeri were affected in the modern material (Table 4). The archaeological sample produced an odds ratio of 2.08, 95 % CI [1.527, 2.835], confirming the observation that humeri were more likely to exhibit enthesopathies than radii. Consequently, the two elements were separated during the following analysis to allow further differences to be observed.

3.1. Age

Unfortunately, there were relatively few complete bones in the archaeological dataset, particularly humeri, as these meat-bearing long bones are often butchered (Grant, 1987). Nonetheless, data for both the archaeological and modern material exhibited similar results (Table 5 and Fig. 5), with a strongly correlated, positive increase in the prevalence and severity of enthesophytes in older animals. The nil values for the modern early fusing/fused categories and archaeological early fusing humeri meant that they were unsuitable to test. The prevalence and severity of early fused and late fused archaeological elements were

Table 5

Summary statistics for the prevalence (prev.) and severity (sev.) of enthesophytes at different age stages for complete elements (see Table 3 for a description of age stages). Including the results of effect size (Hedges *g*) on early and late fused archaeological material showing 95 % confidence intervals.

Archaeological	Early Fusing		Early fused			Late fused			Early/late fused	
	mean	n	mean	n	SD	mean	n	SD	Hedges <i>g</i>	95 % CI
Humerus prev.	0	3	15.4	13	0.38	60	5	0.84	1.16	0.06,2.26
Humerus sev.	0	3	5.1	13	0.12	26.7	5	0.28	1.12	0.10,2.31
Radius prev.			1.4	72	0.12	20.3	64	0.76	0.60	0.26,0.95
Radius sev.			0.5	72	0.04	10.9	64	0.25	0.60	0.25,0.95

Modern	Early Fusing		Early fused		Late fused	
	mean	n	mean	n	mean	n
Humerus prev.	0	2	0	12	5	20
Humerus sev.	0	2	0	12	1.7	20
Radius prev.			0	17	13.3	15
Radius sev.			0	17	4.4	15

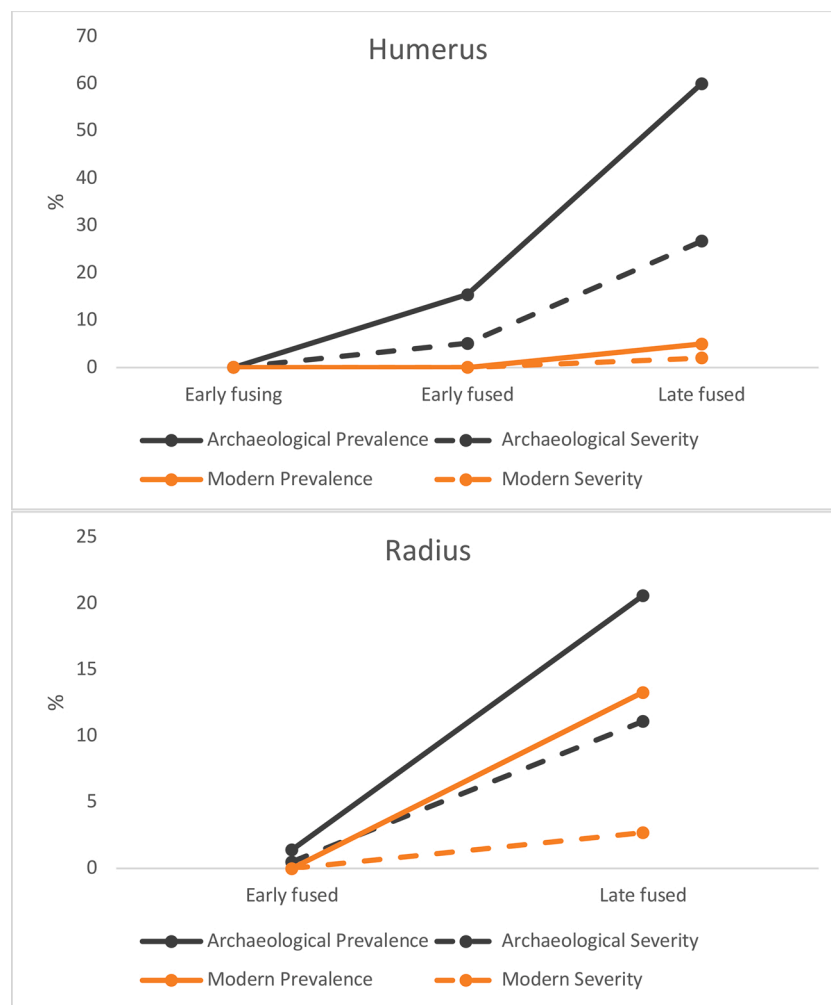


Fig. 5. Percentage of humeri and radii exhibiting enthesophytes by prevalence and severity (see Table 5 for details).

tested using Hedge's *g* (Table 5), which produced a large difference between younger and older sheep exhibiting enthesophytes in both the prevalence and severity of humerus scores, and a medium difference for the radius, with a moderate level of precision. The low proportion of animals exhibiting lesions at the early fused stage suggests that those with enthesophytes in the late fused group are likely to be over three years of age (Table 3). The increase in severity with age further implies that older sheep are not only more likely to have enthesophytes, but those lesions are likely to be more pronounced.

3.2. Body size

Body size was investigated using measurements of humerus BT and HTC and radius GL and SD. The effect size between archaeological groups was small for both humerus measurements and the radius SD, but large for the radius GL (Table 6). This can be observed in Fig. 6 where the size range of the humeri and radius SD with and without enthesophytes is similar, yet they were more commonly reported in larger radii. Enough archaeological data were present to investigate differences in

Table 6

Summary statistics and the results of effect size on archaeological material based on the presence or absence of enthesophytes using Hedges g showing 95 % confidence intervals.

	With enthesophytes			Without enthesophytes			Hedges g	95 % CI
	mean	n	SD	mean	n	SD		
Humerus HTC	28.1	133	1.6	27.6	407	1.7	0.29	0.16, 0.84
Humerus BT	14.0	135	0.9	13.8	417	0.8	0.24	0.04, 0.36
Radius GL	153.0	12	8.4	145.5	44	10.7	0.72	0.79, 14.21
Radius SD	17.2	9	1.7	16.8	15	1.5	0.25	0.58, 1.07

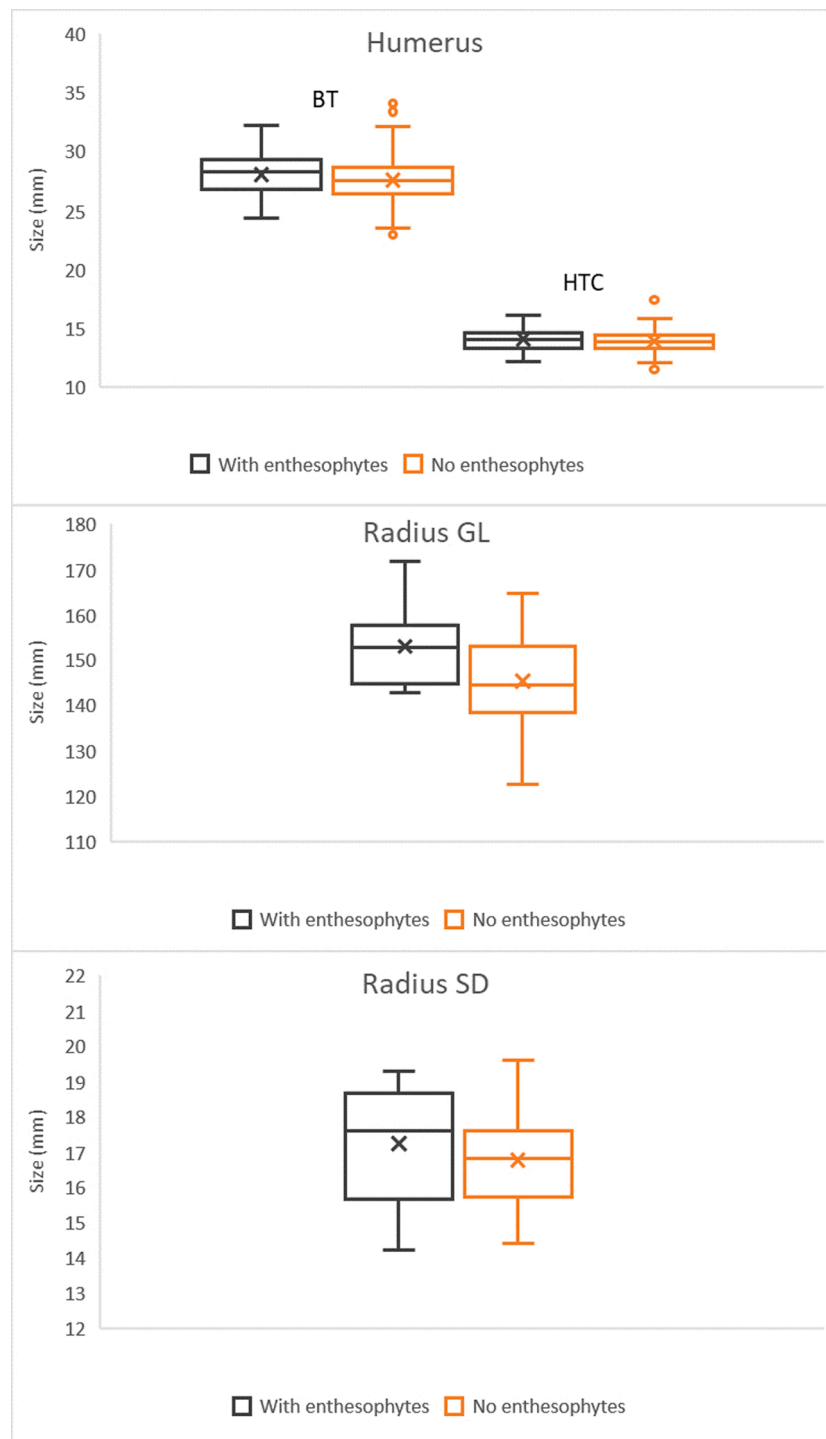


Fig. 6. Box plot of humerus and radius measurements for sheep with enthesophytes and those without from the archaeological sample.

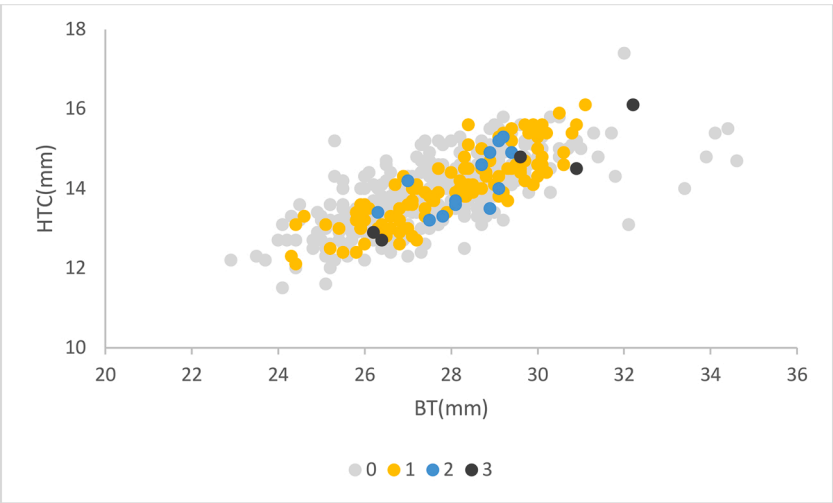


Fig. 7. Plot of humerus measurements showing number of enthesophytes at different stages of development. See Fig. 2 for details.

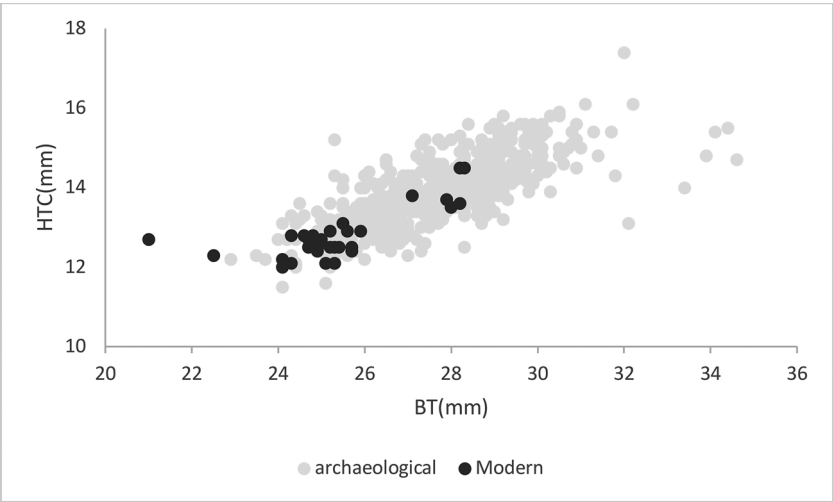


Fig. 8. Plot of humerus measurements for archaeological and modern sheep humeri.

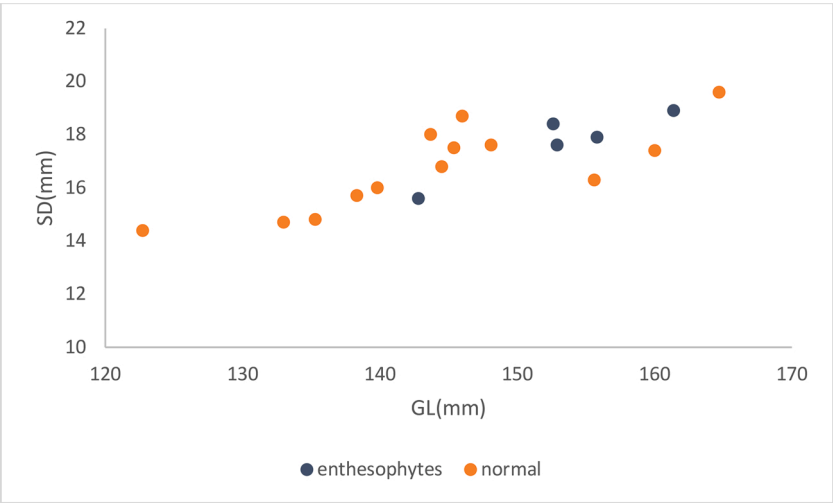


Fig. 9. The prevalence of enthesophytes on sex-dependant measurements in the radius.

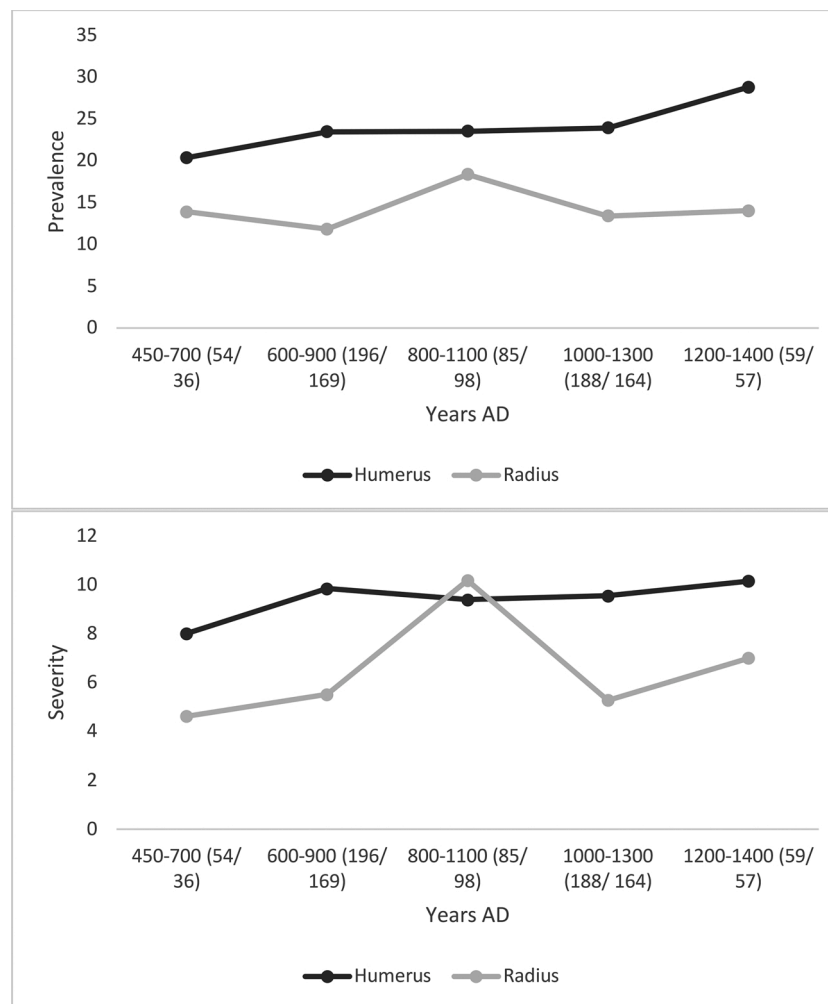


Fig. 10. Prevalence and severity of enthesopathies on the humerus and radius through time. (n/n)= sample sizes for humerus/radius.

the severity of enthesophytes recorded on humeri (Fig. 7), which revealed that most animals with more advanced lesions (i.e. at stages two or three) were generally within the top two thirds of the size range. A group of three smaller humeri with lesions reflect the findings of effect size, that body size alone does not influence enthesophyte formation on humeri.

The Flag Fen sample was too small to test statistically, although the elements with enthesophytes were in the mid-range of measurements taken. However, when the measurements of modern Soay sheep were compared with the archaeological data (Fig. 8), they plot at the small end of the range, and this diminutive size may explain the lower prevalence of enthesophytes in this sample (Table 4).

3.3. Sex

The ratio of radius length (GL) and diaphyseal diameter (SD) is a reliable indicator of sex in sheep (Popkin et al., 2012, 1791). Analysis of these measurements in the archaeological sample (18 bones) revealed that specimens with enthesophytes are more likely to be male (Fig. 9), with 9.1 % of females compared to 57.1 % of males exhibiting lesions. A different result was observed in the modern data, where all three skeletons with lesions were female based on the morphology of the pelvis.

3.4. Chronological trends

The mean prevalence and severity of enthesophytes calculated for the archaeological sample was considered through time (Fig. 10).

Results indicate an increase in all but radius prevalence values from the seventh century, and a peak in radius prevalence and severity in the ninth to twelfth centuries, before receding. With the exception of prevalence in the radius, values again increase from the thirteenth century.

3.5. Environment

The archaeological study sample was considered by topography and geology (Table 1). Urban sites (those from Ipswich, London, Lincoln, Southampton and Stafford) were excluded as sheep could potentially have originated from a wide geographical area. The remaining rural and elite assemblages were located on higher chalk downlands above 100 m, lower clay vales between 50 and 100 m, and alluvial valleys below 50 m (Fig. 11). Sample sizes were small, and the results inconclusive, but some sites on the chalk had the greatest prevalence of radial enthesophytes (Ramsbury and Lyminge) and severest humeral enthesophytes (Ramsbury and Collingbourne).

4. Discussion

The prevalence of enthesophytes is highly variable between populations (Table 7), being greater in the two island studies and very low in the sample from Flag Fen and many archaeological sites (Fig. 12).

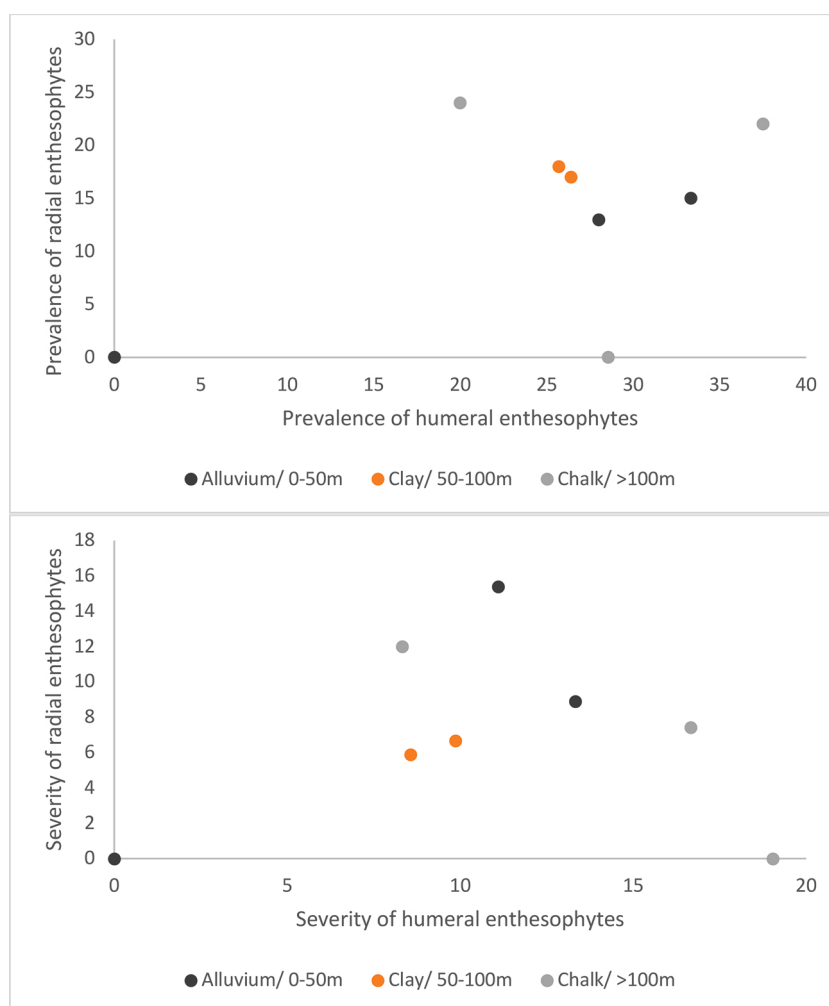


Fig. 11. Mean prevalence and severity of enthesophytes recorded in assemblages on various geologies and elevation (see Table 1 for individual site details).

Table 7

Data from the FeedSax dataset and other archaeological and modern assemblages. See Table 1 for site details.

	Humerus		Radius	
	Total	Prevalence	Total	Prevalence
28 Bow Street, London	17	17.6	32	6.3
Barking Abbey	12	33.3	13	15.4
Cadley rd, Collingbourne Ducis	7	28.6	5	0
Cook Street	14	14.3	16	0
Eynsham	125	26.4	110	17.3
Flaxengate, Lincoln	136	19.9	119	12.6
French Quarter, Southampton	43	34.9	57	8.8
High Street, Ramsbury	8	37.5	9	22.2
Lyminge	40	20.0	25	24.0
Market Lavington	35	25.7	17	17.6
Quarrington, Lincolnshire	5	0	8	0
Stoke Quay	93	29.0	89	11.2
Stratton	25	28.0	15	13.3
West Parade, Lincoln	31	19.4	20	30.0
Orkney sheep	190	38.4	156	34.0
Hirta Soay	no data	no data	162	22.8
Flag Fen Soay	34	2.9	33	6.1

4.1. Role of age

The correlation between age and the prevalence of enthesophytes (Fig. 5) is similar to findings in human palaeopathology, where age is considered the main causal factor (Villotte and Knüsel, 2013, 139). This

is emphasised when the nature of the modern collections is considered. Flag Fen sheep were relatively young (Table 2), yet the bones collected from North Ronaldsay and Hirta were biased towards the fused bones of adult sheep (Clark, 1994, 194; Clutton-Brock et al., 1990, 4). Although both authors suggest that a limited number of bones with one unfused metaphysis were included, these data are not available, and the majority of bones are assumed to be fully fused. When only fully fused bones from the archaeological data and Flag Fen Soays are included, the prevalence observed in the archaeological data is comparable with the Hirta and North Ronaldsay sheep (Fig. 13), and an even higher prevalence of enthesophytes is observed in the proportion of fused humeri.

4.2. Role of size and sex

In the archaeological dataset humerus breadth and depth measurements were poorly associated with the prevalence of lesions. It is pertinent that it is these anatomical planes that reflect robustness and body mass, rather than bone length (Scott, 1990, 301). Conversely, the length of the radius produced a higher correlation with the presence of enthesophytes (Fig. 6). This implies that the height of animals affected enthesophytic formation, the mechanical forces on the joint being greater in a longer bone in the same way that a longer spanner will produce more force on a nut than a shorter one.

The bones of male animals are generally more robust than females (Davis, 2000, 389; Popkin et al., 2012, 1784), and enthesophytes tend to form in these animals. This effect has been observed in live animals (Scott, 2001) and the Orkney sheep (Clark, 1994, 198), whereby male

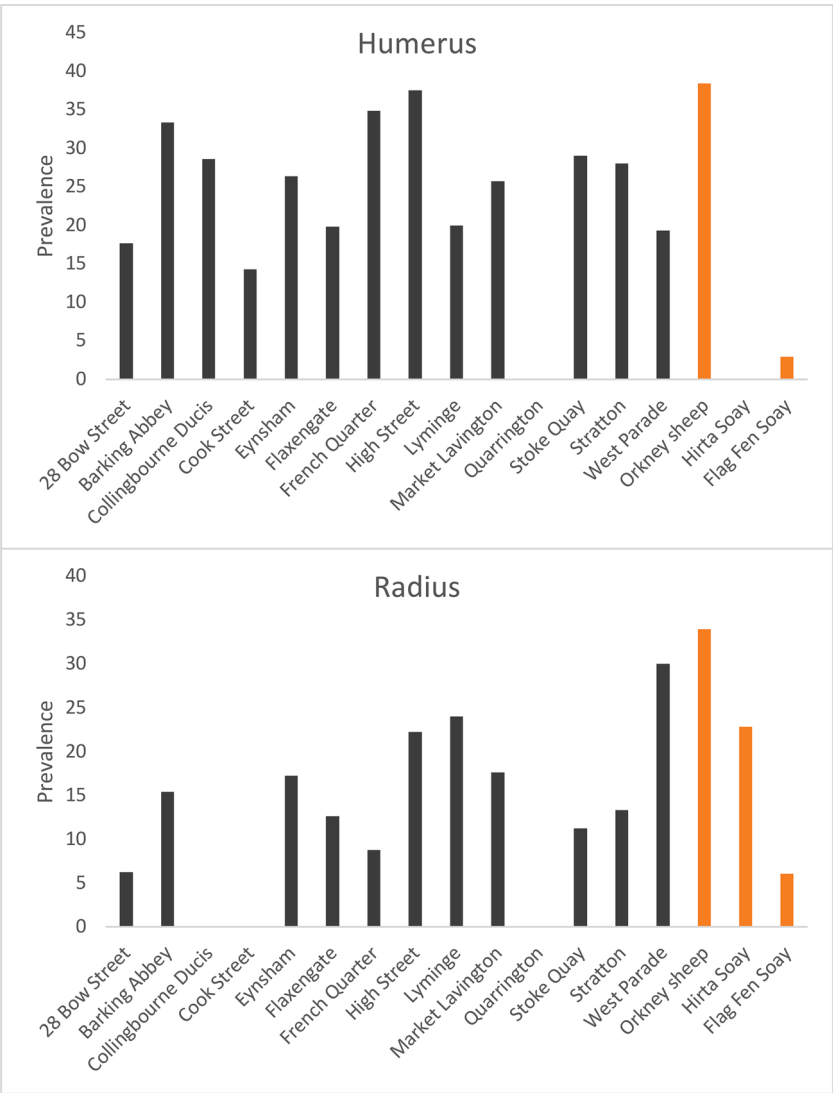


Fig. 12. Prevalence of enthesophytes on sheep elbows from archaeological sites compared with modern data and island sheep. See Table 7 for details.

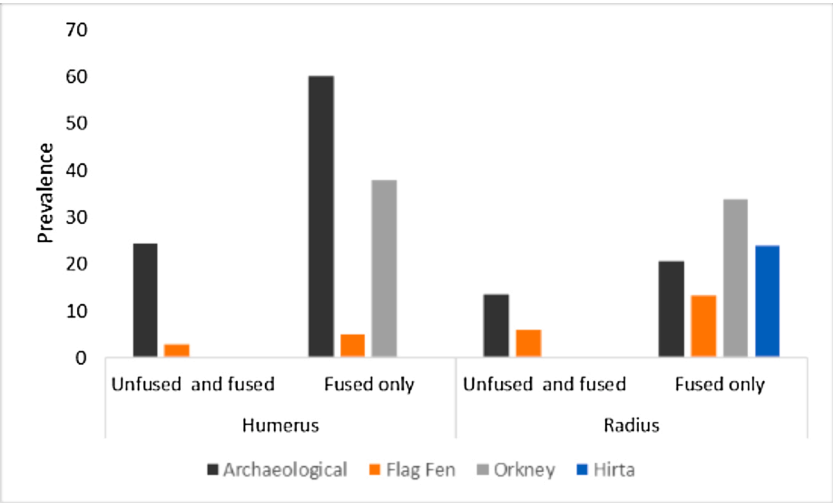


Fig. 13. Comparison of the prevalence of enthesophytes on bones at differing stages of fusion. For sample sizes see Tables 5 and 7.

and more robust animals, respectively, were more likely to be affected. Other bone forming lesions in sheep have been shown to be more common in older male animals (Thomas and Grimm, 2011). Again, it is notable that the Flag Fen sheep were small compared to the archaeological material, which is consistent with the low prevalence of lesions. Yet within the archaeological data set, there was no correlation between breadth or depth measurements and the incidence of enthesophytes, which implies that the robustness of bones has a weak effect, and enthesophyte formation is more likely to be affected by age or the length of the radius.

4.3. Role of husbandry

Husbandry is the most commonly cited cause of enthesophytes in the sheep elbow (i.e. ‘penning elbow’), yet the highest proportion of elements exhibiting lesions come from the feral Orkney sheep and Hirta Soays, indicating that this is an unhelpful misnomer. Sheep husbandry changed little throughout the medieval period under consideration (AD 450–1400), with animals consistently kept for a mixture of meat and small-scale production of wool and/or milk. The relative proportion of sheep increased steadily from the mid-seventh century (Albarella, 2019; Holmes, 2018), reflecting their growing economic importance for wool, as well as their use within the arable economy (Grant, 1988, 151). Furthermore, as sheep gained value as wool prices increased, they were gradually kept to older ages (Holmes, 2018, 112; Sykes, 2007, 36). Sheep were confined and brought into close contact with each other through the use of folds and cotes. Sheep folds were temporary, mobile pens that allowed sheep to manure and graze fallow land, and helped shepherds protect them overnight when away from the farm (Banham and Faith, 2014, 123). They are described in the 10th-century document *Aelfric’s Colloquy* (Swanton, 1993, 109). Sheep cotes were permanent housing for sheep, which became common from the twelfth century (Dyer, 1995).

The combination of increasing sheep numbers, animals living longer and new advances in penning may be expected to result in conditions becoming more crowded with time. The archaeological data are ambiguous (Fig. 10). Humeral enthesophytes increase in both prevalence and severity over time, consistent with the underlying husbandry, yet those affecting the radius peak in the ninth to twelfth centuries. This suggests that, while the increase in age and changes in husbandry may be evidenced in a corresponding increase in enthesophytes, there are other contributing variables that affect the radius.

4.4. Role of environment

Another recurring theme in discussions of enthesophyte formation in sheep elbows in modern and archaeological samples (Bartosiewicz and Gál, 2013; Clark, 1994) is the role of the environment and repeated activity. Clark (1994, 212) found that lesions of the elbow were more common in the North Ronaldsay sheep that lived in steep, rocky areas of the island, than those that inhabited less demanding, sandy areas. North Ronaldsay and Hirta are situated in the archipelago of islands off the north and west coasts of Scotland. The landscape on these islands is rugged and exposed, with high slopes, rocky cliffs and a few sheltered bays (Haswell-Smith, 2008). Both have stone structures that allow sheep to shelter, but there is minimal contact between sheep and people (Clark, 1994; Clutton-Brock et al., 1990). This contrasts strongly with the Flag Fen Soays, which came from the flat, agricultural landscape of the Cambridgeshire fens in the English east midlands (Rouse, 2012), where the sheep were cared for as part of a visitor attraction. It is possible that the wear- and-tear inflicted on the limbs of the island sheep manifests itself as a greater prevalence of enthesophytes than those observed on the Flag Fen sheep whose joints would have been subject to less biomechanical stress. None of the archaeological assemblages used to investigate the role of the environment were as steep or rocky as the Scottish islands. Results are varied (Fig. 11), and there was no indication

of landscape having an impact on prevalence or severity, as high scores were observed for both the topographically highest and lowest sites. However, it is likely that none of the environments inhabited by medieval sheep in this study were as extreme as those on the Scottish islands.

5. Conclusion

The aetiology of enthesophytes affecting the humeral-radial joint in sheep is varied and complex. The most influential factor is age, with a clear correlation observed for the development of lesions in older animals, yet other variables such as limb length, sex and environment are also likely to have played a part. The implication that longer radii act like a lever, resulting in a greater prevalence of enthesophytes is also consistent with likely increased forces on the limbs caused by extreme terrains such as those on the rocky Scottish islands. The tidy relationship between husbandry and ‘penning elbow’, while convenient, is not a likely cause of the observed lesions and the term should be avoided. Similar conclusions have been drawn in human palaeopathology, where enthesophytes have traditionally been used as activity markers (e.g. Hawkey and Merbs, 1995), yet recent work has shown major factors to include age, systemic disease and localised micro-trauma (Villotte and Knüsel, 2013).

Future interpretations of enthesophytes on sheep elbows should take age, sex, size and environmental factors into consideration, and only when these factors are discounted, can the role of husbandry be evaluated. We suggest that rather than focusing on husbandry and the penning of sheep, the pathologies of sheep elbows could be used to compare populations of known age and sex, with the potential to explore the interaction of sheep with their environments. For example, the possible role of transhumance compared to systems that rely less on movement through the landscape. Repeated differences in outcomes for humeri and radii means that the two elements should be considered separately in any future studies.

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