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Traction in Neolithic Çatalhöyük? Palaeopathological analysis of cattle and aurochs remains from the East and West Mounds

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ABSTRACT

Cattle traction was a technological innovation that made a significant impact on production, individual and household wealth, and social organisation. Despite ongoing debates regarding the origins and extent of the harnessing of cattle power among early agropastoral societies, only a few studies have attempted at addressing this matter systematically. In Neolithic Çatalhöyük, several studies have explored the symbolism and domestication of aurochs and cattle, while the systematic investigation of *Bos* skeletal remains regarding the presence of cattle traction has been missing. This study focuses on Neolithic Çatalhöyük in Central Anatolia, renowned for its cattle symbolism, to explore the possibility of cattle traction in the 7th and 6th millennium BCE. We studied the palaeopathological traces on the lower limbs of *Bos* from Çatalhöyük East (Early, Middle, and Late) and West Mounds. Our results suggest that arthropathies are present on the *Bos* lower limbs (particularly anterior elements) in all phases of Neolithic Çatalhöyük. Pathological and sub-pathological changes are on average more severe among the small cattle of Çatalhöyük West than in the preceding periods at Çatalhöyük East, a result affected by a few rather deformed specimens in Çatalhöyük West. We did not observe any clear correlation between cattle survivorship, size, and pathology severity. Although an unequivocal association between pathologies and traction in prehistoric cattle remains challenging, we discuss plausible explanations for the changing nature and intensity of cattle pathologies at Çatalhöyük throughout time. Furthermore, we discuss the implications of possible draught use of cattle for the socioeconomic shifts Çatalhöyük experienced in the 6th millennium BC.

1. Introduction

Pioneering works by Childe (1951), Bökönyi (1974), and Sherratt (1981, 1983) highlighted the harnessing of oxen as one of the leading factors behind the economic, technological, and societal developments among early farming societies. This core idea became a primary component of what Sherratt termed the *Secondary Products Revolution* (SPR) (1981). Sherratt (1981) argued that the use of animal power was distinct from animal domestication and it was a later (4th millennium BCE) innovation originating in southern Mesopotamia. In his argument, SPR brought about radical social and economic changes, including greater territorial control, growth of exchange and transportation, expansion of cultivated land and forest clearance, and diffusion of technology and animal breeds. These transformations led to the formation of complex societies in the Near East and their dispersal to Europe, Eurasia, and North Africa by the 3rd millennium BCE (Sherratt, 1994). Since its introduction, SPR has been criticised for its theoretical and empirical approaches. Criticisms have been supported by, among other evidence, osteological and palaeopathological data that indicated earlier cases of non-intensive use of cattle power (e.g. Gaastra et al., 2018; Greenfield, 2005; Johannsen, 2011; Marciniak, 2011). Indeed, a remarkable amount of zooarchaeological and non-zooarchaeological data demonstrates that, since the 4th millennium BCE, draught cattle and yoking techniques were widespread throughout Southwest Asia and Europe (e.g., Balasescu et al., 2006; Fansa and Stefan, 2004; Johannsen, 2006; Mashkour, 2002; Piggot, 1992; Fedele, 2016). However, as it has been argued before, the explosion of evidence of cattle traction in the 4th millennium BCE may be an artefact of the increased amount of

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faunal remains and preservation in artefactual data. Moreover, as argued by Halstead (1995) and Piggot (1992), these artefacts may represent the elites' monopolised access to animal power rather than the onset of cattle traction use. It is now widely accepted that the SPR model is an indication of the intensification rather than the onset of animal exploitation (Bogucki, 1993; Halstead & Isaakidou, 2011; Ivanova, 2017; Marciniak, 2014). Hence, it is necessary to differentiate and detect the initial know-how and ad hoc use of cattle power in Neolithic contexts from the later widespread and intensive exploitation (Bogucki, 1993; Isaakidou, 2015, p. 96; Halstead & Isaakidou, 2011; Marciniak, 2011).

2. Theoretical principles

An animal's anatomy evolves according to the forces that it naturally encounters (Bartosiewicz, 2008a,b); human-imposed labour is one such force inflicted upon domesticated animals. Throughout an animal's lifetime, in response to increased functional strain, skeletal elements undergo internal and external remodelling (Bartosiewicz, 2008a,b; Wolf, 1892). Under working conditions, this adaptation primarily manifests as sub-pathological deformations in skeletal joints, the nature of which depends on the type, duration, and intensity of the work imposed upon the animal (Bartosiewicz et al., 1997). However, morphological adaptations (pathological) may also develop as a function of interrelated aetiologies, such as an animal's age, sex, live body weight, pasture topography, traumatic injuries, disease, and genetic susceptibility (Baker & Brothwell, 1980; Bartosiewicz et al., 1997; Higham et al., 1981; Holmes et al., 2021; Thomas, 2008). Hence, such anomalies cannot be viewed as unambiguous evidence of draught animal exploitation, and these factors must be disentangled from each other when analysing skeletal specimens. The landmark study of skeletal pathological markers on modern Romanian draught oxen and fattened bulls by Bartosiewicz et al. (1997) has enhanced this debate by developing a system for scoring pathological and sub-pathological changes (including exostosis, lipping, osteoarthritis, and articular extension; for further explanation of these changes see Thomas et al., 2021) in the lower limb bones of cattle that might signify their use for traction. The applications of this method and its variants demonstrate that the regular occurrence and diachronic increase in such pathologies are effective to determine the origins of and changes in the use of animals in draught work.

The systematic use of this method in conjunction with biometric data, mortality profiles, and possible evidence for castration have increased the quality and quantity of zooarchaeological data available to decipher the timeline, scale, and geographical distribution of draught exploitation in prehistoric Europe and the Near East (e.g. Bartosiewicz and Gál, 2013; De Cupere et al., 2000; Dietmeier and Kay, 2018; Galindo-Pellicena et al., 2017; Groot, 2002; Holmes et al., 2021; Isaakidou, 2015; Lin et al., 2016; Bartosiewicz et al., 1997; Johannsen, 2005). To date, pathological and morphometric data from northern Mesopotamia have suggested the use of cattle as draught animals since the early stages of their domestication, which occurred as early as the Pre-Pottery Neolithic B (8700–8200 BCE; Helmer, 2008; Helmer et al., 2018). Based on age, sex, and pathological data, Isaakidou (2006:108–9) argued that adult cows were utilised as beasts of burden in Neolithic Knossos (Crete) possibly as early as the 7th millennium BCE and that this practice intensified from the 3rd millennium BCE. Gaastra et al. (2018) utilised pathological and sub-pathological data to demonstrate cattle may have been occasionally used for traction in the Western Balkans during the Early Neolithic (6100–4500 BCE). Pathological deformations in the limb bones and skulls of cattle, as well as probable yoke fragments from the early Neolithic site of La Draga (the northeast Iberian Peninsula, 5300–5100 BCE), have been discussed in the context of the use of cattle power (Llado et al., 2008; Tarrús et al., 2006), suggesting the extension of cattle traction to Western Europe during the late 6th millennium BCE (Llado et al., 2008; Tarrús et al., 2006). However, after the recent identification of occipital perforation on European bison, it became evident that these anomalies are more linked to genetic developmental disorders rather than traction use (Fabiš and Thomas, 2011)

Research on cattle traction in Neolithic contexts is hampered by difficulties in distinguishing domestic cattle from their wild counterparts in the archaeological records due to genetic (Verdugo et al., 2019) and morphological overlap (Grigson, 1989; Helmer et al., 2005; Wright, 2013). In addition, a recent study by Thomas et al. (2021) on pathological and sub-pathological changes in the semi-feral Chillingham cattle skeleton has further deciphered the interrelated nature of the skeletal changes observed by Bartosiewicz et al. (1997) with animal age, sex, and body mass playing a major role in their development. As a response to these challenges, in this study, we investigate the nature and diachronic occurrence of pathological and sub-pathological remodelling in the lower limbs (metapodials and phalanges) of aurochs and cattle in Neolithic Çatalhöyük between 7100 and 5600 BCE (Hodder, 2020; Orton et al., 2018; Twiss et al., 2021), aiming to disentangle the links between adaptive remodelling of domestic cattle skeletons and those changes caused by biological variables in aurochs.

Çatalhöyük is a key site that contains evidence with implications for the Neolithisation of Southwest Asia and the emergence of farming in Southeast Europe (Hodder, 2007; 2018). In Çatalhöyük, cattle remains are infrequent compared to European contexts (Orton, 2018; Russell et al., 2013a,b; Twiss et al., 2021); however, human-cattle interactions had a central role in the Neolithic way of life (Pawłowska, 2020a; Russell et al., 2005; Twiss & Russell, 2009). Aurochs and cattle from Çatalhöyük have been examined for domestication, symbolism, milk and meat production, and grazing strategies (Russell et al., 2005; Russell et al., 2013a,b; Wolfhagen, 2019; Wolfhagen et al., 2021). Pathologies in cattle remains have been observed and reported frequently in zooarchaeological reports (Twiss et al., 2021:154). Furthermore, the implications of the possible use of animal traction in the plant and cereal cultivation system of Çatalhöyük have been discussed recently (Bogaard et al., 2021). However, pathological traces on *Bos* remains were not investigated systematically to reveal their diachronic nature, intensity, and relation to the use of cattle power at the settlement. Moreover, the abundance of *Bos* remains linked to ritual and feasting activities has caused livestock to be mainly associated with symbolic and subsistence practices while the socioeconomic use of cattle traction in farming communities has been overlooked (Twiss, 2012; Demirergi et al., 2014; Russell et al., 2014; Twiss & Bogaard, 2017). To overcome this knowledge gap, we use the frequency and nature of pathological and sub-pathological changes on *Bos* skeletal remains to determine whether cattle were utilised for their power. We further explore other possible factors that may have contributed to the formation of pathological and sub-pathological changes. Ultimately, we discuss the cultural and economic implications of possible draught cattle exploitation for the Çatalhöyük community.

2.1. The site

Çatalhöyük is a two-mounded tell site located in the Konya Plain in south-central Turkey (Fig. 1). Site excavation was conducted initially by Mellaart in 1961–1965 (Mellaart, 1967) and continued by Hodder in 1993–2017 (Hodder, 2020). The Konya Museum directed excavations in 2018–2019 under the scientific supervision of Çilingiroğlu et al. (2020). Çatalhöyük's East Mound covers 13.5 ha. It contains the site's earliest signs of occupation (ca. 7100–5950 BCE; Bayliss et al., 2015), and chronologically overlaps with that of the West Mound (ca.6100–5600 BCE) in the last quarter of the 7th millennium BCE (Orton et al., 2018; Rosenstock et al., 2019). The Çarşamba River at one time flowed between the mounds, creating alluvial clay deposits that favoured agricultural activities. Recent environmental studies have reconstructed a diverse environment, including wetlands and riparian habitats (Wolfhagen et al., 2020).

Occupation at Çatalhöyük East is grouped into four temporal phases: Early, Middle, Late, and Final (Hodder, 2020). Neolithic life in

Fig. 1. Location of Çatalhöyük.

Çatalhöyük Early was characterised by the continuous construction of similar rectilinear mud-brick houses with middens between dwellings, rich symbolism, and sub-floor burials. The site was densely occupied, with over 1000 people from an early date, for 1500 years (Hodder, 2020). Animal bones are among the most frequent finds and demonstrate relatively satisfactory preservation. They are found both inside houses (either *in situ* on floors, as bucrania, in burials, or the room fills) and in midden deposits (Martin & Russell, 2000; Twiss & Russell, 2009).

The nature of human-cattle interactions at Çatalhöyük has been an important focus of zooarchaeological work at the site throughout its research history. Scholars commonly agree that *Bos* retained a central role in the societal, symbolic, and subsistence organisation of the Çatalhöyük community throughout its long occupation (Twiss & Russell, 2009; Russell, 2016). However, this view has been evolved radically since the first excavations at the site occurred in the 1960s. Initial researchers proposed that Çatalhöyük was the centre of cattle domestication based on the animals' small body size, high relative abundance, and body-part representation (Perkins, 1969). This hypothesis was later rejected following the analysis of a larger set of specimens that revealed predominantly smaller female specimens at Çatalhöyük (Ducos, 1988; Grigson, 1989:91). Utilising body-part distribution, Ducos (1988) has proposed a symbolic rather than a socio-economic significance regarding cattle. Extensive zooarchaeological studies involving the systematic collection of faunal remains from the Hodder excavations (1993–2017) reveal that caprines (sheep and goat) remain dominated the assemblage (c. 60% of the number of identified specimens or NISP) while *Bos* formed only 20−25% (NISP) of the animal bone assemblage, which decreased to 14% during later phases (Russell et al., 2013a,b; Pawłowska, 2020b). Considering the higher meat yield of cattle compared to caprines, beef likely dominated the human diet (Demirergi et al., 2014), although its consumption was primarily confined to human adults during ceremonial feasts (Russell et al., 2013a,b). A study by Russell and Martin (2005) argues that wild *Bos* were prevalent throughout the site's occupation based on their larger size (comparable with Aşıklı Höyük and Musular aurochs in Central Anatolia) and the high proportion of adults in the mortality profiles. A subsequently extended dataset included cattle size, horn morphology, and slaughtering patterns, which exhibits a significant size reduction in cattle over time. Consequently, the population of cattle in Çatalhöyük Late has been interpreted as largely domestic, which corroborates the idea of a proto-domestication status for cattle in Çatalhöyük Middle (Russell et al., 2013a,b, p. 223). Evidence of potential penning areas for *Bos,* with a high accumulation of dung deposits, has been utilised to infer humans controlled the cattle population in Çatalhöyük Late (García-Suárez et al., 2021:273). Recent research into the late and final phases of the East Mound has revealed data (e.g., the occurrence of domestic cattle skeletons in daily and feasting contexts and in association with human burial) that supports cattle management (from c. 6400 BCE onward; Pawłowska, 2020a, 2020b). Long-bone fusion data suggests in Early and Middle Çatalhöyük cattle sex ratios were relatively even (c. 50–60%), which later shifted to juvenile and female (70%) exploitation in Çatalhöyük Late and Final (Wolfhagen et al., 2021:194). Cattle herding likely became commonplace only in Çatalhöyük Final and West Mound (Wolfhagen et al., 2021).

The abrupt appearance of smaller cattle during the later phases of Çatalhöyük has also been attributed to importation from the east (Arbuckle & Makarewicz, 2009), although this has been disputed by Wolfhagen (2019:112). Employing a Bayesian mixture modelled on biometric data, Wolfhagen et al. (2021) demonstrate the body size of cattle remained largely consistent during the first 400 years of human occupation at Çatalhöyük (Çatalhöyük Early) and declined by 10% over the successive 400 years through Çatalhöyük Late. Considering the earlier manifestation of morphologically domestic cattle at other Anatolian sites, aurochs hunting may have remained intrinsic to the social economy of Çatalhöyük as a symbol of prestige for some households, while others invested in animal farming for wealth accumulation (Russell et al., 2013a,b:223). Dietary stable isotope analyses of *Bos* remains from Çatalhöyük Early and Middle largely indicate C_3 plant consumption, which supports the theory that these animals were hunted in open woodlands (Pearson et al., 2015). Cattle at Çatalhöyük Late reveal the inclusion of C_4 plants in their diet, suggesting they grazed with other domesticates in similar ecological zones (Pearson et al., 2015, 2021:222) throughout the site's occupation (Wolfhagen, 2019:132). These transitions in human-cattle interactions coincide with previously observed shifts in architecture, subsistence, agriculture, production intensity, and demography toward more independent households, which occurred at Çatalhöyük beginning in 6500 BCE (Hodder, 2014, 2016; Marciniak et al., 2015; Pawłowska, 2020a).

The excavation of the West Mound was first conducted on a small scale by Mellaart (1965) and resumed by Biehl and Rosenstock (2008), and Erdoğu (2008), with a focus on the cultural and demographic transition from the East to the West Mound. Researchers have argued that socioeconomic and palaeoenvironmental changes instigated the demographic transition (Rosenstock et al., 2019); however, the nature of this transition remains poorly understood. Available data suggest a gradual shift, with the continuance of the living patterns that began in the East Mound and the emergence of large-scale storage pots. Caprines comprise 95% of NISP, while morphologically domestic cattle formed only 3–6% of NISP (Orton & Piliougine, 2013), with females forming 74% of the *Bos* remains (Wolfhagen et al., 2021:194). Furthermore, the symbolism of *Bos* is absent in architecture and special deposits, and cattle size diminution persists at this level (Orton, 2018). Cow milk protein detected in at least two pottery shards from the West Mound reinforces the presence of domestic cattle and dairy production (Hendy et al., 2018). The only available genomic data is from aurochs from the West Mound, suggesting a common matrilineal origin with Neolithic domestic cattle in Anatolia and Iran (Verdugo et al., 2019).

3. Material and methods

To investigate the *Bos* remains in Neolithic Çatalhöyük and determine whether the cattle were utilised for draught purposes, we performed a combination of palaeopathological and osteometric analyses. To take the age-at-death of the Çatalhöyük *Bos* population into account, we used published data (Twiss et al., 2021; Open context.org). We randomly selected 132 lower limb bones of *Bos* (Table 1) that had been recovered from 61 different stratified units, including middens and room fills. Of these specimens, 72 had been studied by previous zooarchaeological teams. Our sample comprises a small portion of the cattle limb bones investigated at the site (c. 1,457 specimens from the East Mound and c. 53 specimens from the West Mound; Russell et al., 2013a,b; Orton, 2018; Twiss et al., 2021). Çatalhöyük Final was not represented in our sample. To avoid counting the same specimen more than once, we counted possible articulating bones as one specimen, utilising unit descriptions, sizes, and bone surface conditions. However, as in the majority of zooarchaeological studies that examine highly fragmented faunal assemblages from palimpsest sites, ascertaining whether different specimens from the same unit or even period represent different individuals is not possible. To mitigate the effect of age, we studied only fused specimens, which means specimens that represented individuals which were at least 1½–2 years old at their death (Schmidt, 1972:75). We distinguished anterior and posterior phalanges, except for nine poorly preserved ones. For this, we used the criteria described by Dottrens (1946) as well as reference specimens with complete skeletons. For undetermined phalanges, we considered only the pathological and sub-pathological information. Though Thomas et al. (2021) questioned the reliability of Dottrens method's usefulness to distinguish the anterior and posterior third phalanges, we believe that anterior and posterior third phalanges are of distinct shapes and when the sample size is limited, like in most Southwest Asian prehistoric sites (in particular, Çatalhöyük), it is useful to include them in the analysis. We scored the pathological and sub-pathological traces in the specimens using the method described by Bartosiewicz et al. (1997). According to this method, pathological and sub-pathological markers are scored from 0 to 4 (0 = absent; 4 = most severe). These scores are then calculated in a pathological index (PI), which enables a systematic, quantitative investigation of pathological and sub-pathological alterations on fragmented zooarchaeological remains. In the original study by Bartosiewicz et al. (1997), only complete bones are included; however, cattle bones in Çatalhöyük are highly fragmented. To maintain a sufficient sample size, we included incomplete specimens in our analysis and adjusted the original formula (De Cupere et al., 2000):

$$PI = \frac{(sum\ of\ scores) - (number\ of\ variables)}{(maximum\ score) - (number\ of\ variables)}$$

This formula reveals PI values ranging between 0 (absence of pathologies) and 1 (pathologies present at the maximum level). We calculated the mean PI for each chronological subgroup to observe the diachronic changes in the average levels of pathological and sub-pathological remodelling. Furthermore, we calculated the grand mean PI for each chronological subgroup relative to our control groups, which included Romanian draught oxen (aged 6–19 years, 112 elements), Romanian fattened bulls (aged 2 years, 32 elements; Bartosiewicz et al., 1997), and the recently published semi-feral Chillingham cows and bulls (aged 2–14 years, 94 elements; Thomas et al., 2021). Among the Romanian bulls and Chillingham cattle, remodelling was evident in 23% and 47% of the specimens, respectively. Conversely, among Romanian oxen, 96% of the specimens revealed pathological deformations to a certain degree (PI > 0). PIs higher than 0.625 were revealed for 17% of the specimens in this population; these specimens represent the highest mean PI and standard deviation (0.41 ± 0.215) compared to the Romanian bulls (0.023 ± 0.046) and Chillingham cattle (0.073 ± 0.091).

In the next step, we used the modified pathological index (mPI) formula advanced by Thomas et al. (2021), following the analysis of the Chillingham semi-feral cattle skeleton to assess the extent to which age and sex have affected the skeletal remodelling in our dataset. In previous studies of arthropathies on cattle skeletons, significant differences have been observed in the distribution of pathologies in cattle limbs (Bartosiewicz & Gál, 2013:152). Forelimbs typically display higher PIs than hind limbs, which probably is due to the stress of accommodating the weight of forequarters and horns (Bartosiewicz et al., 1997:61), while traction appears to disproportionately affect the hind limbs (Holmes et al., 2021). To account for this, we compared the distribution of PI values between anterior and posterior elements and among chronological subgroups. We utilised Welch's analysis of variance (ANOVA) to examine any significant changes in the frequency and intensity of PI values over time.

A positive correlation between animal size (live weight) and pathological frequency, in which older and larger bulls have a greater number of bone lesions compared to cows, has been observed in the modern Romanian cattle study (Bartosiewicz et al., 1997), early medieval and the semi-feral cattle at Chillingham (Holmes et al., 2021; Thomas et al., 2021), and a 16th-century English cattle population (Thomas, 2008).

Table 1
Frequency of Çatalhöyük *Bos* specimens included in the study, their chronology, and calibrated radiocarbon dates (Orton, 2018; Hodder, 2020). UD = undetermined position.

Mound	Phase	Cal BC	Metacarpus	Metatarsus	1st phalanx			2nd phalanx			3rd phalanx		
					anterior	posterior	UD	anterior	posterior	UD	anterior	posterior	UD
West	–	6100–5600	3	3	2	3		3	4		7	5	
East	Late	6500–6300	2	3	7	13		5	8		3	1	
East	Middle	6700–6500	3	4	7	7	3	10	11	1	4	3	2
East	Early	7100–6700		1			3	1					

Because of the significant diachronic reduction in cattle size observed in Çatalhöyük (Wolfhagen et al., 2021) as well as our desire to assess the impact of large body size as a possible significant factor affecting PI values, we examined the correlation between cattle size and pathologies in Çatalhöyük. All specimens were measured following von den Driesch (1976). Given the influence of some particular measurements on pathological and sub-pathological changes reported in the study by Thomas et al. (2021), we calculated the logarithmic size index (LSI) which represents general animal body size, as one of the most debated topics regarding *Bos* at Çatalhöyük (e.g. Arbuckle et al., 2014; Russell et al., 2005; Wolfhagen, 2019; Wolfhagen et al., 2021). For calculating LSI, we employed the method advanced by Meadow, 1999 and used the Danish female aurochs (Degerbøl & Fredskild, 1970) as the standard animal. We plotted the LSI of anterior and posterior specimens separately against their corresponding PI values.

Exostosis on cattle limbs has largely been associated with advanced age and trauma (Baker & Brothwell, 1980:117), while lipping and broadening on articular surfaces have been observed exclusively among working animals (Bartosiewicz et al., 1997). Ageing and heavy activities may both cause osteoarthritis (Baker, 1984). To examine the role of age, sex, live weight, and possibly traction in the development and distribution of pathologies in cattle's fore- and hind limbs, we compared our results with those from our control group (i.e. Romanian draught oxen, Romanian fattened bulls, and semi-feral Chillingham cows and bulls) by utilising principal component analysis (PCA).

4. Results

Of the 132 specimens observed, 62% demonstrated pathological and sub-pathological changes to a certain degree (PI > 0) (Table S1; for examples, see Figs. 2 and 3). In 60% of our specimens, pathological alterations were minor to moderate (scores of 2–3). The most severe pathological stages were observed on third phalanges, with 76% of these scoring between 2 and 4, whereas most metacarpals scored between 1 and 3. The PIs of anterior elements were slightly higher than those of the posterior elements, except for the third phalanges in which both anterior and posterior demonstrate high PIs.

Çatalhöyük Early yielded five specimens, three of which displayed no pathologies (Table 2). The mean PI was calculated for one anterior second phalanx (0.364) and one metatarsal (0.143). These specimens scored high (2–3) for proximal lipping and exostosis as well as distal exostosis.

For Çatalhöyük Middle, the PI was calculated for 55 specimens, 60% of which presented deformations to a certain extent (scores of 2–3). Anterior and posterior third phalanges, metacarpals, and metatarsals revealed the highest degrees of deformation. Proximal lipping and exostosis were the most frequently observed pathologies at this level, with the latter being more common among anterior elements (Fig. 3). In 78% of the third phalanges, the proximal lipping had a score of 3.

In Çatalhöyük Late, we tested 42 specimens, in which slight deformations (score of 2) were observed in 64% of the samples. Proximal lipping on phalanges was the most common pathology recorded in this assemblage. Of 30 specimens from Çatalhöyük West, 56% demonstrated elevated pathological deformations (scores of 2–4). Scores between 3 and 4 included proximal exostosis and lipping on 67% of third phalanges.

The mean and standard deviations of the PIs in our sample were lowest (0.101 ± 0.142) in Çatalhöyük Early and highest (0.225 ± 0.229) in the West Mound, which represents greater diversity in the degree of deformation on *Bos* specimens from Çatalhöyük West. As proposed by De Cupere et al. (2000), utilising the Romanian oxen (a 100% draught population) as a benchmark, the relative mean PIs were 26% in Çatalhöyük Early (note the small sample size in Table 2), 37% in Çatalhöyük Middle, 28% in Çatalhöyük Late, and 55% in Çatalhöyük West.

Due to our unequal sample size and the heterogeneity of variances (Levene's statistic: $p < 0.05$), we used Welch's ANOVA test to evaluate the statistical significance of the differences between the chronologically grouped assemblages (Table S2). The test result was significant, Welch's $F (6, 47.02) = 52.11$, $p < 0.001$, meaning that not all assemblages had the same PI scores based on cattle pathological and sub-pathological traces. Upon conducting the Games-Howell post hoc procedure, it was revealed that PI values of Çatalhöyük assemblages (Early, Middle, Late, and West) did not differ significantly from each other. However, the Middle, Late, and West differed significantly from Romanian oxen and Romanian bull. Furthermore, the Middle and West differed significantly from Chillingham cattle.

Using the mPI formula in order to remove the age-related characters suggested by Thomas et al. (2021), we observed that the mean

Fig. 2. Advanced exostoses and lipping in the proximal articulation of the third phalanges of *Bos* specimens. From left to right, specimens are from Çatalhöyük Middle (Unit 19348, proximal exostosis score of 3), Middle (Unit 21140, proximal exostosis score of 3), and West (Unit 16992, proximal exostosis score of 4).

Fig. 3. Examples of distal exostosis (left, Çatalhöyük Early, Unit 1037, score of 3) and lipping at the proximal end (right, Çatalhöyük Middle, Unit 30563, score of 2) in the second phalanges of *Bos* specimens.

Table 2
The mean pathological index (PI), Total mean, and standard deviation (SD) for the anterior and posterior skeletal elements of *Bos* from Çatalhöyük Early, Middle, Late, and West Mounds compared to those from modern Romanian draught oxen, bulls (data from De Cupere et al., 2000), and Chillingham cattle (all criteria included; Thomas et al., 2021). (*n* = number of specimens, MC = metacarpus, MT = Metatarsus, PH1 = first phalanx, PH2 = second phalanx, PH3 = third phalanx, A = anterior, P = posterior, and UD PH = phalanx with undetermined position). Colour codes represent the range of PIs from higher (dark grey) to lower (light grey and white).

	MEAN PI										
Assemblages	MC	PH1A	PH2A	PH3A	MT	PH1P	PH2P	PH3P	UD PH	**Total Mean**	**SD**
Early (n = 5)			0.364		0.143				0.000	0.101	0.142
Middle (n = 55)	0.352	0.096	0.091	0.464	0.246	0.013	0.105	0.286	0.145	0.154	0.161
Late (n = 42)	0.310	0.057	0.116	0.238	0.170	0.075	0.068	0.429		0.114	0.116
West (n = 30)	0.245	0.045	0.061	0.476	0.095	0.000	0.114	0.333		0.225	0.229
Romanian bull (n = 32)	0.012	0.000	0.018	0.057	0.021	0.000	0.030	0.048		0.023	0.046
Chillingham cattle (n = 94)	0.044	0.061	0.045	0.167	0.036	0.033	0.025	0.167		0.073	0.091
Romanian ox (n = 112)	0.333	0.358	0.370	0.686	0.313	0.308	0.336	0.560		0.410	0.215

pathological index values for both anterior and posterior elements and total mean values in different assemblages are generally lower using the modified formulae (Table 3). This suggests that the age profiles of the cattle assemblages partially influenced our dataset. However, metatarsals are exceptions to this pattern with higher PIs in Çatalhöyük Early, Middle, West, and Romanian oxen. This might be partially due to the limited sample size for Çatalhöyük Early. However, in Çatalhöyük Middle, West, and Romanian oxen the high PIs of metatarsals are probably not age-related.

Fig. 4 presents the distribution of PIs among the anterior and posterior elements of *Bos* specimens in Çatalhöyük, as compared to the control groups. The occurrence of PIs in Çatalhöyük Early, although not advanced, was observed in both anterior and posterior elements. In Çatalhöyük Middle, the number of specimens with no pathologies (n = 19) as well as those with a certain degree of deformation (n = 30) was balanced between anterior and posterior elements, excluding six phalanges within the undetermined position. Anterior elements, however, demonstrated slightly advanced PIs (PI ≥ 0.455) in four third phalanges and metacarpals. In Çatalhöyük Late, pathologies were more common in posterior elements (57%), which was in contrast with other cultural levels at the site. The observed PIs for *Bos* specimens from Çatalhöyük West demonstrated a wide distribution in pathological deformation, with three anterior third phalanges whose PIs were as high as 0.667. Approximately 63% of the specimens with pathologies belonged to anterior elements.

Among our control groups, in Romanian oxen and Chillingham cattle, the mean PI for anterior elements was higher than that of posterior elements. Anterior elements comprised 54% and 57% of the pathologies in Romanian oxen and Chillingham cattle, respectively. Among the Romanian oxen, the PIs were significantly advanced (0.909), peaking between 0.273 and 0.455. Romanian bulls illustrated a balance between the PIs calculated for fore- and hind limbs. Skeletal remodelling was more common on anterior elements (57%) among the rest of the specimens in this population.

Fig. 5 compares the sizes (as LSI) and PIs of the anterior specimens. Specimens with no observed pathologies were present at all levels and in all body sizes, which means specimens had diverse LSIs. One specimen from Çatalhöyük Early was larger than the female aurochs and indicated a relatively high PI. *Bos* in Çatalhöyük Middle presented the greatest diversity in size, with larger specimens displaying higher degrees of pathology. Conversely, the West Mound included the smallest *Bos* specimens, four of which were the smallest in the entire assemblage and had the highest level of pathology. This indicates that the Çatalhöyük West assemblage has the greatest diversity and intensity of PIs. Conversely, the Çatalhöyük Late assemblage had the lowest size range and PI severity.

Table 3
The mean of "modified pathological index" (mPI) following the method proposed by Thomas et al. (2021), Total mean, and standard deviation (SD) for the anterior and posterior skeletal elements of *Bos* from Çatalhöyük Early, Middle, Late, and West Mounds compared to those from modern Romanian draught oxen, bulls (data from De Cupere et al., 2000), and Chillingham cattle (suggested age-related criteria excluded; Thomas et al., 2021). (*n* = number of specimens, MC = metacarpus, MT = Metatarsus, PH1 = first phalanx, PH2 = second phalanx, A = anterior, P = posterior, and UD PH = undetermined position of phalange). Colour codes represent the range of mPIs from higher (dark grey) to lower (light grey and white).

	mPI								
Assemblage	MC	PH1A	PH2A	MT	PH1P	PH2P	UD PH	**Total Mean**	**SD**
Early (n = 5)			0.364	0.250			0.000	0.205	0.186
Middle (n = 46)	0.278	0.096	0.091	0.264	0.013	0.105	0.083	0.133	0.099
Late (n = 38)	0.226	0.045	0.097	0.037	0.045	0.068		0.086	0.072
West (n = 18)	0.208	0.045	0.061	0.167	0.000	0.114		0.099	0.079
Romanian bull (N = 24)	0.014	0.000	0.018	0.033	0.000	0.030		0.016	0.014
Chillingham cattle (n = 70)	0.036	0.031	0.045	0.033	0.000	0.025		0.028	0.015
Romanian Oxen (n = 84)	0.305	0.292	0.370	0.323	0.240	0.336		0.311	0.044

The posterior elements (Fig. 5) of *Bos* specimens revealed overlap in the distribution of PIs and LSIs throughout the assemblage. The pathologies generally had lower intensities, with no specimens displaying PIs > 0.455. The large specimen from Çatalhöyük Early presented slight pathologies. In Çatalhöyük Middle, the *Bos* LSI featured a wide range. Specimens with high PIs had different LSIs, suggesting no correlation between a specimen's size and its PI value. In Çatalhöyük Late, specimens indicated a wide range of LSIs and PIs, in contrast to the pattern observed in anterior elements at this level. Similar to the anterior elements, Çatalhöyük West comprised the smallest specimens with the highest PI values among posterior samples.

Fig. 6 displays the results of the PCA performed on all phalanges in the Çatalhöyük assemblage and on our control groups, positioning them relative to each other based on the type and the severity of the pathologies they displayed. The majority of the information has been derived from the first component (69% of variances), which had the highest correlation with proximal lipping (correlation coefficient = 0.8) and proximal exostosis (correlation coefficient = 0.6). The second component expresses 16% of total variances, which were strongly correlated with distal exostosis (correlation coefficient = 0.9). Chillingham cattle and Romanian bulls clustered together, and they were distinctly separate from the draught oxen. The majority of the Çatalhöyük specimens were distributed on the left and overlapped with the Romanian bulls and Chillingham cattle. A slight overlap between Çatalhöyük West and Early specimens and oxen was observed.

5. Discussion

The palaeopathological assessment of the lower limbs of *Bos* specimens from Çatalhöyük East and West demonstrates that bone lesions were widespread in both morphologically wild and domestic cattle throughout the occupational history of the site. This reiterates previous observations that bone deformations occur not only due to human-induced labour but also 'naturally' due to aetiologies such as body weight, advanced age, and genetic disposition (Bartosiewicz & Gál, 2013; Thomas et al., 2021). However, the frequency and severity of the pathological deformations fluctuated over time in Çatalhöyük. The *Bos* assemblage from Çatalhöyük West contained the smallest specimens with generally more severe pathological and sub-pathological changes than those attested in Çatalhöyük East, particularly in Çatalhöyük Early. Differences in the frequency and intensity of pathologies were not statistically significant between the chronological units. Larger sample sizes are required to verify these findings. Nevertheless, apparent trends allow a discussion of the relative contributions of sex, age, body weight, and labour to the development of these anomalies.

In Çatalhöyük Early, primarily old male *Bos* were hunted (Wolfhagen, 2019:108). This would explain the presence of pathologies at this level. However, we noted body size did not always correlate positively with pathological deformations. In Çatalhöyük Middle, the observed increase in the number of pathologies coincides with the predominance of smaller-bodied females (Russell et al., 2013a,b:220; Wolfhagen, 2019:106). Given the reduction in cattle body size that is observable from Çatalhöyük Early to Middle (Wolfhagen et al., 2021), and the subsequent decrease in cattle body weight, we may conclude that neither animal live weight nor the higher occurrence of large-bodied males is responsible for the increased pathologies. Instead, the increase may be related to changes in mobility, diseases, and the grazing environment of cattle, among other nonanthropogenic factors.

In Çatalhöyük Late, the low frequency of pathologies in lower limb bones, compared to the Middle and West, can be attributed to a number of factors. Juveniles, subadults, and females increase in relative numbers in Çatalhöyük Late (Russell et al., 2013a,b:220; Twiss et al., 2021:153) and a new cattle horn type, possibly in domestic males, appears (Twiss & Russell, 2009). Notably, Russell et al. (2013a,b: 220) reported several cases of exostosis and osteoarthritis, particularly in cattle hips, at this level, which they associate with age and stress. In Çatalhöyük West, the frequency and severity of pathologies increase, despite a continued decrease in body size and domination of females in the assemblage (Wolfhagen et al., 2021). Four small-bodied cattle from the West Mound sample display the most severe pathologies (highest PIs) in the entire sample. Considering the cattle population in the West Mound was most likely domesticated (Wolfhagen et al., 2021), we cannot rule out the non-intensive use of cattle in traction as a possible factor for the slight increase in PIs that is largely evident in Çatalhöyük West. Alternative explanations may relate to environmental factors or the introduction of a new, small-bodied cattle population midway through the site's occupation (Arbuckle & Makarewicz, 2009). Given the low aDNA coverage in Çatalhöyük cattle (Verdugo et al., 2019), assessing the role of new cattle types in the development of pathologies will remain challenging.

Deformations were generally more common and intensive among the anterior elements in our dataset, similar to findings in Romanian oxen (Bartosiewicz et al., 1997) and Chillingham cattle (Holmes et al., 2021; Thomas et al., 2021). Higher frequencies of pathologies in forelimbs than hind limbs in prehistoric cattle have been reported by previous researchers, who interpreted this pattern as a consequence of the natural

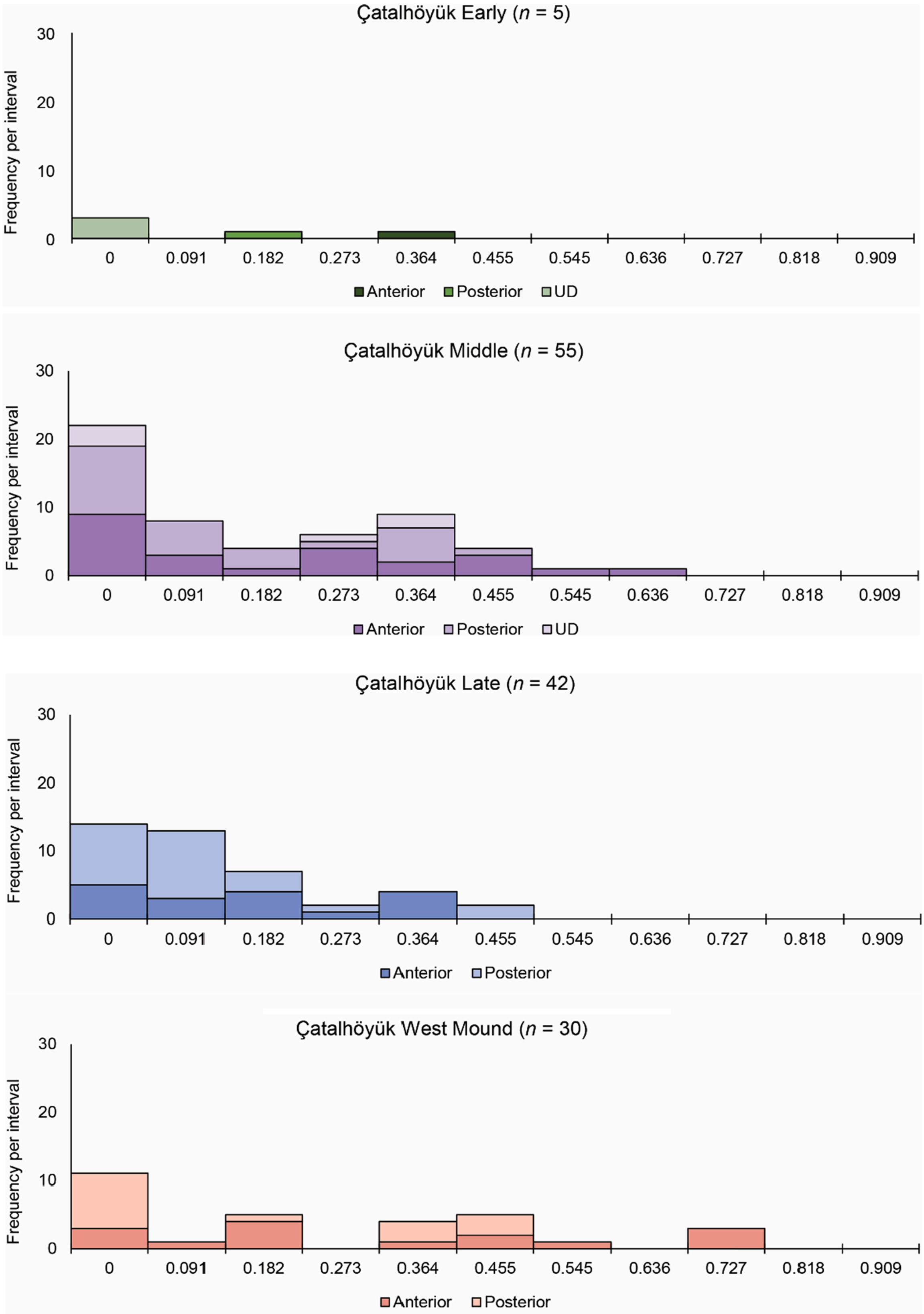

Fig. 4. Diachronic distribution of the pathological index (PI) values in anterior and posterior elements calculated for *Bos* from Çatalhöyük Early, Middle, Late, and West Mounds compared to those from modern Romanian bulls and oxen (data from De Cupere et al., 2000) and Chillingham cattle (all criteria included; data from Thomas et al., 2021). UD = undetermined position.

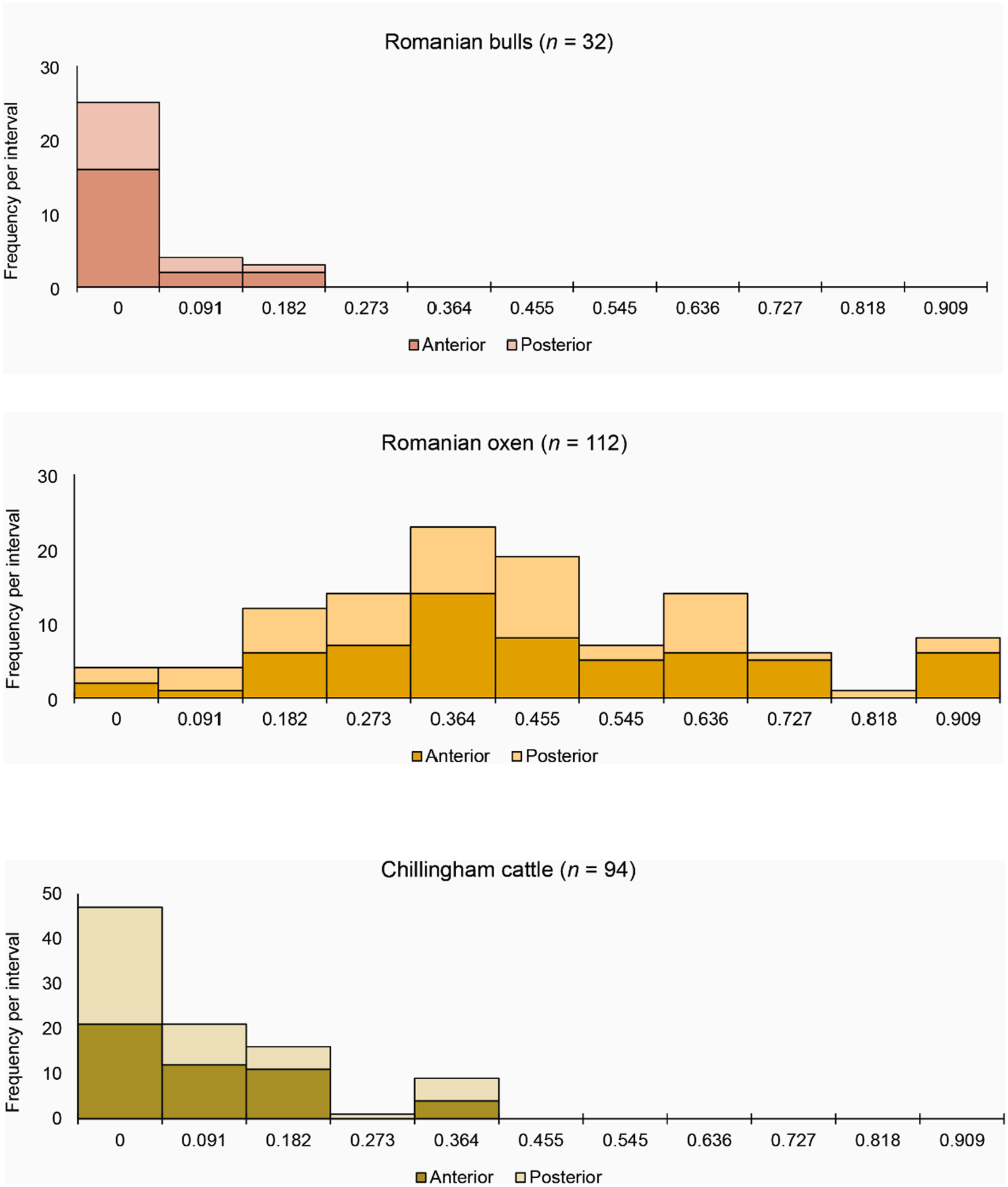

Fig. 4. (*continued*).

weight distribution in the ruminant body and possibly of ad hoc exploitation of cattle for traction (Bartosiewicz & Gál, 2013:151). Pathologies become more dominant in hindlimbs in the Roman Period, most likely as a result of the intensification of farming in general, and specifically, the switch from an ard to a mould-board plough with coulter, which exerts a greater strain on cattle hindlimb (Bartosiewicz & Gál, 2013:154).

However, an exception is evident in the third phalanges in the Çatalhöyük assemblage, in which pathological deformations were common and severe in specimens we identified as anterior and posterior elements. Environmental conditions such as grazing in wet environments amplify hoof deformation in cattle and other hoofed animals, such as horses (Newsome et al., 2016; Biggs et al., 2019). Grazing in wet environments, which is supported by seasonal variations in stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) values in the tooth enamel of domestic cattle and aurochs (Wolfhagen, 2019:130), may have contributed to the deformations in the cattle hooves in our dataset. Based on their study of the Chillingham cattle, Thomas et al. (2021) have suggested third phalanges are best excluded from assessments of cattle traction use because these bones are highly susceptible to biological variables such as age, sex, and body size. Nevertheless, we observe that although both Chillingham cattle and Romanian draught oxen reached advanced ages, pathologies were at least three times more severe in Romanian oxen hooves than in Chillingham cattle (see Table 2). In addition, hoof breakage and excessive wear are also frequently observed among working animals (Bartosiewicz et al., 1997:117). Three-dimensional measurements of the third phalanges in modern draught cattle in New Zealand and Thailand have also revealed excessive pathological deformations in cattle hooves (Higham et al., 1981). We, therefore, do not rule out the possibility that a combination of environmental and biological parameters and work-

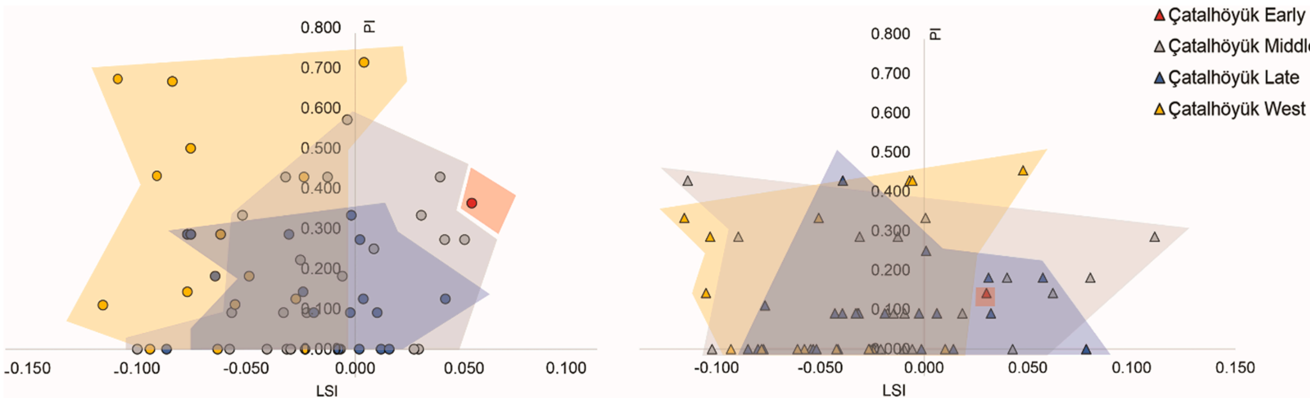

Fig. 5. Distribution-based clustering of *Bos* logarithmic size index (LSI) in anterior (displayed on the left) and posterior (indicated on the right) elements and their corresponding PI values (Çatalhöyük East and West Mounds).

related trauma may have caused intense lesions in some cattle hooves in Çatalhöyük West.

Utilising PCA, we observed that proximal lipping (associated with traction; Bartosiewicz et al., 1997), as well as proximal and distal exostosis (associated with age; Thomas et al., 2021), were the main pathologies in Çatalhöyük cattle. It is noteworthy that none of the pathologies suggested by Thomas et al. (2021; eburnation on either proximal or distal articular surface, palmar/plantar depressions on the metapodials, ankylosis of the second and third metacarpal, and transverse striations on the medio-proximal surface of the metatarsal), as the best markers of traction are well represented in our dataset. In fact, the proximity of Çatalhöyük specimens to the Romanian bulls and Chillingham cattle in the PCA may explain the significance of non-anthropogenic factors in the development of particular pathologies. However, the overlap in results between Çatalhöyük West and Romanian oxen requires attention. Romanian draught oxen were extensively utilised in logging operations on hilly terrain almost throughout their entire lifetimes (Bartosiewicz et al., 1997). Ad hoc and unspecialised exploitation of animal power would not necessarily cause severe and detectable changes in bone morphology (Johannsen, 2006). Hence, caution should be applied when interpreting these results. The pathologies at Çatalhöyük West should not be expected to be as pronounced as those in modern specimens for several reasons, including the absence of metal plough parts in the Neolithic. Additionally, cattle were highly likely to be utilised primarily for hauling rather than intensively for ploughing (Bogaard, 2005). Concurrently, the West Mound PI values have the highest standard deviation, potentially reflecting the diversity of physical strains imposed on the individuals at Çatalhöyük.

These results are mostly in agreement with recent evidence for the use of cattle life-time products, especially draught and milk, prior to the 4th millennium BCE, contrary to Sherratt's (1981) SPR model (e.g. Bogucki, 1993; Debono Spiteri et al., 2016; Evershed et al., 2008; Marciniak, 2011; Halstead and Isaakidou, 2011). Moreover, the proposed date for domestication, castration, and draught cattle in Cafer Höyük (8500–7500 BCE; southeastern Turkey), as suggested by osteometric data (Helmer et al., 2018), is at least 2 millennia earlier than the initial evidence that suggests cattle harnessing in Çatalhöyük West.

In Neolithic Anatolia, regional diversity in cattle domestication and

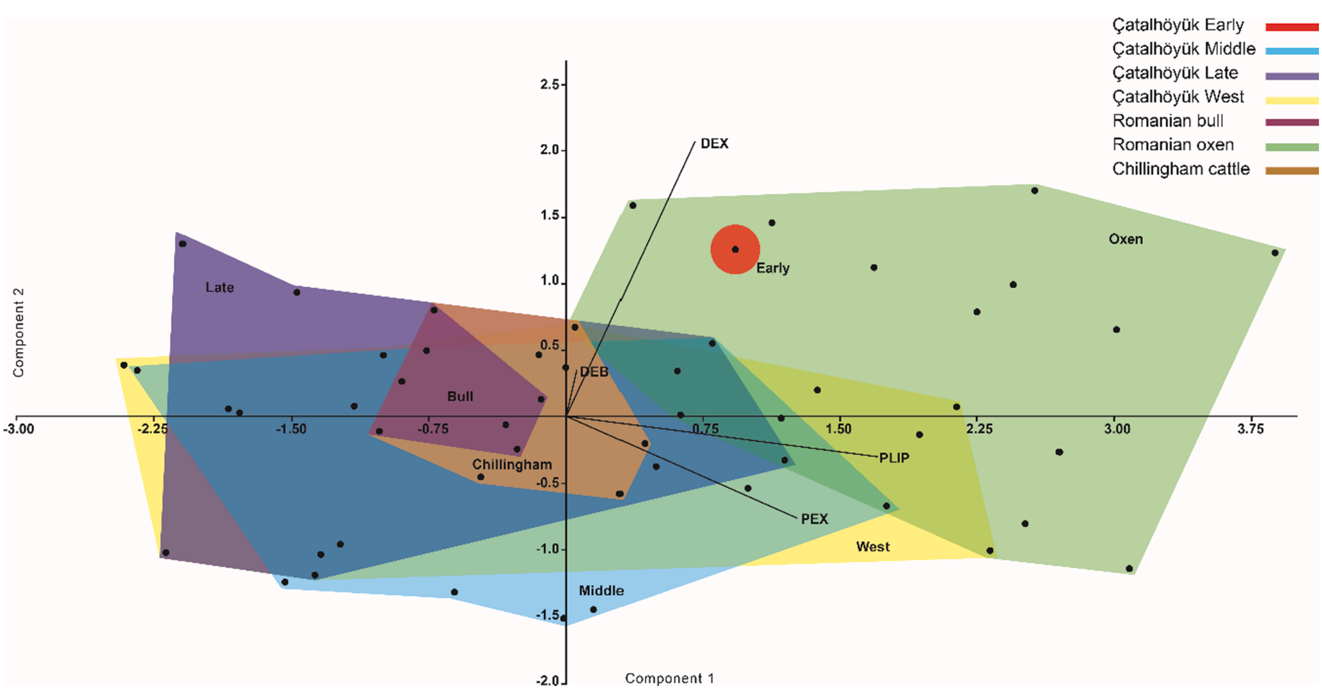

Fig. 6. Principal component analysis (PCA) of the raw pathological scores (following Bartosiewicz et al., 1997) of *Bos* phalanges (Table S1) from Çatalhöyük, Romanian oxen, and bulls (Bartosiewicz et al., 1997) and Chillingham cattle (all criteria included; Thomas et al., 2021). PEX = proximal exostosis, PLIP = proximal lipping, DEX = distal exostoses, and DEB = distal eburnation.

husbandry has previously been demonstrated, reflecting the interrelated roles of cultural and environmental factors in the transition to agropastoral lifestyles (Arbuckle et al., 2014). In Çatalhöyük, early human-aurochs interactions were laden with symbolism and ritual since the onset of the settlement. Spiritual use and increasing entanglement of human activities with local aurochs populations evolved into cattle herding simultaneous with a shift into individual households (Russell et al., 2005, 2013a,b). This enabled small-scale cattle husbandry and the incorporation of primary and secondary products into household subsistence (Pawłowska, 2020a). The introduction of domestic cattle to Çatalhöyük (either as an independent innovation or an imported population) may have also facilitated technological innovations, thus increasing economic activities such as tilling wider agricultural lands, travelling, and transporting goods (Greenfield, 2010). It should be noted, however, that new knowledge or innovations would not have been adopted unless they were compatible with cultural, spiritual, economic, and environmental conditions extant within a community (Leppek, 2017). An innovation such as harnessing cattle strength occurs in direct connection with subsistence, social structure, and local environmental conditions (Greenfield, 2010). Cattle must be trained to pull weight, and castration manipulates cattle physiology and behaviour to maintain the compliance needed to draught heavier weights for longer periods. Such knowledge, once innovated, must be transferred across human generations. Once fully incorporated into the social economy of the Çatalhöyük community, unspecialised use of cattle power would reduce the need for human labour in agriculture and increase the area available for cultivation (Bogaard, 2005). Increased competition for land would be accompanied by changes in the social and economic value of cattle ownership, lead to substantial inequality, and possibly create turbulent transitions in community organisation (Bogucki, 1993; Bogaard et al., 2019).

The presence of exchange networks that moved obsidian, Mediterranean shells, and additional raw materials and commodities confirms Central Anatolia was culturally and economically engaged with the wider world of Southwest Asia (Asouti, 2006). The limited range of raw materials reported throughout Çatalhöyük Early and Middle had become considerably diversified by Çatalhöyük Late (Bains et al., 2013). Outcrop sources of the obsidian present in Çatalhöyük Early and Middle were identified at Cappadocia (130 km east of the site) as well as at the Bingöl and Nemrut Dağ mountains (650–800 km east of the site) (Carter et al., 2008). Stable isotope data regarding human and sheep mobility patterns also indicate greater mobility and wider use of the landscape in upper levels of the site (Pearson et al., 2007, 2021), while work-induced skeletal trauma and periostitis among people in Çatalhöyük Middle and Late decline dramatically (Hillson et al., 2013). Although our dataset cannot be directly associated with evidence for increased human movement, exchange of goods, and intensifying agriculture accompanied by reduced physical stress, it is perfectly plausible that cattle domestication and the incorporation of secondary products into the agricultural system—particularly traction—may have evolved over time and contributed to socioeconomic shifts in Çatalhöyük (Hodder, 2014).

6. Conclusions

Investigating the pathologies in Çatalhöyük *Bos* specimens contributes to the ongoing debate regarding the origin and trajectories of the use of cattle for traction and its implications for the socio-economic developments of early farming communities. Our analysis of pathological and sub-pathological changes in the lower limbs of Çatalhöyük cattle, combined with biometric data suggests they occurred in morphologically wild and domestic cattle. Pathological and sub-pathological changes were more advanced in forelimbs than in hind limbs. Trends in severity and frequency of the pathologies were mostly independent of survivorship and inferred domestication status. However, a few small-bodied individuals in Çatalhöyük West display the highest mean PI with the most severe pathological and sub-pathological traces. Although there is no method to directly relate pathological and sub-pathological traces in populations with no known life history to traction with any degree of certainty, our results corroborate with early and recent zooarchaeological studies at Çatalhöyük indicating the intensified use of domestic cattle products at Çatalhöyük West. However, small sample sizes hinder the diachronic implications of our results. Future studies should expand the dataset, particularly from primary and secondary units from Çatalhöyük Early and the West Mound, and compare animal size and pathologies directly to age, sex, and palaeodietary data when interoperable datasets are available.

CRediT authorship contribution statement

Safoora Kamjan: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Pınar Erdil:** Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. **Esmee Hummel:** Formal analysis, Investigation, Methodology, Visualization. **Çiler Çilingiroğlu:** Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Canan Çakırlar:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

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. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2022.101412.

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