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Metrical Discrimination between Mandibular First and Second Molars in Domestic Cattle

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ABSTRACT The difficulty of distinguishing between loose first and second mandibular molars of domestic cattle (*Bos taurus)* from archaeological sites is well known. This paper proposes cervical length as a discriminatory measurement. The possibility that cervical measurements of first and second mandibular molars may be sexually dimorphic is also explored.

Keywords: Cattle, mandibular molars, measurement, cervical length, cervical breadth, radiographs, age, sex ratios.

Metrical distinction between Mi and Ma

Introduction

The morphological similarity between first and second mandibular molars of Bos *taurus* makes it difficult to differentiate between them. Third mandibular molars are readily identifiable by their distinctive form. However, as observed on cattle from the Bronze Age midden at Crimes Graves[1] and in the Chillingham wild white cattle,[2] some third molars have only a vestigeal hypoconulid and in others it is completely absent so that their crowns may be indistinguishable from M_1 or M_2. Nevertheless their roots retain sufficient of the characteristic M_3 form that when found as loose teeth they are readily distinguished from M_1 or M_2.

Owing to differences in the timing of the development and eruption of first and second mandibular molars more accurate determination of the age structure of a sample is possible if single teeth can be identified correctly. Thus, in order to be able to use single loose teeth as a reliable source of data it is clearly advantageous to be able to distinguish whether such a tooth is a first or a second molar.

Samples

A large sample of cattle jaws and teeth from the Bronze Age midden at Crimes Craves was both the stimulus and a major component of this investigation.[1,3,4] The sample of teeth from this site included 88 identified first and second molars from 57 mandibles in which the whole or partial tooth row had survived. Also included in this study were 25 identified first and second molars from 2 mandibles and 14 partial mandibles from the Stepleton Enclosure of the Hambledon Hill Neolithic complex;[5,6] the mandibles from the Bronze Age site at Down Farm;[7] one mandible from the Roman site at Blackhorse Road;[8] three mandibles from a Roman context, Inmost Ward, Tower of London;[9,1010] one mandible of unknown date from a waterlogged context at the Plant Breeding Institute in East Anglia and one unprovenanced archaeological mandible. The Grimes Graves assemblage includes mandibles of both juveniles and mature cattle.[3] The mandibles from other archaeological sites all represent

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Table 1. Archaeological sample: mandibles containing M_1 and/or M_2.

M_1 and M_2		M_1		M_2	
Grimes Graves	31	Grimes Graves	22	Grimes Graves	4
Stepleton	9	Stepleton	5	Stepleton	2
Down Farm	2	Down Farm	1		
Blackhorse Road	1	Unprovenanced	1		
Inmost Ward	3				
Plant Breeding Institute	1				

mature cattle. Although the partial mandibles from Stepleton were in a fragmented condition, enough of each had survived for teeth to be related to their own and adjacent sockets. We stress that each tooth positively identified as M_1 or M_2 in our sample was identified on the basis of the presence of all or part of its own socket and the presence of an adjacent tooth or socket (P_4 or M_3). The composition of the archaeological sample is shown in Table 1. In addition, first and second molars from mandibles of modern cattle of various breeds were measured (Table 2).

Measurements

In order to determine which measurements could differentiate between mandibular first and second molars, six measurements were taken from each of these two teeth from mandibles where both were in place. These measurements were the mesiodistal and buccolingual diameters (length

Table 2. Modern sample: measured teeth from mandibles.

		M_1 and M_2	M_1 only
Cows	Friesian	6	
	Jersey	1	
	Longhorn cross	—	1
	Devon Poll	—	1
	Breed unknown	2	5
	Chillingham	8	
Bulls	Ayrshire	1	
	Hereford	1	
	Charolais	1	
	Spanish	4	
	Chillingham	4	

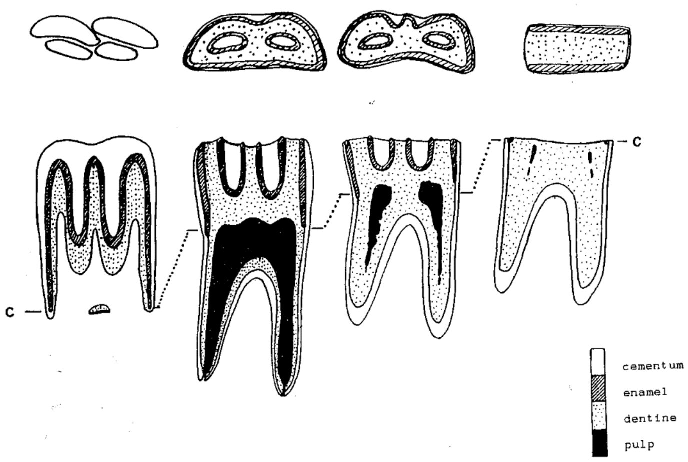

Figure 1. (Below) Longitudinal section diagrams of a mandibular molar (M_1 or M_2) at four stages in its life. (Above) Diagrams of the occlusal surface. From the left: crown formation is complete and root formation is commencing, the occlusal surface is unworn; root formation is complete and the tooth is in full wear; the tooth is well worn; crown height has been reduced so that the neck of the tooth, where cervical length is measured, is at the occlusal surface. The line C–C shows how the base of the crown approaches the occlusal surface as the animal ages.

Figure 2. Down Farm: M_1 and M_3 from the oldest individual from our archaeological sample. On M_1 only two fragments of enamel remain at the base of the crown, which coincides with the occlusal surface. On M_3 the infundibulae have completely worn away and only a small rim of enamel remains around the dentine.

and breadth) at (i) the occlusal surface, at (ii) the alveolar margin and at (iii) the cervix or neck of tooth where the base of the enamel is situated. On teeth that are in full wear, cervical length is normally less than either occlusal or alveolar length. Cervical length relates to a part of the tooth which is present from the time of crown completion until the crown has worn down in old age. Although its relative position within the alveolus moves upwards during the life of the tooth, its absolute position on the tooth itself is constant (Figure 1). It was anticipated, therefore, that cervical length would be a useful discriminant between first and second molars. By contrast, the parts of the crown represented by measurements at the occlusal surface and at the alveolar margin are subjected to continual variations, which arise from changes during development and attrition.

On older animals, cervical length becomes coincident with length at the alveolar margin, first on M_1 and then on M_2. The most worn first molar in our sample from Down Farm had no enamel left on its mesial cusps and only two small flakes of enamel, with a maximum height of 3 mm, remained on the distal cusps (Figure 2). On this tooth cervical length was measured at the occlusal surface, which was level with the alveolar margin.

To facilitate the process of measuring, vernier calipers were modified so that their points could pass into the narrow spaces between the teeth. However, as indicated above, it is only on the

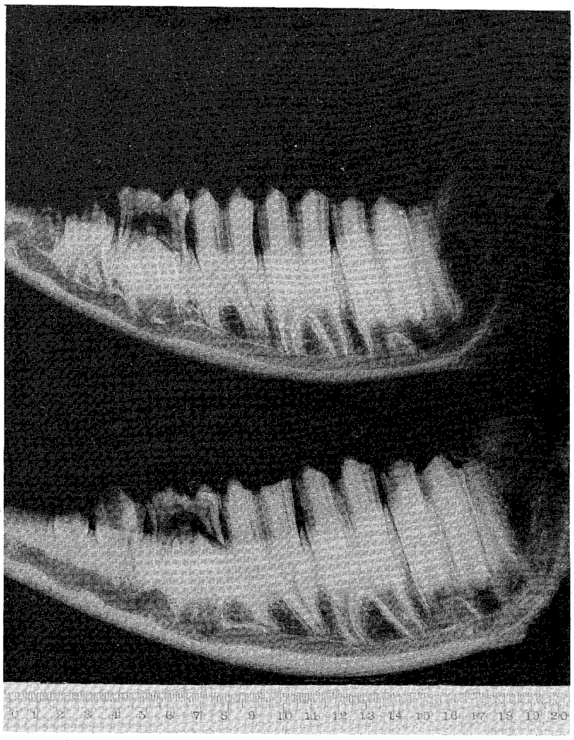

Figure 3. Grimes Graves: radiograph of two mandibles. Note the position of the base of the crowns.

mature cattle, where eruption is more advanced, that the cervical region is accessible above the alveolar bone.' The cervical region of the molars of younger cattle is well below the alveolar margin and cannot be measured without extracting the tooth. This cannot be done without cutting the bone and so, on mandibles where the neck of the tooth was inaccessible, measurements of cervical length were taken from radiographs (Figure 3). This avoided causing unnecessary damage to archaeological specimens. The crown of M_1 begins to develop *in utero,* and so cervical length of M_1 could be measured on all mandibles with permanent dentition in place. On the younger jaws from Grimes Craves, cervical length could not be measured for second molars in the early stages of wear because crown formation was incomplete at the time of death. To ensure comparability of measurements the cervical length of each M_1 and M_2 from the Crimes Craves assemblage, which had already been measured with vernier calipers on the tooth itself, was also measured from radiographs. Teeth extracted from jaws for use in cementum banding studies were remeasured after extraction. As shown in Figure 4, these measurements were sufficiently close to those taken from radiographs that on most specimens measurements taken in either manner discriminated between first and second molars. The cervical breadth of these extracted teeth was also measured.

Interpretation

It is proposed that once the size range of the sample has been established by measuring teeth present in mandibles, it is possible to identify individual teeth within a single archaeological population as mandibular M] or M; on the basis of the single measurement of cervical length. For most prehistoric teeth measured during this study the range is such that teeth for which this measurement is less than 21.5mm are almost invariably M_1 and where it exceeds 22.0mm they are M_2. For example, of 31 mandibles from the Bronze Age midden at Grimes Graves in which both first and second molars were present, 26 conformed to this pattern. Of the remainder, an abnormally small mandible had a second molar with a cervical length of only 20.0 mm; one mandible had cervical lengths of 22.3 mm for $M_1$and 23.2 mm for M_2 and another had cervical lengths of 23.5mm for M_1 and 24.2mm for M_2. In the mandible with the largest molars this measurement was 23.6 mm for M_1 and 27.6 mm for M_2 (Figures 5 and 6). It is possible that the largest pair of measurements represents a bull. Measurements for the other five prehistoric samples studied are

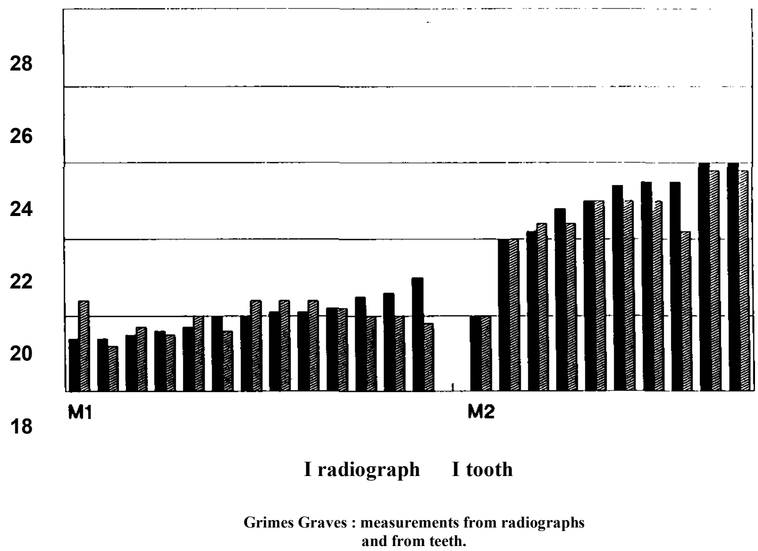

Figure 4. Grimes Graves: comparison of cervical lengths measured from radiographs and from teeth.

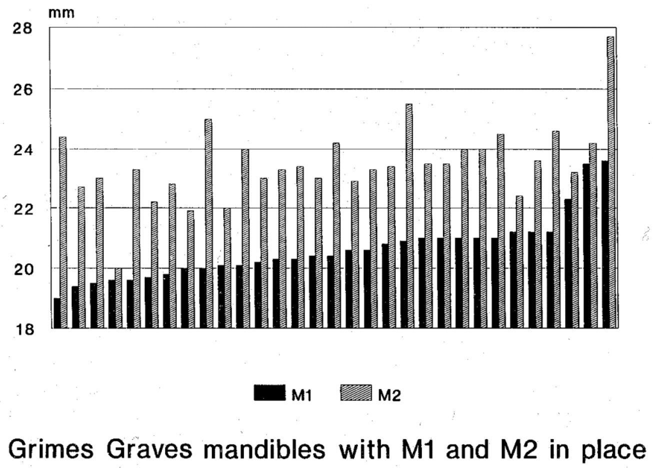

Figure 5. Grimes Graves: measurements of cervical length of M_1 and M_2 from mandibles in which both these teeth were present, in rank order according to cervical length of M_1.

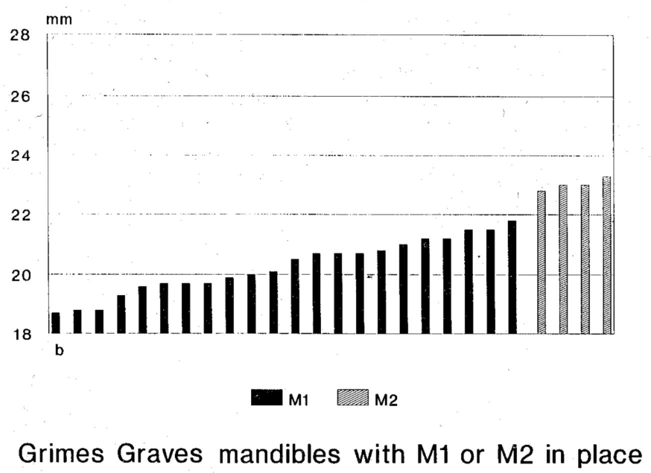

Figure 6. Grimes Graves: measurements of cervical length of M_1 and M_2 from mandibles in which only one of these teeth was in place. The smallest tooth (b) was burnt.

shown in Figure 7. Mandibles from the Bronze Age site at Down Farm had M_1 and M_2 cervical lengths that conformed to the Grimes Graves pattern. All M_2 from complete and partial mandibles from Stepleton also conformed to this pattern, but cervical length of some M_1 from this Neolithic population exceeded that of the Bronze Age specimens. The mandible from the Roman site at Blackhorse Road conformed to this pattern, but second molars from the Inmost Ward, Tower of London had cervical lengths of 22.0 mm only.

Twelve modern domestic cows of various breeds (Friesian, Jersey, Ayrshire and, unknown) fell within this range. Jaws of eight Chillingham

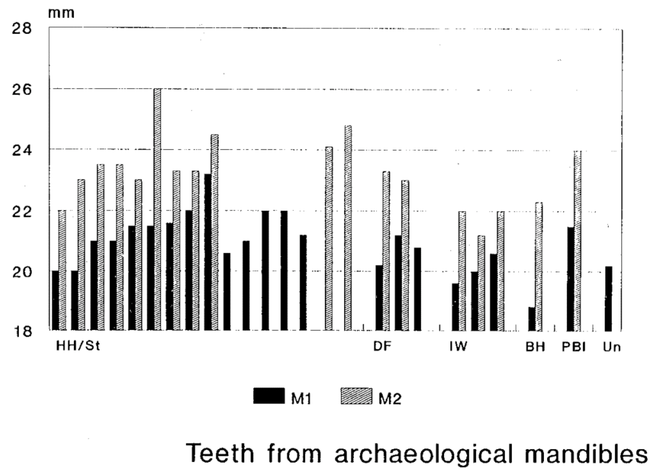

Figure 7. Cervical length of M_1 and/or M_2 from archaeological mandibles. Rank order within site samples is on cervical length of M_1. Sites are indicated at the left of each sample: HH/ST, Hambledon Hill/Stepleton; DF, Down Farm; IW, Inmost Ward, Tower of London: BH, Blackhorse Road; PBI, Plant Breeding Institute; U, provenance unknown.

cows and two of the four Chillingham bulls broadly conformed to this pattern for M_1 and M_2 cervical lengths, although M_1 from the other two Chillingham bulls fell in the indeterminable range (21.6 and 21.8 mm) and M_2 from the same animals measured 23.0 mm. One of the cows had both M_1 molars measuring 20.0 mm and the left M_2 measuring 23.0 mm, but the right M_2 measuring 21.0 mm only. In four bulls of the Spanish fighting breed, cervical lengths of M_2 ranged from 23.7 to 26.8 mm, and two M_1 measurements at 19.5 and 20.6 mm were in the range for first molars of the Grimes Graves sample, whereas two with cervical lengths of 22.0 and

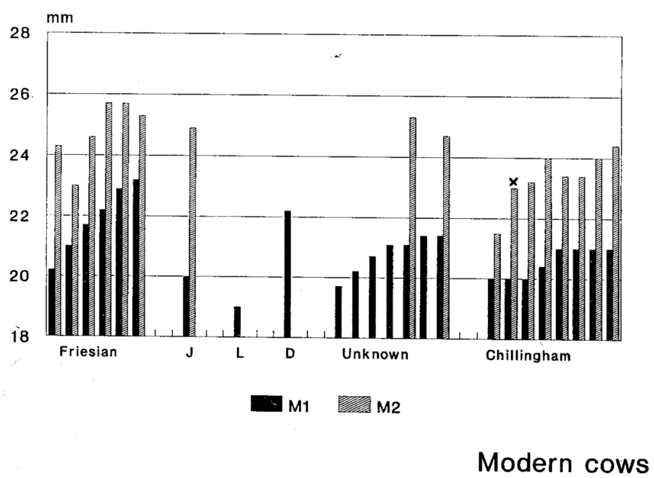

Figure 8. Cervical length of M_1 and M_2 from modern cows. Rank order within breed samples is on cervical length of M_1. Letters below samples indicate breeds: J, Jersey; L, Longhorn cross; D, Devon poll. M_2 from the other side of the mandible indicated by X measured only 21.0 mm.

22.3 mm were slightly larger. On a mandible from a modern Hereford bull the cervical lengths of M_1 and M_2 were 22.0 and 26.6 mm, respectively; those for a Charolais bull were 22.9 and 26.7 mm. Measurements for the modern cows are shown in Figure 8 and for bulls in Figure 9.

Cervical breadth cannot be measured from our standard radiographs, but was measured on loose teeth and teeth extracted from the Grimes Graves' mandibles for cementum banding analysis.[4] On scattergrams of cervical length against cervical breadth, first and second molars from this smaller sample separate into two groups (Figure 10). Comparisons of scattergrams based on cervical length and cervical breadth, with histograms showing the distribution or cervical length, indicate that the single measurement of cervical length is a good discriminant for first and second mandibular molars of cattle. A rule of thumb for prehistoric cows is that teeth with a cervical

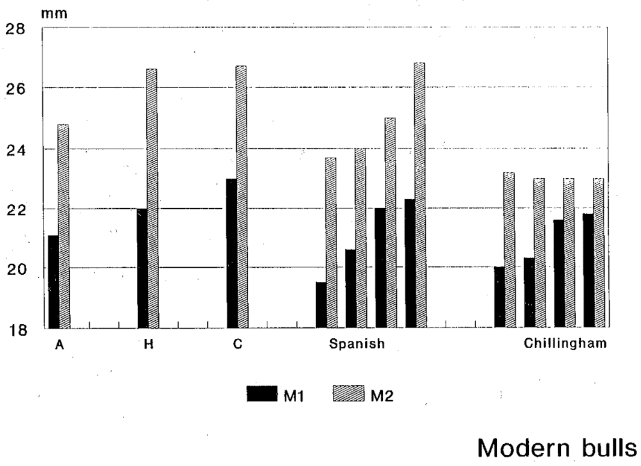

Figure 9. Cervical length of M_1 and M_2 from modern bulls. Rank order within breed samples is on cervical length of M_1. Letters below samples indicate breeds: A, Ayrshire; H, Hereford; C, Charolais.

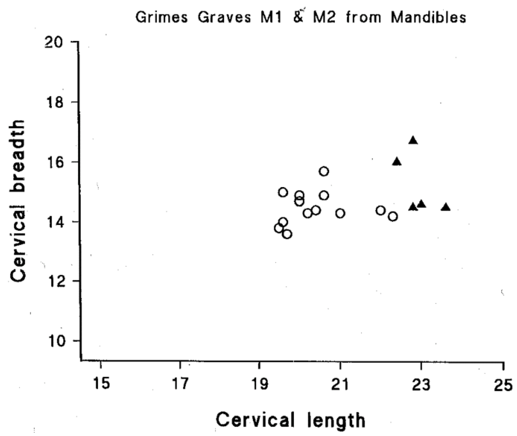

Figure 10. Grimes Graves: scattergram of cervical length and cervical breadth of M_1 (open circles) and M_2 (closed triangles).

length less than 22.0mm are normally M_1 teeth with a cervical length of less than 21.5mm are almost certainly M_2 teeth with a cervical length greater than 22.0 mm are normally M_2 and teeth with a cervical length greater than 23.0mm are almost certainly M_2 The figures for the largest pair of teeth from Crimes Craves suggest that this measurement may be larger for bulls.

Identification level

For record-keeping purposes a system of identification for M_1 or M_2 is proposed.

1 = identification certain; i.e. tooth from mandible.

2 = identification is fairly secure; i.e. teeth with measurements on either side of the ambiguous range, with < 21.5 mm being recorded as M_1 identification level 2 and > 2.20 mm being recorded as M_2 at identification level 2.

3 = indeterminate; teeth only identifiable as either M_1 or M_2; i.e. cervical length falls within ambiguous range between 2.15 and 2.20mm.

Neither the addition of cervical length and cervical breadth, nor the multiplication or division of length by breadth provided so clear a distinction as cervical length alone on the Grimes Graves' specimens and it is fortunate that this single measure proved to be so useful. However, scattergrams of cervical length and breadth may help to identify loose teeth at identification level 3, particularly in samples where no mandibles are available to check the baseline. These two measurements were plotted for nine loose teeth from an Iron Age site at Haddenham[11] two of which had cervical lengths in the uncertain range. Two clearly separated scatters emerged (Figure 11).

Problems, conclusions and suggestions for further research

A potential problem that was considered with regard to the hypothesis that maximum cervical length is a reasonably constant measurement through the life of a tooth is the effect of interstitial wear and mesial drift. This presents little difficulty in practice, because interstitial wear can be seen and allowance made where appropriate. As shown in Figure 12, interstitial wear can reduce minimum cervical length by a noticeable degree whereas the maximum cervical length on the same tooth remains almost unaltered.

Unusually thick cementum occasionally increases cervical dimensions of a tooth. On the majority of teeth, however, cementum in the cervical region is thinner than on other areas of the tooth and does not increase greatly with age to alter the measurement of cervical length. Our comparison of the measurements taken directly from the teeth with those from their radiographs,

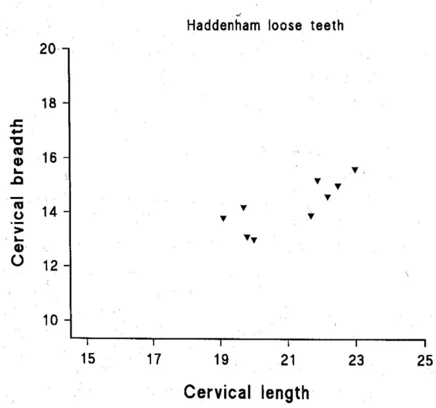

Figure 11. Haddenham: Scattergram of cervical length and cervical breadth of isolated loose teeth.

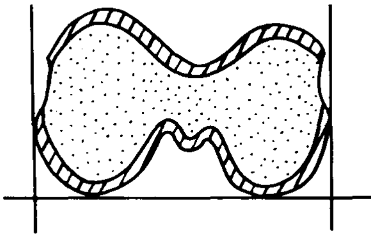

Figure 12. Cross-sectional diagram of the base of the crown of a mandibular molar M, or Mg showing the effect of interstitial wear. Note how minimum cervical length is much reduced where the enamel has worn away whereas maximum cervical length is virtually unaltered. Dentine is stippled, enamel is hatched.

where the cementum thickness can be seen, demonstrates that this is only a minor problem. Although, as shown in Figure 4, the absolute values of the two sets of measurements are different, the identifications of teeth as first or second molars are the same from both sets. As has already been emphasized, occlusal measurements and measurements at the alveolus are more variable according to development and attrition, and for this reason are unsuitable for distinguishing between first and second molars.

The system described here was used to identify first and second mandibular molars present as isolated teeth in our archaeological samples. For example, isolated teeth from the Crimes Craves assemblage that proved identifiable from measurements were added to our sample of teeth from mandibles, and enabled us to increase the numbers of teeth suitable for creating age profiles based on tooth wear, crown heights and incremental banding in dental cementum. Because younger cattle can be aged from tooth development,[3,12] our sectioning of teeth for cementum analysis has focused on the older specimens. In order to minimize destruction of archaeological material, specimens for sectioning were selected mainly from the isolated teeth that had been identified using this metrical distinction.

The broad comparability of the measurements taken from mandibles from Crimes Craves, Hambledon Hill, Down Farm and our modern specimens indicates that the single measurement of cervical length discriminates between first and second mandibular molars of *Bos taurus* and is of value where there is a need to identify loose teeth from an archaeological faunal assemblage. Further research should enable the accuracy of this metrical distinction to be refined. For instance, although the Roman mandible from Blackhorse Road had molars with measurements compatible with our prehistoric sample, second molars from Roman cattle mandibles from the Tower of London Inmost Ward were smaller than those from the prehistoric sites. This raises the possibility that a figure lower than 22.0 mm may distinguish between M_1 and M_2 for this period. More teeth from cattle from Roman sites need to be measured to clarify this point.

Whenever complete mandibles are present in a sample, it would be sensible to measure cervical length on their first and second molars to determine whether any adjustment of the particular values cited here would be appropriate for that sample of an archaeological population. There is a need for a large number of cervical length measurements of M] and M^ from cattle mandibles or from identifiable sockets from various archaeological periods. Given a large enough comparative data base it should be possible to refine this metrical distinction and calibrate it according to archaeological period. Our results indicate, however, that even without such calibration, it is only teeth with cervical lengths fitting the central indeterminate range of our Grimes Graves values that will remain unidentifiable and we believe that the measurement of cervical length and cervical breadth are of value in enabling teeth of ambiguous identity to be referred to M_1 or M_2

Sex ratios

A second application of the measurements of mandibular first and second molars is concerned with investigation of the sex ratios represented by archaeological faunal assemblages. Legge has proposed that the remains of cattle at Crimes Craves and at Hambledon Hill each represent different aspects of dairy economies in which the majority of mature animals would have been cows.[1,3,4,13] This proposal is supported by bone measurements and dental data. At Crimes Graves, the high percentage of juvenile mandibles,

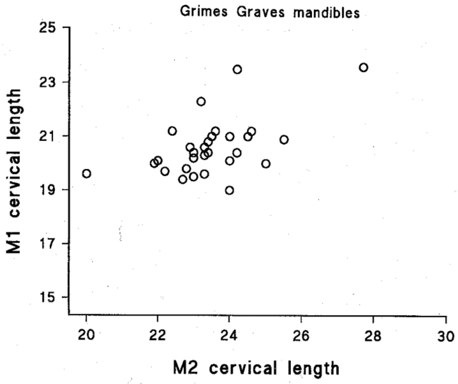

Figure 13. Grimes Graves: scattergram of cervical lengths of M_1 and M_2.

reflecting the prevalence of juvenile slaughter, as well as a substantial number of mature cattle jaws from Crimes Graves and from Stepleton, supports this theory. Slaughter curves for Grimes Craves are shown in Legge 1981a[3] and in Figures 9-11 of Legge 1992.' Cementum analysis on the teeth of cattle whose molar teeth were all in full wear at the time of death has shown that many of the mature cows slaughtered at these two sites were aged between 4 and 8 years.[1,4,6]

Further support comes from the sex structure of the herd, which can be inferred from the cervical lengths of the first and second molars (Figure 5) and from the relationship between cervical length of M_1 and M_2 shown in Figure 13. It is suggested that the largest pair of measurements for M_1 and M_2 from a Crimes Graves mandible may represent a bull. The third molar from the same mandible was only just coming into wear and the hypoconulid was masked by bone. Length near the top of the crown of this tooth, measured from a radiograph, is 370mm, the maximum length, towards the base of the crown, is 385 mm and the cervical length is 380mm. Comparison of these measurements with Crigson's data on *Bos primigen*ius and New Grange Neolithic cattle[14] indicates that these teeth are unlikely to represent Bos *primigenius.* A similar inference regarding a bull was made from measurements of cervical length and breadth of maxillary molars from Stepleton, where the three molars from one maxilla were substantially more bulky than other maxillary molars from this site.[6] Such a sex ratio had been proposed previously by Legge on the basis of his measurements from metacarpals and humeri from the main enclosure at Hambledon Hill.[4] Davis has pointed out the possibility that domestic animals were (actively or accidentally) crossed with their wild relatives in prehistoric times.[15] It seems, nevertheless, more feasible that our data indicate the presence of bulls and demonstrate the sex ratios in these herds. In the Stepleton assemblage the largest M_1 and the largest M_2 are from different mandibles, and no mandibular teeth stand out from the rest as clearly as the large maxillary molars from Stepleton or the mandibular molars of the Grimes Craves 'bull'. In the Grimes Graves assemblage the measurements of the second and third largest paired molars are ambiguous. It is perhaps too speculative to suggest that they may represent steers, and because this is interpreted as a dairy herd, not highly probable. It occurs to us that the different composition of a herd raised for beef might result in a blurring of the distinctions between sex and anatomical part (M_1 or M_2). This is a consideration to bear in mind when analysing cattle teeth from other sites.

None of our groups of modern specimens is wholly appropriate for testing the proposition that cervical length of M_1 and M_2 is sexually dimorphic. Some of our measurements for teeth from Chillingham bulls and Spanish bulls of the

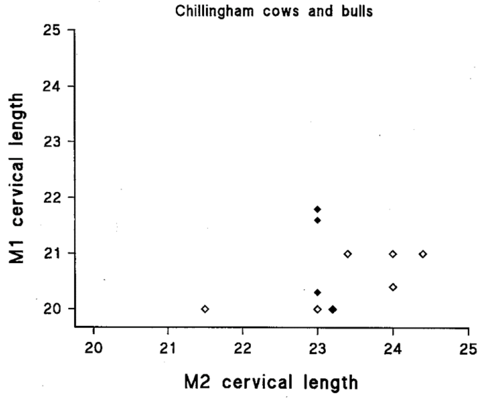

Figure 14. Chillingham cows (open symbols) and bulls (closed symbols): scattergram of cervical lengths of M_1 and M_2.

fighting breed fall within the range where 21.5–22.0 mm marks the division between M_1 and M_2. Measurements of the modern farm bulls are larger. There were no castrates in our modern sample, but comparative data from the Chillingham wild cattle show that tooth size of bulls can overlap with that of cows in the same population (Figures 8, 9 and 14). However, we reiterate that irregularities, including congenital absence of the hypoconulid on M_3 and congenital absence of P_2, have been observed in the Chillingham teeth. These may, perhaps, be related to overall tooth row shortening and are perhaps a consequence of the small gene pool. For the modern farm animals we do not have a sample of cows and bulls of a single breed. Measurements

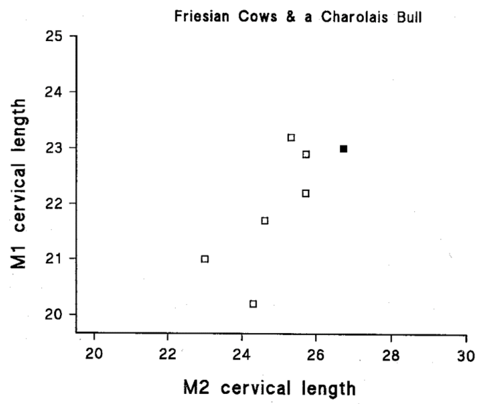

Figure 15. Friesian cows (open symbol) and a Charolais bull (closed symbol): scattergram of cervical lengths of M_1 and M_2.

from the Friesian cows and a Charolais bull are plotted in Figure 15 as the most reasonable compromise available from our collections to date.

Conclusion

That sexual dimorphism in our modern samples does not appear to be very pronounced may be related to the inadequacy of our samples in that direction. Our research on the prehistoric cattle teeth leads us to consider that the cervical dimensions of the molar teeth of cattle are moderately sexually dimorphic and that these measurements have a diagnostic role in investigations of sex ratios in populations of domestic cattle.

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