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Spavin in modern and archaeological cattle: Reassessing its association with traction use

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ABSTRACT

Objective: To investigate the correlations of biological factors, including age, body size, and sex, with the occurrence of spavin, demonstrating that using spavin to indicate cattle use for draught work from archaeological sites is questionable.
Materials: Metatarsals from 126 modern non-draught cattle kept under similar conditions, along with published data of 18 draught oxen.
Results: This study demonstrates that spavin strongly correlates with age, body weight, and to some extent, restricted movement, with no observed correlation with sex in non-draught cattle. No significant difference in spavin prevalence was found between the draught and non-draught groups.
Conclusions: Age, body weight, and potentially restricted movement, may partly explain the higher frequency of spavin observed in historic times compared to prehistory, reflecting changes in livestock management. The potential influence of traction on spavin should not be ignored, but this paper argues that the connection between spavin and draught use is primarily mediated by age and other factors.
Significance: This study presents the first systematic analysis of one of the most frequently described palaeopathology in cattle, suggesting that spavin should not be uncritically used to identify draught cattle.
Limitation: We have not found a significant relationship between sex and spavin occurrence, but this is worth further exploration.
Suggestions for further research: Sexing pathological metatarsals from archaeological sites in future works could contribute to clarifying the causes of spavin.

1. Introduction

Spavin, a degenerative joint disease of the tarsal joints, is one of the most common pathological conditions discussed in zooarchaeological literature. This lesion has long been regarded as a 'traction pathology', as it is predominantly observed in horses and cattle. Nonetheless, sheep, dogs, and deer can also be affected (e.g. Baker and Brothwell, 1980: 117; Ballin Smith and Carter, 1994: 1-E6; Albarella et al., 1997; O'Connor, 2008; Bartosiewicz and Gál, 2013: 125; Bulatović et al., 2016; Albarella, 2019: 245).

The term 'spavin' is considered to have originated from the Latin word '*spavenius*' in the thirteenth century, initially indicating diverse non-specific pathological conditions near the hock joint (Goldberg, 1918: 225). Modern studies refer to spavin as the chronic ankylosis of the intertarsal and tarsometatarsal joints. The two primary intertarsal joints in cattle, namely the proximal and distal intertarsal joints, consist of five distinct tarsal bones organised into three rows (Fig. 1) (nomenclature follows Barone, 1976). The proximal row comprises the astragalus and calcaneum, whilst the middle row is the navicularcuboid (C+T4). The distal row comprises the large cuneiform (T2 + 3) and the dorsally located small cuneiform (T1).

Spavin can manifest in various forms. The most common type of spavin affects the lower hock joint, including distal intertarsal and tarsometatarsal joints (Baker and Brothwell, 1980: 117; Eksell et al., 1998), whereas high spavin denotes the lesion in the proximal intertarsal joints, leading to a more severe lameness than typical spavin (Stashak, 2013:

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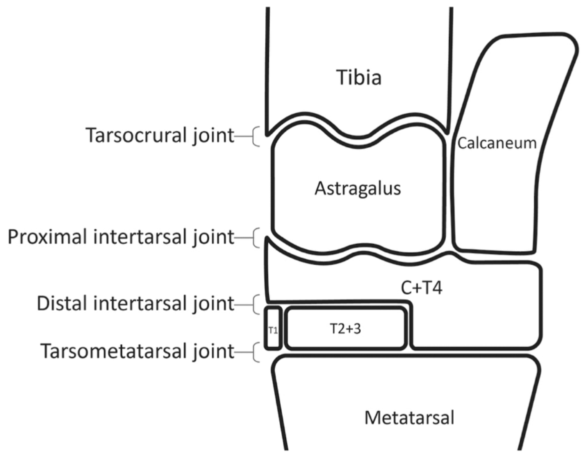

Fig. 1. Hock joints in cattle. C+T4: navicularcuboid; T1: small cuneiform; T2 + 3: large cuneiform. Tarsal terminology follows Barone, 1976.

313). The other two forms, blood and bog spavin, occur without osseous changes (Baker and Brothwell, 1980: 118; Stashak, 2013: 313); thus, these latter forms are imperceptible in archaeological specimens. Partial spavin may occur, such as the fusion of the large cuneiform, the small cuneiform and the navicularcuboid, without involving the tarsometatarsal joints. A rarer but similar condition, carpal spavin, may occur in carpometacarpal joints.

Spavin is an advanced form of degenerative joint disease. This lesion is classified as osteoarthritis; although the joint articular surfaces are usually unaffected, extensive bone hypertrophy occurs around the tarsal joints (Baker and Brothwell, 1980: 118; Stashak and Baxter, 2020: 663). Findings from both magnetic resonance imaging and radiography suggest that osteophyte formation initiates in the mediodorsal segments of the hock (Holmberg and Reiland, 1984; Bartosiewicz et al., 1997a; Bartosiewicz et al., 1997b). The formation of bone cysts involves the adjacent subchondral bone of the hock joints, which is observable through radiography in the initial stage (Stashak, 2013: 313). The osteophytes fully bridge the joint surfaces as the lesion progresses to the final stage. Typical spavin induces mild lameness; animals with moderately ankylosed tarsal joints can still perform slow work (Baker and Brothwell, 1980: 119).

Although various speculations about the causes of spavin, such as genetics, ageing, weight, limited exercise, direct trauma and uneven terrain, have been proposed (e.g. Van Pelt, 1975; Holmberg and Reiland, 1984; Eksell et al., 1998; Björnsdóttir et al., 2010), spavin is traditionally viewed as a characteristic of draught animals resulting from repetitive overloading. The excessive mechanical loading possibly adds compression and tension to the lower tarsal joint capsule, stimulating new bone formation, eventually leading to spavin (Baker and Brothwell, 1980: 118; Stashak, 2013: 313). The analysis of modern draught oxen indicates mechanical stress potentially contributes to the formation of spavin, though the effects of age and weight are inseparable (Bartosiewicz et al., 1997b). In particular, the studied modern draught animal samples were kept alive for prolonged periods, ranging from 6 to 19 years. This complexity makes it challenging to isolate whether age alone or the effect of traction is a more significant factor in spavin formation in draught cattle. The direct link between spavin and draught work is, therefore, uncertain.

Spavin is well-studied *in vivo*, particularly in horses; nonetheless, comparative data from documented cattle skeletal collections is lacking. This paper demonstrates that using spavin to indicate the use of cattle for draught work from archaeological sites is questionable. Such a conclusion is reached through three lines of enquiry:

1. A review of the literature for cattle spavin cases from British archaeological sites.
2. The record of spavin manifestation in the skeleton of 126 modern non-working cattle that have been kept under similar conditions.
3. The analysis of the correlations of biological factors, including age, body size and sex, with the occurrence of spavin.

2. Bovine spavin in British archaeological sites

Spavin in cattle has been found on British archaeological sites from the Iron Age to the Post-medieval period (Table 1). No cases have been described for Neolithic and Bronze Age sites. All identified cases show the most typical form of spavin to be characterised by the fusion of the distal intertarsal and tarsometatarsal joints, except for the Roman site of Papcastle. The pathological condition documented at Papcastle is described as "… an astragalus and tarsal have fused together" (Stallibrass and Mainland, 1990: 18), representing a rare example of high spavin. Partial fusion of the large cuneiform and the small cuneiform with the navicularcuboid is noted at Stoke Quay (Rielly, 2020: 357). Although the author interprets this condition as a congenital defect, it is more likely to be a form of early-stage spavin.

Table 1 reveals that spavin cases only appear from the Iron Age onwards, but this may partly be due to the imbalance in data availability. The smaller number of prehistoric sites inevitably reduces the probability of discovering a spavin specimen. As shown in the literature, interpretations of spavin in archaeological sites have predominantly been attributed to draught use. However, this study suggests that additional factors may explain the higher frequency of cattle spavin in later periods, which will later be discussed through the analysis of modern cattle.

3. Materials and methods

We examined 126 modern non-working cattle skeletons housed at the Museum für Haustierkunde Julius Kühn of the Martin Luther University of Halle-Wittenberg in Germany (hereafter referred to as the Julius Kühn collection). The cattle in the Julius Kühn collection represent various breeds, crossbreeds, and species, which were part of crossbreeding experiments that began in the nineteenth century (Wussow, 2013). These animals were kept in a similar environment within the institute and received comparable nutrition (Jones and Sadler, 2012). In particular, the crossbred cattle were born and raised there, while others were introduced to Halle later for breeding. Thus, age and sex were generally documented. For those cases in which age data were absent, age estimates relied on mandibular tooth wear. Tooth wear stages were recorded following Grant (1982). The age at death of these cattle was estimated based on Jones and Sadler's (2012) analyses focusing on the Julius Kühn collection. Moreover, data for 18 draught modern oxen were obtained from Bartosiewicz et al. (1997b: 71) to use as a comparison with the non-draught group.

Spavin was recorded on an absence or presence basis. Non-parametric tests were adopted to analyse the correlation between spavin and biological factors, considering the limited sample size and the potential non-normal distribution of the variables. Point-biserial correlation tests were conducted to evaluate the relationship between spavin and age, as well as body size. Additionally, Mann–Whitney-U tests were employed to compare the differences in age and body size between animals with spavin and those without. The Fisher's Exact test determined if spavin prevalence varied between sexes and between draught and non-draught cattle.

Lastly, a non-parametric decision tree model was used to identify the most important variables affecting spavin. The importance of each variable was assessed using Mean Decrease Accuracy (MDA). This metric measures the reduction in model accuracy when a specific variable is removed from predictions. Consequently, a higher MDA indicates a stronger influence of the variable on spavin occurrence.

Data analyses were conducted using RStudio (version 2023.03.1 +446), and the decision trees were constructed using the

Table 1
Bovine spavin identified in British archaeological sites. The question mark indicates that the number of cases is unavailable in the literature.

Period	Site (County)	Spavin case	Description	Interpretation by the original author(s)	Ref.
Iron Age	High Pasture Cave (Isle of Skye)	1	A cow tarsal in Zone 2 presenting fusion of tarsal bones as is commonly caused by spavin.	-	Drew, 2006: 78
Iron Age	Winklebury (Hampshire)	1	The distal tarsal bones (2nd, 3rd. tarsal bones, centroquartal bone and the 1st tarsal bone) are all fused together and to the proximal articulatory surface of the metatarsal.	It is impossible to say with any degree of certainty the cause of this change.	Jones, 1976: 9
Late Iron Age	Alington Avenue (Dorset)	1	A cattle metatarsus (1340-Phase 36) whose proximal articulation had become fused to the adjacent tarsals.	The presence of these and at least two metacarpi with pathologically splayed distal articulations may suggest that some of the older cattle were kept for ploughing and other work and developed stress-related conditions.	Maltby, 1988: 16
Late Iron Age	Holme House (County Durham)	1	One is a metatarsus with bony growth, distortion and pitting of the proximal articular surface and the tarsal 2 + 3 fused to part of the centroquartal also with pitting of the articular surface.	This was probably caused by a bacterial infection or septic arthritis and does not appear to be a spavin caused by excess draught work	Gidney, 1990: 16
Late Iron Age	Stanground South (Cambridgeshire)	1	A right metatarsal bone with fused tarsal.	There is evidence that some of these cattle had been employed as draught animals.	Armitage, 2021: 219
Late Iron Age	Howe (Orkney)	1	Lateral cuneiform (tarsal) fused on.	-	Ballin Smith and Carter, 1994: 1-E6
Iron Age-Early Roman	Owslebury (Hampshire)	?	The same condition appears to have affected cattle. Its presence accounts for the reasonably high proportion of pathological tarsals and metatarsi that were recorded.	This would suggest that these cattle may have been working animals used either as plough animals or as beasts of burden.	Maltby, 1987: 516
Roman	Balkerne Lane (Essex)	4	The proximal cattle metatarsal illustrated here is also indicative of spavin.	It may be due to heavy draught work, but may also, as with spavin, be associated with use of the beast on hard unyielding surfaces, thus resulting in traumatic injury to the articular cartilage.	Luff and Brothwell, 1993: 109
Roman	Butterfield Down (Wiltshire)	1	One animal had spavin which is associated particularly with draught animals resulting in their only being able to manage light loads.	Draught use.	Egerton, 1996: 35
Roman	Segontium (Gwynedd)	2	Spavin (8–9, 10 A).	-	Noddle, 1993: 103
Roman	Lyde Green (Gloucestershire)	1	A possibly early stage of spavin was identified on a cattle metatarsal from (3234).	-	McElligott et al., 2021: 84
Roman	Dragonby (Lincolnshire)	4	Four bovine cannon bones to which are fused all the tarsal bones except the os calcis and astragulus and as far as could be determined radiologically the joint surfaces were normal.	-	Baker and Brothwell, 1980: 119
Roman	Bob's Wood (Cambridgeshire)	2	Spavins consisting of ankylosed hock elements as recovered from Period 4.2 Ditch [4529] (4669) and Period 4.3 [3186] (4667).	More severe pathologies also typical of draught animals include spavins.	Baxter, 2009: 4
Roman	Ivy Chimneys (Essex)	2	Cattle proximal metatarsal showing spavin.	-	Luff, 1999: 221
Roman	Caister-on-sea (Norfolk)	2	One metatarsal is severely affected by spavin (PI. XXXIV, C right); other shows signs which may also result from spavin (PI. XXXIV, C left)	-	Harman, 1993: 229
Roman	Brancaster (Norfolk)	1	The degree of bone growth in these areas has been sufficient to join the fused second and third tarsal bones and the centroquartal (now broken off) to the proximal articular surface of the metatarsal.	The fusion of the tarsal bones to the proximal metatarsal may have been caused by many factors, including infection.	Jones et al., 1980: 33
Roman	Rectory Farm (Cambridgeshire)	1	Pond 2 also yielded a cattle metatarsal with spavin.	Although this condition is associated more with horses, it is found in trek oxen.	Luff and Smith, 2019: 244
Roman	Papcastle (Cumbria)	2	At Papcastle the latter is apparent in one example where an astragalus and tarsal have fused together. As no exostosis is visible it is probable that the articulation was affected. Similarly, a metatarsal displayed exostosis of the articulation and is probably a slightly milder case of spavin.	A factor behind the development of spavin is thought to be constant trauma to the joint as a result of heavy work and/or working on hard surfaces.	Stallibrass and Mainland, 1990: 18
Roman	Redlands Farm (Northamptonshire)	1	A cattle proximal metatarsal from context 356 has bony outgrowths (exostoses) on most of the articular surface where the bone normally articulates with the adjacent tarsal bone (the naviculo-cuboid) indicating that the metatarsal and naviculo-cuboid were fused.	-	Davis, 1997: 6
Roman	Annetwell Street (Cumbria)	1	A fourth metatarsal appears to have been ankylosed on the naviculo-cuboid by a spavin infection.	Most of them can be explained either by heavy muscular use (as in traction of heavy items such as ploughs or wagons), or by damage caused by concussion on hard ground.	Stallibrass,1992: 47
Roman	Lewthwaites Lane (Cumbria)	1	There is only one case of spavin, where the naviculocuboid has become fused onto the proximal metatarsal by excessive bony growth.	-	Stallibrass, 1994: 54
Roman	Alcester (Warwickshire)	1	A metatarsus in pit (170) had the second and third tarsal fused to its proximal surface.	This arthropathic condition may be an indication that the animal in question was	Maltby, 2001: 283

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Table 1 (*continued*)

Period	Site (County)	Spavin case	Description	Interpretation by the original author(s)	Ref.
				relatively old, as such conditions are more likely to occur in mature animals.	
Roman	Greyhound Yard (Dorset)	4	Four metatarsals from Period 350–450 A.D. were fused pathologically with the centroquartal by severe exostoses.	It is likely that the fusion was caused by spavin - a disease of the tarsal joint perhaps associated with working animals.	Maltby, 1990: 42
Roman	Sibford Road (Oxfordshire)	1	An articulating bone group from cattle from layer 1276, comprising the proximal end of another metatarsal (left hand side) with the articulating fused second/third tarsal and navicular cuboid, could be another case of spavin.	-	Smith, 2018: 25
Roman	The Park (Lincolnshire)	1	Metatarsal with naviculocuboid fused in situ, probably as a result of chronic strain to the ankle joint.	As a result of chronic strain to the ankle joint.	Scott, 1999: 176
Roman	Northgate House (Hampshire)	2	The assemblage also produced two tarsals and two metatarsals with bone absorption, varying stages of fusion and exostoses.	These were interpreted as spavin, and most likely represent older draught animals.	Strid, 2011: 8
Roman	Northern Lanes (Cumbria)	3	Three of the proximal metatarsals of the cattle examined have one or more abnormally fused (ankylosed) tarsal bones.	Likely causes of bovine spavin include excessive strain.	Connell et al., 2019: 632
Roman	Oakridge II (Hampshire)	3	There were three cases where one or more of the tarsals had fused with each other and/or the proximal articular surface of the metatarsus.	The condition is typical of spavin, which principally affects the tarsus of horses but has also been observed in draught cattle. Again the presence of this condition suggests that some of the mature cattle in this group were working animals.	Maltby, 1993: 53
Roman	Camp Ground, Earith (Cambridgeshire)	2	Two cases of spavin were noted on metatarsals, one from the Phase II assemblage and the other from Phase III.	The evidence for joint disease, particularly the two cases of spavin, supports the notion that some cattle may have been used for traction.	Higbee, 2004b: 178
Saxon	Stoke Quay (Suffolk)	2	Further congenital defects may be indicated by the fusion of two cattle tarsals, a navicular cuboid and a cuneiform.	Congenital defects.	Rielly, 2020: 357
Saxon	Bloodmoor Hill (Suffolk)	1	The other metatarsal was recorded with spavin.	Both of these conditions have generally been associated with the use of cattle as draught animals.	Higbee, 2009: 293
Saxon	Cobb House (Oxfordshire)	1	The pathologies on the cattle bones comprise of fusion of tarsal bones.	Such pathologies have been associated with the use of cattle as draught animals, although while they may derive from muscle strain, fusion of bones in particular can also derive from age related wear and tear of the joints.	Strid, 2014: 19
Saxon	Goltho (Lincolnshire)	1	A cattle metatarsal and associated tarsal bones, from period 5, are ankylosed together.	-	Jones and Ruben, 1987: 4
Medieval	30–38 St Thomas Street (Bristol)	1	This evidence takes the form of a metacarpal (foot bone) from late 13th-/14th-century pit fill 173 with a condition known as spavin.	This condition has many initiating factors however, it occurs most frequently in animals used for traction.	Higbee, 2004a: 47
Medieval	St Nicholas' Street (Norfolk)	2	Evidence for spavin (after Baker and Brothwell, 1980) was noted on a proximal metatarsal and also on a tarsal.	This would have caused lameness and may be the result of intensive working of the animals for traction	MacDonald, 1999: 81
Medieval	Stricklandgate (Cumbria)	1	A robust cattle metatarsal from phase 3 is possibly from a male animal and exhibits bony proliferation on the proximal anterior face. This is probably a case of spavin.	-	Gidney, 1989: 10
Medieval	Gatehouse Nurseries (Greater London)	1	A left metatarsal from the same context showed exostoses on the proximal articulation, which could be an early stage of spavin where ultimately the tarsals become fused to the metatarsal.	This could have been caused by concussion on the joint possibly associated with heavy work.	Locker, 1985: 5
Medieval	Catridge Farm (Wiltshire)	1	As suggested by a pathological metatarsal which could represent an individual with spavin.	It is possible that adult cattle were also used for traction.	Forward et al., 2020: 35
Medieval	Llangibby Castle (Monmouthshire)	1	Trench 9 topsoil contained a cattle metatarsus with signs of beginning spavin.	This suggests that animals were used for draught activities, but ultimately ended on the table.	Wessex Archaeology, 2009: 15
Medieval	Mill Street and King Edward Street (Perth and Kinross)	?	A range of pathological conditions, such as bovine spavin and osteoarthritis at Mill Street and King Edward Street indicated that the remains of draught oxen, which were slaughtered when they became unfit for work, were present.	Draught use.	Bowler et al., 1996: 986
Post-Medieval	Castle Hill (Oxfordshire)	1	A post-medieval cattle navicular-cuboid tarsal from context 3023 had fused to the cuneiform and had extra bone formation.	This may indicate that the animal was used for heavy traction, although it can also be hereditary or related to ageing or husbandry.	Worley and Kitch, 2019: 76
Post-Medieval	Meal Vennel (Perth and Kinross)	?	Evidence from abnormal bones may indicate the reason for culling some of the cattle; bones were found displaying the symptoms of conditions such as osteoarthritis, spavin, high ring bone and laminitis.	It is possible that some of these animals may have been plough oxen, drafted out because of their inability to work through lameness.	Cox et al., 1997: 794

(*continued on next page*)

Table 1 (*continued*)

Period	Site (County)	Spavin case	Description	Interpretation by the original author(s)	Ref.
Post-Medieval	Gaol Street, St Peter's School (Herefordshire)	1	An example from Gaol Street phase 6 context (246) also has proximal exostoses indicative of spavin.	-	Baxter, 2023: 4
Post-Medieval	Harrison Street (Herefordshire)	1	Another example of spavin is an ankylosed centrotarsale and tarsal 2 + 3 fragment from Harrison Street phase 3 (135).	-	Baxter, 2023: 4
Post-Medieval	46–54 Fishergate (Yorkshire)	1	A fused proximal metatarsal and naviculocuboid exhibiting this condition was recovered from 8003 (Period 7c).	Both spavin and osteoarthritis could be seen as likely to be age-related degenerative conditions, though long-term slight abnormal stress to the joints may also be implicated. In a culture which used cattle as draught animals, neither causative factor can be rejected.	O'Connor, 1991: 267

'rpart' package. Detailed data on the modern cattle recorded for this study is available in the supplementary materials.

4. Spavin in modern cattle

A total of 26 cattle from the Julius Kühn collection (n = 126) (Table 2) were identified with spavin, resulting in a prevalence of 20.6 %. Fourteen cattle were affected on one side; the remaining cattle exhibited a bilateral spavin. All pathological specimens showed the typical form of spavin, which includes the fusion of the distal intertarsal and tarsometatarsal joints. Different stages of ankylosis have been noticed (Fig. 2). For instance, cattle 251 and 322 present an advanced stage of spavin. Both intertarsal joints and the tarsometatarsal joint were fully bridged by osteophytes (Fig. 2A and B).

Two Kerry cattle (ID: 289 and 295) show mild conditions, with a complete fusion of the distal intertarsal joint, but the tarsometatarsal joint line still visible (Fig. 2C and D). The right metatarsal of 289 displays an early sign of degeneration, indicated by new bone formation at the proximal metatarsal margin, which could potentially develop into spavin over time (Fig. 2C).

Specimen 251 shows that the tarsometatarsal joint fusion occurred on the dorsal side while the plantar aspect remained separate (Fig. 2E). The sesamoid bone of this specimen was also fused with the right metatarsal.

Table 2
List of modern non-draught cattle with spavin.

ID	Age in year (Estimated age)	Type/Breed/Species	Sex	Affected side
22	9	Ansbach-Triesdorfer	Female	Both sides
31	Unknown	Holstein Friesian	Female	Right
74	(9.6)	Breitenburger	Female	Right
83	17	Butjadinger	Female	Left
110	Unknown	Yak (*Bos grunniens*)	Male	Left
251	(7.3)	Shorthorn	Female	Both sides
255	9.5	Hereford	Female	Left
289	(7.3)	Kerry	Female	Right
294	13	Podolian	Male	Both sides
295	6.9	Kerry	Male	Left
298	6.8	Shorthorn crossbreed	Male	Both sides
322	(12)	Schwyzer	Female	Left
323	Unknown	Schwyzer	Female	Right
327	Unknown	Shorthorn crossbreed	Male	Both sides
328	(7.3)	Shorthorn	Female	Both sides
351	(7.3)	Simmental	Female	Right
415	12.2	Kerry	Male	Right
476	7	Shorthorn crossbreed	Female	Both sides
537	16.7	Hollander crossbreed	Female	Both sides
540	4.3	Hollander crossbreed	Female	Left
569	11.1	Shorthorn crossbreed	Male	Both sides
580	4.6	Shorthorn crossbreed	Female	Both sides
612	7.3	Shorthorn crossbreed	Male	Both sides
760	4.5	Shorthorn crossbreed	Female	Left
891	3.9	Normande	Male	Left
5342	Unknown	Unknown	Female	Both sides

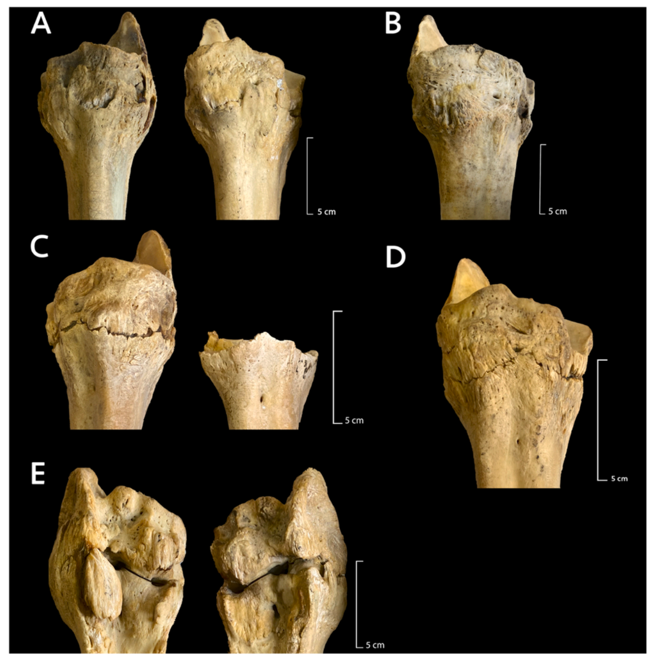

Fig. 2. Different stages of spavin observed in the Julius Kühn collection. (A) Dorsal view of both metatarsals of specimen 251, a Shorthorn cow with an estimated age of 11 years; (B) Dorsal view of the left metatarsal of specimen 322, a Schwyzer cow with an estimated age of 12 years; (C) Dorsal view of both metatarsals of specimen 289, a Kerry cow with an estimated age of 11 years; (D) Dorsal view of the left metatarsal of specimen 295, a 6.9-year-old Kerry bull; (E) Plantar view of both metatarsals of specimen 251, a Shorthorn cow with an estimated age of 7.3 years.

4.1. Risk factors for spavin

Eighty per cent of the cattle with spavin were over five years old. The mean age of the animals with spavin was 8.8 years, whilst those without had a mean age of 7.0. The point-biserial correlation test indicates a highly significant positive correlation of spavin with age (Table 3). This strong correlation between spavin and ageing is further illustrated in

Table 3
Summary of point-biserial correlation for determining the relationship between biological factors and spavin.

	Coefficient	*P*
Age	0.27	0.00 * *
Body size	0.22	0.02 *

* * = highly significant (P ≤ 0.01), * = significant (P ≤ 0.05).

Fig. 3A; animals with spavin are, in general, significantly older than those without. Nonetheless, relatively young animals could also suffer from spavin, as demonstrated by a 3.9-year-old Normande bull (Table 2).

The living weights of these animals were not available; thus, the relative body size was estimated by the greatest breadth of the distal end (Bd) on metatarsals. It has been suggested that the width measurements of bovid bones are strongly associated with body weight (Scott, 1983). A significant correlation was found between body size and spavin (Table 3). Specifically, cattle afflicted with spavin exhibited a broader distal end than their counterparts (Fig. 3B). These results indicate that cattle with a wider distal end, potentially associated with a larger body size, were more likely to develop spavin. However, there is also a possibility that a wide distal end is related to metatarsal splaying or that the animal was stocky in relation to its height.

Bulls show a higher prevalence of spavin (29 %, 9/31), compared to cows (18 %, 17/94). There is, however, no significant correlation between sex and the development of spavin in our dataset (Table 4). This is, however, a subject that will be worth further exploration in the future.

4.2. Spavin and draught use

This section explores whether external stress added by draught work significantly increases the possibility of developing spavin in cattle. The modern draught oxen data from Bartosiewicz et al. (1997b: 71) were used for this analysis (Table 5) along with data from the non-draught animals from the Julius Kühn collection. The prevalence rate of spavin is 28 % (5/18) in the draught group. All of the oxen with spavin are aged above 8 years old, except one of unknown age. Despite the higher spavin prevalence in the traction animals, there is no significant difference between draught and non-draught cattle (Table 6).

When considering all variables (age, sex, body size proxy, and work history) in the decision tree model, age is indicated as the most influential factor in the occurrence of spavin, followed by body size proxy (Bd) and sex, with work history (draught or non-draught) being the least important (Fig. 4). This result aligns with the analysis of non-draught cattle, demonstrating that age is the dominant risk factor in spavin. Thus, it can be speculated that the high prevalence in the draught group results from older age, given the higher average age (10.2 years) within this group.

5. Discussion

Spavin and several other pathologies, including hip joint deformations, ring depressions on horncores, and cranial perforations, have often been used to suggest draught cattle exploitation (e.g. Maltby, 1993; Bowler et al., 1996: 986; Egerton, 1996: 35). Recent works demonstrate that these conditions are largely multifactorial and can occur in other species unrelated to draught use (e.g., Albarella, 1995; Fabiš and Thomas, 2011; Kierdorf et al., 2016; Thomas et al., 2018; Rassadnikov, 2021), challenging the assumed link with draught use. Nonetheless, spavin, despite being a frequently identified lesion in

Table 4
Summary of Fisher's Exact test for the association between sex and spavin.

	n	*P*
Cow with spavin	9	0.21
Bull with spavin	17	

Table 5
List of modern draught cattle with spavin (data adopted from Bartosiewicz et al., 1997b: 71).

ID	Age (year)	Breed	Sex	Affected side
91.107.M3	10	Romanian Grey x Brown	Castrated	Both sides
91.107.M9	12	Romanian Grey x Brown	Castrated	Right
91.107. M10	9	Romanian Grey x Brown	Castrated	Right
91.107. M11	8	Romanian Grey x Brown	Castrated	Both sides
91.107. M24	Unknown	Romanian Grey x Brown	Castrated	Left

Table 6
Summary of Fisher's Exact test for the variation between type (draught or non-draught) and spavin.

	Without spavin	With spavin	*P*
Draught cattle	12	5	0.36
Non-draught cattle	101	26	

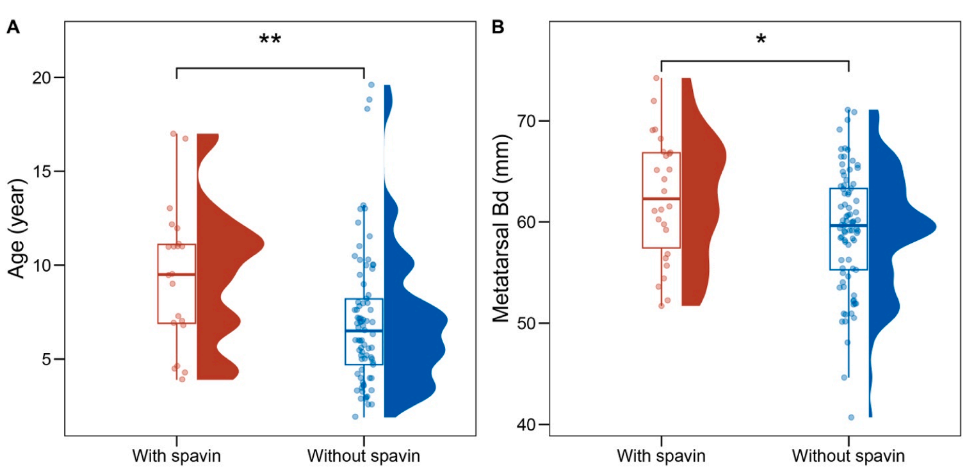

Fig. 3. Comparisons of (**A**) age and (**B**) body size proxy (metatarsal Bd) between modern non-draught cattle with and without spavin. Mann–Whitney-U tests were performed. * * = highly significant (*P* ≤ 0.01), * = significant (*P* ≤ 0.05).

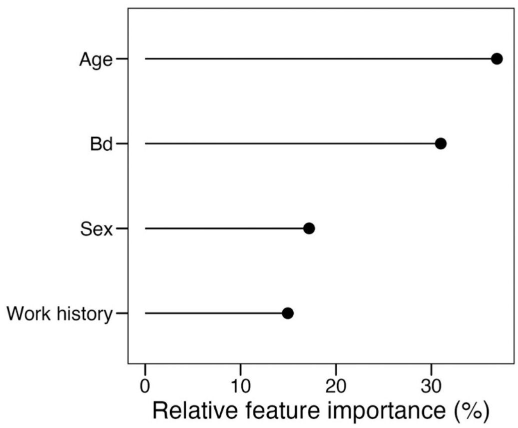

Fig. 4. Relative Feature importance of spavin occurrence in the decision tree model of modern draught and non-draught cattle. The greatest breadth of the distal end of metatarsals (Bd) is used as a body size proxy. Relative feature importance is calculated based on Mean Decrease Accuracy.

archaeological assemblages, has yet to be fully understood.

Reviewing the literature reveals that spavin in cattle was frequently observed in British archaeological sites from the Iron Age to the post-medieval period. This pathology is, however, absent in Neolithic and Bronze Age sites. The greater abundance of spavin occurrence in the historical period may have contributed to the perceived association between spavin and the use of cattle for traction – a likely late prehistoric innovation. This study discusses causal factors for cattle spavin through the analysis of modern draught and non-draught cattle bones, confirming that spavin is a weak indicator of draught cattle.

5.1. Draught use

Repeated external loading on cattle, mainly when used for traction, has been suggested as a risk factor for spavin (Baker, 1984: 254; O'Connor, 2008: 177). A complex interplay of biological factors is, however, involved in developing this pathological condition (Bartosiewicz et al., 1997a; Baker and Brothwell, 1980: 118). No significant difference in spavin prevalence was found between the draught and non-draught groups in this study, although caution is advised due to the small sample size of the draught group. While comparable studies have not been conducted in cattle, it is worth noting that in horses, where spavin is more prevalent, there is no observed association between work intensity and radiographic signs of bone spavin (Eksell et al., 1998). The high prevalence of spavin in modern non-draught cattle casts further doubt on the direct association of traction with the development of spavin in cattle.

5.2. Ageing and sex

Degeneration of the tarsal joints is a chronic condition in which ageing exacerbates the ankylosis of the joint. The results in this paper concur with previous studies on Swedish dairy cattle and Icelandic horses, indicating that the severity of spavin increases with age (Holmberg and Reiland, 1984; Eksell et al., 1998; Björnsdóttir et al., 2010). Nonetheless, a relatively young, 3.9-year-old Normande bull from the studied collection showed signs of spavin. This observation aligns with the radiographic changes observed in the tarsal joints of dairy cows before the age of two, with fusion occurring when the animals reach four years old (Holmberg and Reiland, 1984). The higher prevalence rate of spavin in modern draught cattle compared to the non-draught cattle in the Julius Kühn collection may, in part, be attributed to external stress stemming from traction. The strong correlation of age with spavin in the non-draught group, however, suggests that traction is likely to be a confounding factor, given the extended lifespan of draught cattle kept for work. This hypothesis is supported by the absence of spavin in modern draught cattle below eight years old, suggesting that advanced age is the predominant factor contributing to this lesion rather than draught work.

While old age and draught use are generally associated, the direct interpretation of spavin as an indication of draught animals in an archaeological material is not recommended. Old age is not exclusively associated with the use of an animal for traction; cows can also be kept alive to a mature age for milk production (e.g. Legge, 1981; O'Connor, 2013) or for reproduction. In this research we have not found a significant relationship between sex and spavin occurrence, but this is worth further exploration in the future. Sexing pathological metatarsals from archaeological sites in future works could contribute to clarifying the issue and throw further light on the causes of spavin. Overall, the intense utilisation of secondary products that leads to animals being kept alive until older, whether for milk or traction, is likely to have contributed to the higher frequency of spavin in historic periods.

5.3. Restricted movement

Restricted movement is one particular condition of the animals in the Julius Kühn collection that may have exacerbated spavin development. Most of these cattle were primarily kept at the institute, with exercise limited to about an hour daily in a small yard. The correlation between lack of exercise and spavin has been previously demonstrated by a study on live dairy cattle, indicating that the tied herds had a higher prevalence of spavin compared to animals with loose housing within the same age group and breed (Holmberg and Reiland, 1984). The confined living conditions likely cause uneven stress on hock joints through static loading. Immobility disrupts normal weight distribution, inducing chronic joint stress and promoting degenerative changes. Such restricted movement could have constrained natural joint motion, concentrating biomechanical load on the joint articular surfaces and potentially accelerating spavin development.

Cattle are believed to have been kept mainly free-range during the Neolithic and Clark (1952: 125) and Bogucki (2013) suggests that cattle-stalling did not occur before the Early Iron Age in Europe. Although Waterbolk (1975) disagrees, stating that the phenomenon can be as early as the Late Neolithic or Early Bronze Age, there can be no doubt that housing livestock became more prevalent in historical times. Cattle sheds and agricultural buildings with stalls are known from Roman times, while longhouses for sheltering livestock have been found in Medieval sites in Britain (Morris, 1979; Zimmermann, 1999). This closer control of the cattle facilitated more convenient feeding, milking and manure management. However, it could have limited the movement of livestock, potentially increasing the likelihood of developing spavin.

5.4. Body weight

A higher prevalence of spavin in heavier cattle is indicated in this study. Bulls showed a slightly higher prevalence than cows, though no statistically significant difference was identified. Heavy bulls have been noticed to be commonly affected by tarsal degenerative joint disease (Van Pelt, 1975). Weight is, however, correlated with sex. Sexual size dimorphism in mammals typically favours males, where males exhibit larger body weight than females.

As the live weights of the modern non-draught cattle were unavailable, the distal breadth (Bd) of the metatarsal was used as a proxy for body size in this paper. Bone width in bovids is suggested to be associated with living weight (Scott, 1983). The results suggest a significant correlation between distal breadth and the prevalence of spavin, meaning that heavier animals are more likely to develop spavin. This positive correlation, however, may also suggest that stocky animals or those with splayed metatarsals have a higher likelihood of spavin occurrence rather than necessarily being a consequence of absolute size/weight. Nonetheless, the results of this study suggest that body size or weight may have a more substantial positive correlation with spavin than sex, though the two factors are not so easily disentangled.

5.5. Genetic inheritance

A comprehensive analysis of the effect of breed type was omitted in the present study due to the limited sample size available for each breed; however, Kerry cattle seemed more likely to present signs of spavin. A previous survey of living cattle reveals that the prevalence of spavin varied significantly between breeds. In particular, the Swedish Jersey cows had a higher incidence rate of 50 % (13/26), whereas the Swedish Friesian cows had an incidence rate of 20 % (9/44) (Holmberg and Reiland, 1984). It therefore seems that genetic inheritance can be partially responsible for this degenerative joint disease.

6. Conclusion

We analysed 126 non-working cattle skeletons from the Julius Kühn collection, showing a prevalence rate of spavin of 20.6 % (26/126). Despite a higher prevalence of spavin has been observed in modern draught cattle, no significant statistical difference in spavin prevalence was found between the draught and non-draught groups in this study. The results from modern non-working cattle revealed that spavin positively correlates with age and body size, whilst no statistically significant prevalence difference occurs between bulls and cows. The limited movement of the non-working cattle could have also contributed to the high prevalence of spavin. These findings illustrated that spavin, similar to those lesions traditionally regarded as traction-related, is multifactorial.

While the high spavin prevalence in an assemblage may indirectly suggest a heightened proportion of older cattle, potentially associated with draught use, the interpretation of pathologies is not straightforward. Changes in livestock management may increase the likelihood of cattle developing spavin, for instance, confining cattle in byres and intensive utilisation of secondary products. These factors could account for the elevated frequency of spavin cases from the British Iron Age onwards, notwithstanding that the higher absolute number of cases may be influenced by the greater availability of data from the historical period.

Animal palaeopathology remains valuable for understanding past human-animal relationships. However, interpretations of palaeopathological evidence require systematic analyses, particularly in incorporating modern data as references. As demonstrated by the present study, modern data contribute to interpreting spavin cases found in archaeological sites. Despite the fact that no single cause can be attributed to the development of spavin, changes in cattle management over time potentially influenced the prevalence of spavin in cattle. Although the effect of traction on spavin formation must be considered, this paper argues that the connection between spavin and draught work is indirect because it is mainly associated with old age. Spavin should not be used uncritically to identify draught cattle but it remains a valuable condition to record as it can be part of a broader package of changes in cattle husbandry, as we have seen in the contrast between the British prehistoric and historical evidence.

CRediT authorship contribution statement

Salvagno Lenny: Writing – review & editing, Supervision, Conceptualization. **Liu Phoebe:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Albarella Umberto:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijpp.2025.02.003.

References

Albarella, U., 1995. Depressions on sheep horncores. J. Archaeol. Sci. 22, 699–704. https://doi.org/10.1016/S0305-4403(95)80155-3.

Albarella, U., 2019. A Review of Animal Bone Evidence from Central England. In: Research Report Series, 61. Portsmouth, Historic England, p. 2019.

Albarella, U., Beech, M., Mulville, J., 1997. The Saxon, Medieval and Post-Medieval Mammal and Bird Bones Excavated 1989-91 from Castle Mall. Ancient Monuments Laboratory Rep. English Heritage, Norwich, Norfolk. London, 72/97 24.

Armitage, P.L., 2021. Mammal, bird, fish, amphibian and reptile bones. In: Excavations at Stanground South, Peterborough: Prehistoric, Roman and Post-Medieval Settlement along the Margins of the Fens. Archaeopress Publishing, Oxford, pp. 216–232.

Baker, J.R., 1984. Animal diseases and agricultural practices. In: Clutton-Brock, J., Grigson, C. (Eds.), Animals and Archaeology. 4. Husbandry in Europe. British Archaeological Reports International Series, Oxford, pp. 253–257.

Baker, J.R., Brothwell, D.R., 1980. Animal diseases in archaeology, Studies in archaeological science. Academic Press, London; New York.

Ballin Smith, B., Carter, S., Society of Antiquaries of Scotland (Eds.), 1994. Howe: four millennia of Orkney prehistory excavations, 1978-1982, Monograph / Society of Antiquaries of Scotland monograph series. Society of Antiquaries of Scotland, Edinburgh.

Barone, R., 1976. Anatomie comparée des mammifères domestiques. Tome 1: ostéologie. Vigot Frères, Paris.

Bartosiewicz, L., Demeure, R., Mottet, I., Neer, W.V., Lentacker, A., 1997. Magnetic resonance imaging in the study of spavin in recent and subfossil cattle. Anthropozoologica 25 (26), 57–60.

Bartosiewicz, L., Gál, E., 2013. Shuffling nags, lame ducks: the archaeology of animal disease. Oxford, Oakville, CT.

Bartosiewicz, L., Van Neer, W., Lentacker, A., 1997b. Draught cattle: their osteological identification and history. Musée royal de l'Afrique centrale, Tervuren, Belgique.

Baxter, I.L., 2009. Faunal Remains from Bob's Wood, Hinchingbrooke, Cambridgeshire. Unpublished report.

Baxter, I.L., 2023. Hereford City Excavations V: The faunal remains. Unpublished report.

Björnsdóttir, S., Axelsson, M., Eksell, P., Sigurdsson, H., Carlsten, J., 2010. Radiographic and clinical survey of degenerative joint disease in the distal tarsal joints in Icelandic horses. Equine Vet. J. 32, 268–272. https://doi.org/10.2746/042516400776563590.

Bogucki, P., 2013. Open-range cattle grazing and the spread of farming in Neolithic Central Europe, in: environment and subsistence - forty years after Janusz Kruk's "Settlement Studies," Studien Zur Archäologie in Ostmitteleuropa. Inst. Archaeol. Rzeszów Univ. R. Habelt Rzeszów Bonn. 261–273.

Bowler, D., Cox, A., Smith, C., Brann, M., McGavin, N., Clark, P., Blanchard, L., Hall, D., Ford, B., Underwood, C., Cameron, N., Hodgson, I., Bruce, M., Bennett, H., Thomas, C., Walsh, A., Moran, F., 1996. Four excavations in Perth, 1979-84. Proc. Soc. Antiqu. Scotl. 125, 917–999. https://doi.org/10.9750/PSAS.125.917.999.

Bulatović, J., Marković, N., Stevanović, O., Marinković, D., Stojanović, I., Krstić, N., 2016. Spavin in red deer: a case study from the early neolithic Blagotin, Serbia. Int. J. Paleopathol. 14, 31–35. https://doi.org/10.1016/j.ijpp.2016.04.006.

Clark, G., 1952. Prehistoric Europe: The Economic Basis. Methuen, London.

Connell, B., Davis, S., Bates, A., 2019. The Animal Bones, in: Roman and Medieval Carlisle: The Northen Lanes, Excavations 1978-82, Lancaster Imprints. Oxford Archaeology (North), Lancaster, pp. 613–654.

Cox, A., Blanchard, L., Burrows, J., Sermon, R., Cheer, P., Smith, C., Clark, P., 1997. Backland activities in medieval Perth: excavations at meal vennel and scott street. Proc. Soc. Antiqu. Scotl. 126, 733–821. https://doi.org/10.9750/PSAS.126.733.821.

Davis, S., 1997. Animal Bones from the Roman Site Redlands Farm, Stanwick, Northamptonshire, 1990 Excavation (No. 106/1997), Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Drew, C., 2006. Specialist Report 2005 - The Mammal Bone Assemblage (Butchery at High Pasture Cave). 〈http://www.high-pasture-cave.org/index.php/the_work/article/specialist_report_2005_the_mammal_bone_assemblage〉.

Egerton, J., 1996. Animal bones, in: prehistoric sites and a Romano-British settlement at Butterfield Down, Amesbury. Wilts. Archaeol. Nat. Hist. Mag. 35–36.

Eksell, P., Axelsson, M., Broström, H., Ronéus, B., Häggström, J., Carlsten, J., 1998. Prevalence and risk factors of bone spavin in icelandic horses in Sweden: a radiographic field study. Acta Vet. Scand. 39, 339–348. https://doi.org/10.1186/BF03547782.

Fabiš, M., Thomas, R., 2011. Not just cattle: cranial perforations revisited: cranial perforations revisited. Int. J. Osteoarchaeol. 21, 347–350. https://doi.org/10.1002/oa.1133.

Forward, A., Last, J., Roberts, D., 2020. Excavations at Catridge Farm, Lacock, Wiltshire (No. 193/2020), Research Report Series. Historic England.

Gidney, L., 1989. The Animal Bone from Excavations at Stricklandgate, Kendal Cumbria 1987-88 (No. 103/1989), Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Gidney, L., 1990. The Animal Bone from Holme House, Piercebridge, Co. Durham (No. 115/90), Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Goldberg, S.A., 1918. The Pathology of Spavin. In: The Journal of Medical Research, 38, pp. 225–266. https://doi.org/10.5962/bhl.title.43117.

Grant, A., 1982. The use of tooth wear as a guide to the age of domestic ungulates. In: Wilson, B., Grigson, C., Payne, S. (Eds.), Ageing and Sexing Animal Bones from Archaeological Sites. BAR British Series. BAR, Oxford, pp. 91–108.

Harman, M., 1993. The Animal Bones, 1951-55, East Anglian Archaeology Report. Field Archaeology Division. In: Caister-on-Sea Excavations by Charles Green. Norfolk Museums Service, Dereham, Norfolk, pp. 223–238, 1951-55, East Anglian Archaeology Report. Field Archaeology Division.

Higbee, L., 2004a. The Faunal Remains (No. 19), Archaeological Excavations at Nos. 30-38 St Thomas Street & No. 60 Redcliff Street, Bristol, 2000. Bristol and Avon Archaeology.

Higbee, L., 2004. Mammal, bird and fish bone. In: Evans, C., Regan, R., Webley, L. (Eds.), Camp Ground Excavations: Colne Fen, Earith Assessment Report. Cambridge 660 Archaeological Unit Report 164, Cambridge, pp. 160–200.

Higbee, L., 2009. Mammal and bird bone, in: The Anglo-Saxon Settlement and Cemetery at Bloodmoor Hill, Carlton Colville, Suffolk, East Anglian Archaeology Report. Cambridge Archaeological Unit, Cambridge.

Holmberg, T., Reiland, S., 1984. The influence of age, breed, rearing intensity and exercise on the incidence of spavin in Swedish dairy cattle: a clinical and morphological investigation. Acta Vet. Scand. 25, 113–127. https://doi.org/10.1186/BF03547285.

Jones, R., 1976. Winklebury, Hants: Animal Bone (No. 2173). Ancient Monuments Laboratory Reports (Old Series). Ancient Monuments Laboratory.

Jones, R., Langley, P., Wall, S., 1980. The Animal Bones from Brancester (No. 3189). Ancient Monuments Laboratory Reports (Old Series). Ancient Monuments Laboratory.

Jones, R., Ruben, I., 1987. Animal bones, with some notes on the effects of differential sampling, in: Goltho: the development of an early medieval manor c 850-1150. Archaeol. Data Serv. 197–206.

Jones, G.G., Sadler, P., 2012. Age at death in cattle: methods, older cattle and known-age reference material. Environ. Archaeol. 17, 11–28. https://doi.org/10.1179/1461410312Z.0000000002.

Kierdorf, U., Meng, S., Kahlke, R.-D., 2016. Resorptive depressions on a horn core of Late Pleistocene (MIS 3) Bison priscus (Bovidae, Mammalia) from northeastern Germany. Int. J. Paleopathol. 15, 76–82. https://doi.org/10.1016/j.ijpp.2016.08.006.

Legge, A., 1981. The Agricultural Economy. Grimes Graves Norfolk, Excavations 1971–72. In: Mercer, R.J. (Ed.), Department of the Environment Archaeological Reports. Her majesty's stationary office, London, pp. 79–100. Grimes Graves Norfolk, Excavations 1971–72.

Locker, A., 1985. Gatehouse Nurseries, West Drayton. The Animal Bones (No. 4588), Ancient Monuments Laboratory Reports (Old Series). Ancient Monuments Laboratory.

Luff, R., 1999. Animal and human bones, in: Excavations of an Iron Age Settlement and Roman Religious Complex at Ivy Chimneys, Witham, Essex 1978-83, East Anglian Archaeology. Heritage Conservation, Essex County Council, Chelmsford, Essex, pp. 204–224.

Luff, R., Brothwell, D., 1993. Health and Welfare. In: Animal bones from excavations in Colchester, 1971 - 85, Colchester Archaeological Report. Colchester Archaeological Trust, Colchester, pp. 101–125.

Luff, R., Smith, I., 2019. Faunal remains. Rector Farm, Godmanchester, Cambs.: Excav. 1988-1995, Neolit. Monum. Rom. Villa Farm, East Angl. Archaeol. 233–255 (Oxford Archaeology East, Cambridge, UK).

MacDonald, R.H., 1999. Animal Bones from St Nicholas' Street and and Guildhall Street. In: Excavations in Thetford, North of the River, 1989-90, East Anglian Archaeology Report. Field Archaeology Division, Norfolk, pp. 75–83.

Maltby, M., 1987. The Animal Bones from The Excavations at Owslebury, Hants. An Iron Age and Early Romano- British Settlement (No. 6/1987). Ancient Monuments Laboratory Reports (New Series). English Heritage.

Maltby, M., 1988. The Animal Bones from the 1984 and 1985 Excavations at Alington Avenue, Dorchester, Dorset (No. 182/1988). Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Maltby, M., 1990. The Animal Bones from The Romano- British Deposits at The Greyhound Yard and Methodist Chapel Sites in Dorchester, Dorset (No. 9/1990). Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Maltby, M., 1993. The animal bone from a Romano-British well at Oakridge II, Basingstoke, Hampshire. Proc. Hamps. Field Club Archaeol. Soc. 49, 47–76.

Maltby, M., 2001. Faunal remains (AES 76-7). in: Roman Alcester Volume 3: Northern Extramural Area 1969-1988 Excavations, Roman Alcester Series. Archaeology Data Service, pp. 265–289. https://doi.org/10.5284/1081741.

McElligott, M., Newman, R., Hobson, M.S., Stoakley, M., 2021. Zooarchaeology. In: Hobson, M.S., Newman, Richard (Eds.), Lyde Green Roman Villa, Emersons Green, South Gloucestershire, Archaeopress Roman Archaeology. Archaeopress Publishing Ltd, Oxford.

Morris, P., 1979. Agricultural buildings in Roman Britain, Series 70. British Archaeological Reports British, Oxford.

Noddle, B., 1993. Bones of larger mammals. In: Excavations at Segontium (Caernarfon) Roman Fort, 1975-1979, Council for British Archaeology Research Reports. Council for British Archaeology, pp. 97–103. https://doi.org/10.5284/1081775.

O'Connor, T., 1991. Bones from 46-54 Fishergate, The archaeology of York. Council for British Archaeology, London.

O'Connor, T., 2008. On the differential diagnosis of arthropathy in bovids. In: Grupe, G., McGlynn, G., Peters, J. (Eds.), Limping Together through the Ages: Joint Afflictions and Bone Infections, Documenta Archaeobiologae, 6. Verlag Marie Leidorf, Rahden, pp. 165–186.

O'Connor, T., 2013. Animals as Neighbors: The Past and Present of Comensal Species. East, Lansing.

Rassadnikov, A., 2021. Bone pathologies of modern non-draft cattle (Bos taurus) in the context of grazing systems and environmental influences in the South Urals, Russia. Int. J. Paleopathol. 32, 87–102. https://doi.org/10.1016/j.ijpp.2020.11.003.

Rielly, K., 2020. Mammal and Bird Bone. In: Excavations at Stoke Quay, Ipswich: Southern Gipeswic and the Parish of St Augustine, East Anglian Archaeology. Oxford Archaeology South, Oxford, pp. 340–373.

Scott, K.M., 1983. Prediction of body weight of fossil artiodactyla. Zool. J. Linn. Soc. 77, 199–215. https://doi.org/10.1111/j.1096-3642.1983.tb00098.x.

Scott, S., 1999. Animal bones, in: The Defences of the Lower City: Excavations at The Park and West Parade 1970-2 and a Discussion of Other Sites Excavated up to 1994. Council for British Archaeology Research Reports. Council for British Archaeology, pp. 169–178. https://doi.org/10.5284/1081768.

Smith, I., 2018. Animal Bone. In: Roman Occupation and Burials at Sibford Road. Oxford Archaeology, Hook Norton, pp. 23–26.

Stallibrass, S., 1992. Animal Bones from Excavations at Annetwell Street, Carlisle, 1982-4 Period 3: The Earlier Timber Fort (No. 132/1991). Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Stallibrass, S., 1994. Animal Bones from Excavations in The Southern Area of The Lanes, Carlisle, Cumbria, 1981-1982 (No. 96/1993). Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Stallibrass, S., Mainland, I., 1990. The Animal Bone from the 1984 Excavations of the Romano-British Settlement at Papcastle. Cumbria (No. 4/1990), Ancient Monuments Laboratory Reports (New Series). Ancient Monuments Laboratory.

Stashak, T.S., 2013. Practical Guide to Lameness in Horses. Wiley.

Stashak, T.S., Baxter, G.M., 2020. Adams and Stashak's lameness in horses, 7th edition. Wiley Blackwell, Hoboken.

Strid, L., 2011. Mammal and Bird Bones, Winchester-a city in the making: archaeological excavations between 2002 and 2007 on the sites of Northgate House, Staple Gardens and the former Winchester Library. Jewry St. Oxford Archaeology.

Strid, L., 2014. Animal Bones, Archaeological Excavation and Watching Brief at Cobb House Bampton Oxfordshire. Oxford Archaeology.

Thomas, R., Sykes, N., Doherty, S., Smith, D., 2018. Ring depressions in cattle horncores as indicators of traction use – a cautionary note. Int. J. Paleopathol. 22, 140–142. https://doi.org/10.1016/j.ijpp.2018.07.002.

Van Pelt, R.W., 1975. Tarsal degenerative joint disease in cattle: blood and synovial fluid changes. Am. J. Vet. Res. 36, 1009–1014.

Waterbolk, H.T., 1975. Evidence of cattle stalling in excavated pre- and protohistoric houses. In: Clason, A.T. (Ed.), Archaeozoological Studies: Papers of the Archaeozoological Conference 1974, Held at the Biologisch-Archaeologisch Instituut of the State University of Groningen. North-Holland Pub. Co. American Elsevier, Amsterdam, New York, pp. 383–394.

Wessex Archaeology, (2009).Llangibby Castle, Near Usk, Monmouthshire, South Wales Archaeological Evaluation and Assessment of Results (No. 71500.01).

Worley, F., Kitch, J., 2019. Unpublished report. Anim. Bone, Castle Hill Little Witten. Oxfs.

Wussow, J., 2013. Das Museum für Haustierkunde "Julius Kühn"– im Spiegel der Tierzuchtforschung. Z. Uchtungskunde 4, 324–336.

Zimmermann, W.H., 1999. Favourable Conditions for Cattle Farming, one Reason for the Anglo-Saxon Migration over the North Sea? About the Byre's Evolution in the Area South and East of the North Sea and England. In: Sarfatij, H., Verwers, W.J.H., Woltering, P.J. (Eds.), In Discussion with the Past: Archaeological Studies Presented to W.A.van Es. Stichting Promotie Archeologie, Zwolle, pp. 129–144.