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TITLE A comparison of methods of age determination from the mandibular dentition of an archaeological sample of cattle

Kleinenberg, 1967; Morris, 1972; 1976; Spinage, 1976a) and that with the greatest potential for archaeology are the incremental lines recognised in the cementum of teeth.

This paper discusses a collection of 1st and 2nd century cattle jaws from the Roman settlement at Carlisle. It attempts to assess the potential of studies of cementum annuli and other tooth measures for chronological/absolute age determination of the slaughtered population.

Method

Four recordable aspects of this sample of jaws, each of which has potential, or has been used, for age assessment are compared and discussed.

Each mandible studied was recorded for the following information

1. The tooth wear stage (after Grant, 1975; 1982) was recorded for all surviving teeth. This was computed to a mandibular wear stage (MWS, see Grant, 1982).
2. The crown height of the M1 was measured with electronic calipers on the lingual half of the longitudinally sectioned tooth as illustrated in Fig. 1.
3. The thickness of the cementum pad between the roots was measured using a binocular microscope and graticule and subsequently converted to millimetres (see Fig. 1).
4. True crown height was calculated by subtraction of the cementum thickness from the measured crown height- true crown height (CRHT) is the figure used in all subsequent analyses.
5. Annuli were counted in the cementum on the pad, the roots and on the ventral surfaces of the crown. The latter were often the clearest (Plate 1) and were counted down the tooth to record the maximum number of annuli, but the pad and roots (Plate 2) were in some instances clearer or contained more visible annuli. Four researchers looked at all or part of the series and up to six counts were produced for each tooth. In the analysis below the maximum count recorded for a tooth is the one used.

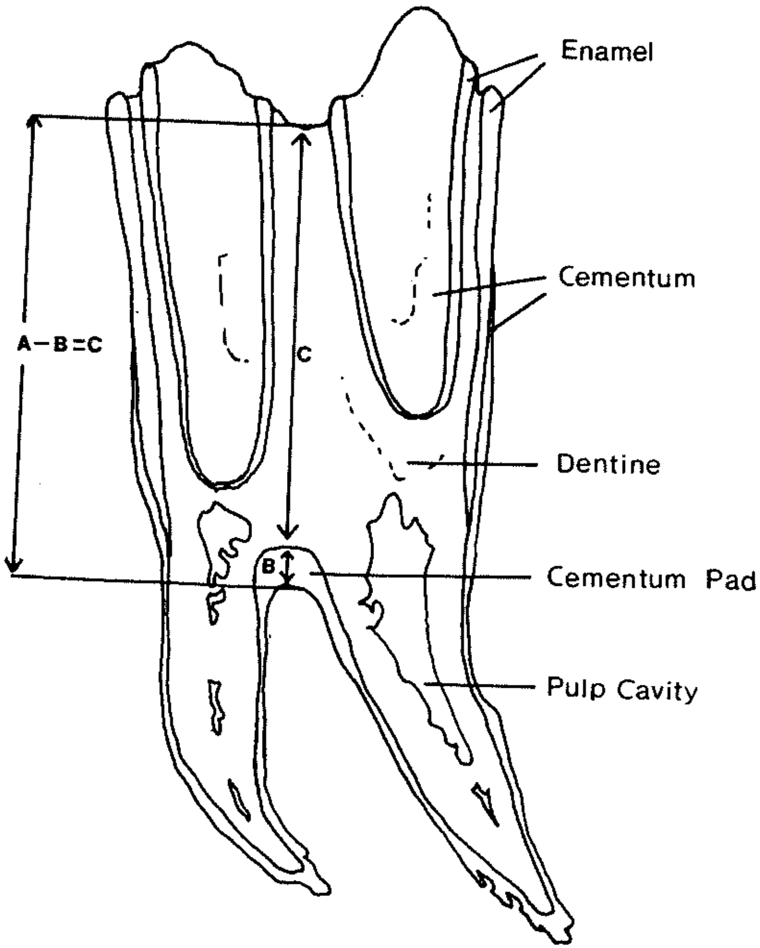
Experimental error

It must first be admitted that the body of data considered below are subject to potentially large experimental error. These fall into the following categories.

1. Crown height and cementum thickness are subject to those errors normally occassioned by measurement, this is potentially the least significant error.
2. Tooth wear stages were recorded by visual comparison using the series illustrated by Grant (1982). This is subject to a certain amount of error (see Levitan, 1982) and in the more advanced wear stages, which coincidentaly

Fig. 1

Longitudinal section through a cattle molar 1 showing the location of the measurements taken and the general tooth structure.



represent the longest periods chronologically, assignment to a wear stage may be based purely upon individual practice and is likely to be inconsistent between workers (Keiss, 1969) although rarely more than one stage discrepancy. This recording error is potentially significant when endeavouring to assess absolute age owing to the relatively long period of time the later wear stages may represent (see Deniz and Payne, 1982).

3.In this article for the sake of comparison assessment of absolute age rests upon the results of the counts of cementum annuli. Therefore the accuracy of the counts is very important. This measure constitutes the most significant experimental error for the following reasons:

a). Although the material discussed here is exceptionally well preserved the clarity of the annuli is extremely variable (Plates 1-3). The counting has relied upon diamond saw cut sections with no artificial staining, the detail visible in the Plates is occassioned by natural staining resultant upon the burial of the teeth in organic rich deposits. The darker stained areas are those strongly calcified and low in cementocytes, and the cellular and lighter areas those traditionally assigned to the summer and fall growth season (Mitchell, 1967; Stallibrass, 1982). This staining is differential between specimens affecting their clarity.

b). It was noticed that in many of the specimens, even those from relatively unworn teeth, sharpeys fibres and resorption and redeposition of cementum had considerably obscured parts of the incremental pattern laid down in the cementum pad and that on the roots (Plate 3). In no specimen was the lower part of the root suitable for counting because of these factors. This contrasts with Stallibrass's (1982) assertion that cementum is very stable and seldom subject to remodelling or resorption.

c). A number of workers (Saxon and Higham, 1968; Mitchell, 1967; Laws, 1952; Low and Cowan, 1963) have mentioned the occurrence of minor or stress lines that they believe are extra to the major banding noted above. These may be associated with pregnancy, breeding, the rut or nutritional factors and increase the number of bands formed each year. The difficulty in following lines in this material meant that many were not visibly continuous and an identification of one line as minor and another as the major increment is somewhat subjective. Where fine lines occurred between strongly stained darker lines these were not counted. A thin sectioning technique would probably improve the definition of these lines.

d). Increasing age generally produced increasing thickness of cementum and in some specimens increasing resorption and redeposition. Therefore annulus counts on some relatively worn teeth were more likely to be

less accurate and generally in the direction of underestimation. In Figure 2 those counts designated as difficult or likely to be incomplete due to resorption or obscurity are noted by a triangle.
5.The position of the section may have affected visibility of all annuli on the pad but this would be less of a problem where the count was made down the side of the crown.

The error deriving from the problems associated with counts of annuli is by far the largest in this data set, and whereas in modern studies the annulus counts have been verified against known age animals, with fossil material this is of course not possible.

Since the sectioning and recording of annuli is a lengthy business and anyway only possible in exceptionally well preserved material it is important to establish from those well preserved collections the limits within which such easily observable or measurable quantities as MWS and crown height (CRHT) can be used for establishing chronological age. Klein and Cruz-Uribe (1984) have indicated that they are not aware of differential wear within populations of a single species except in domestic sheep in New Zealand and Australia (Ludwig, Healy and Cutress, 1966), but Grant (1978) suggests more rapid wear in an Orkney population of sheep owing to bone gnawing and sand ingestion and Weiner and Purser (1956) also report variation in eruption rate associated with different diets and nutrition level and it must be presumed that both these variations will occur between populations feeding in markedly different vegetational communities, those in good pasture by comparison with marginal areas or where high stock density can be artificially maintained. Perhaps in wild animals such differences are less marked. It is therefore likely that the results of this study will not be directly applicable to other geographic areas where a similar study may be necessary to establish the rate of wear in relation to annulus counts. Certainly the work of Coy et al (1982) suggests that age as represented by annulus counts is much younger for a given MWS for Saxon cattle from Southampton than those discussed here.

Estimation of absolute age

The estimate for absolute age in this sample is based entirely upon the results of the sectioning and annulus counts.

This requires some justification. Stallibrass (1982) recently reviewed the potential of this as a method for absolute ageing of archaeological material. The technique has been applied on archaeological and fossil material with varying success by a number of authors (Saxon & Higham, 1969; Speiss, 1979; Coy et al, 1982; Bourque et al, 1978; Kay, 1974; Rackham, 1982). Coy et al (1982) had some reservations concerning the utilisation of the technique and the failure rate of their archaeological sections was high for a number of reasons. In contrast of the eighty mandibular molar 1's (M1) sectioned in this study only five specimens were not used in the analysis- one of these because of poor preservation had denatured cementum and in the others poor preservation, resorption or convolution had permitted only a minimum count. Sectioning of material from other sites (Rackham, in press) showed a high failure rate due to poor preservation of the cementum. It would appear that burial in an organic rich environment may be necessary for clarity of microstructure in the cementum. Certainly material otherwise describable as well preserved revealed denatured cementum when teeth were sectioned.

Although most of the work on modern animals has involved wild species some workers (Saxon and Higham, 1968; Klevezal and Kleinenberg, 1967) report incremental lines for domestic species which can be correlated with age. While the biological reasons for the formation of these lines is still unclear (Grue and Jensen, 1979) much work has established from known age animals a correlation between age and annulus number (Mitchell, 1967; Marks and Erickson, 1966; Ransom, 1966;) although some work (Lowe, 1967) has failed to confirm this relationship. The lines have been observed in zoo animals and others where they cannot be attributed to seasonal availability of food and would appear to be a physiological response associated with growth. They occur twice annually in wild ungulates in parts of Africa (Spinage, 1976) subjected to two dry seasons in the year. The body of evidence would support a conclusion that these annuli are laid down yearly in temperate regions. The clarity of the lines (Plates 1-3) in most specimens in this study encourages me to use them as a means of determining absolute age.

The annuli in the material under study consist of broad, light (poorly stained) cellular bands and thinner, dark (stained) acellular lines. The accepted interpretation of these (see Mitchell, 1967) is the light band represents summer and autumn growth and the dark ring the deposition of acellular cementum during the winter and spring.

In this study the tooth chosen for sectioning was the M1. This is the first tooth of the adult dentition to erupt and therefore the annuli will most closely represent the actual age. Modern cattle maxillary molar 1's have fully erupted at approximately one year and one month (Andrews, 1982) although Silver (1969) records this eruption slightly earlier and Grigson (1982) notes the figures used by a number of other authors. Cementum is believed to be laid down during or immediately after eruption and certainly in the least worn teeth in this sample a layer of cementum was already present. Novakowski (1965) however in his study of American Bison suggested that the cementum on the M1 was not laid down in these animals until four and a half years of age, well after the eruption of this tooth. In the present study it is taken that the first pale band is laid down in the summer and fall of the year following birth although we cannot guarantee either that the cementum is laid down immediately after the eruption of the tooth or that this tooth had fully erupted at approximately twelve months in cattle of the Roman period. It may be supposed that if anything this assumption will produce an error biased towards underestimation of real age.

Estimated age in years is therefore taken to be:

$$ANNU/2 + 1$$

where ANNU= total number of light+dark bands

<u>Analysis</u>

The estimate of age based upon the annulus counts is compared with two other commonly used measures for assessing age or relative age, crown height (CRHT) (Spinage, 1972; Klein and Cruz-Uribe, 1984) and mandibular wear stage (MWS) (Grant, 1982).

In 1971 Spinage studying a sample of modern Impala empirically arrived at an equation that modelled CRHT in relation to an age based upon wear patterns. This gave the equation:

$$Y=YO(1-(T/N)^{k})$$

where Y=the worn CRHT of the M1; YO=mean unworn CRHT of M1; N=mean age at which Y=0; T=age in years and k is a constant. Spinage (1972) later studied modern zebra where he applied this curve to data on CRHT and cementum annulus counts giving a most significant fit (r=0.959, P= 0.05 0.02) with k=1/2. He subsequently applied this model to further ungulate samples (Spinage, 1976a; 1976b). Grimsdell's (1973) study of buffalo arrived at a quadratic function for the relationship between CRHT and cementum annuli for the mandibular M1:

$$Y=36.283-1.191X+0.009X^{2}$$

where Y=number of cementum lines; 36.283=mean unworn CRHT and X=mean CRHT. This regression on his data was for the purpose of predicting the number of annuli from CRHT and is algebraically similar to Spinage's model. Klein et al (1981; 1983; 1984) later adopted Spinage's model for application to archaeological samples. He and others (Klein et al, 1981; 1983) analysed a sample of modern known age wapiti in which they used the quadratic regression as the predictive model

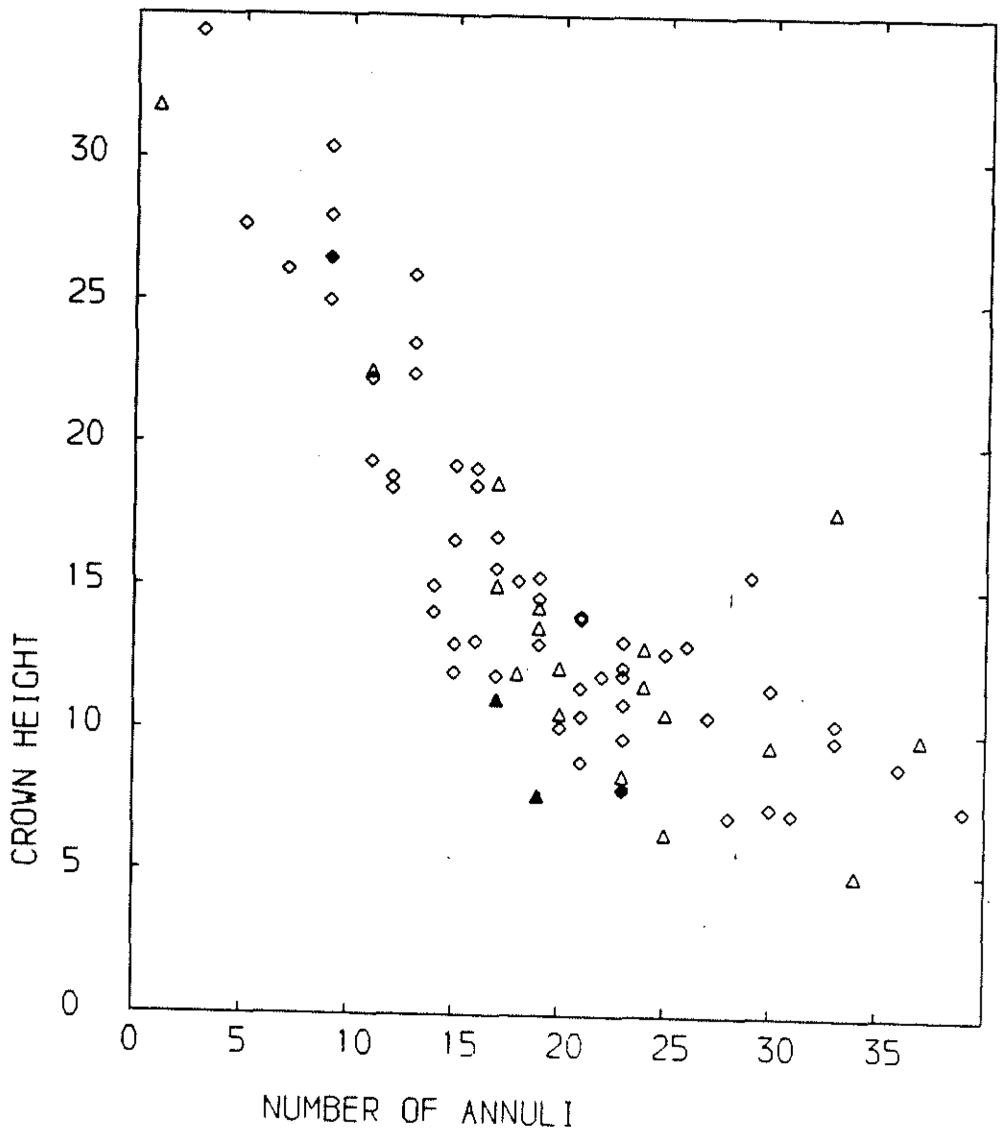


figure 2. scattergram of crown height against
annulus count for 1st and 2nd century
cattle mandibular molar 1 from carlisle.

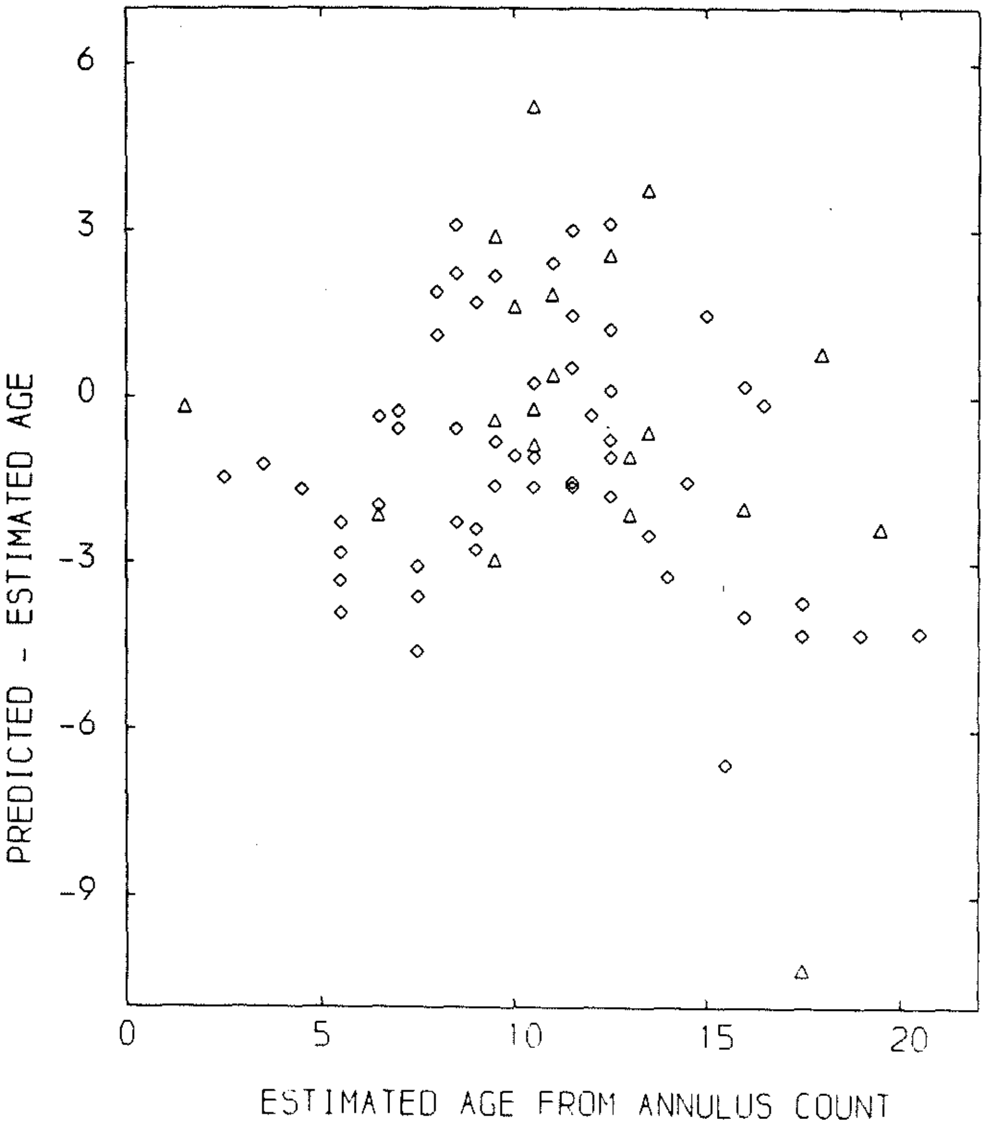


figure 3. scattergram of residuals of predicted minus estimated age against estimated age for cattle mandibles from

for age from CRHT on the M1. Klein and Cruz-Uribe (1984) in their recent book advocate an age estimation formula from CRHT based upon an algebraic translation of Spinage's model.

$$T=N-2(N-Z)(Y/YO)+(N-Z)(Y^2/YO^2)$$

where Z=the age at which the permanent tooth erupts and the other variables are as above.

In the sample of Roman cattle mean maximum age (N- at which M1 is completely worn down) is not known although records exist for cattle surviving nearly 36 years (Odlum, 1950); most modern cattle in regular use (ie for milking and work) survive to an age of approximately 20 years (pers. comm. Peter Reynolds; Grimsdell, 1973). Furthermore no examples existed in the sample with no wear, mean unworn CRHT (YO) is therefore unknown. Therefore using the model presented by Spinage (1971) the data was analysed iteratively to produce a best fit. The least squares fit (least squares=718) was produced when k=0.083, N=30 and YO=169 mm. This figure for YO is obviously impossible, the maximum measured CRHT was 34.2 mm. Therefore although the maximum age may be appropriate the data for the young age groups is not modelled by this equation. Furthermore substantial changes in the value of k produced fairly small increases in the least squares- ie when least squares=812 k=0.5, YO=32 and N=18. The relationship of this data to the model was further tested by plotting the residuals (predicted age from model minus estimated age) against the estimated age (Fig. 3) when k=0.5, YO=36 mm and N=25 years. The pattern illustrates that this model underestimates estimated age in the young age categories, overestimates in the middle and underestimates again in the old age categories. The data therefore wants to curve more than the model predicts and this is true for all values of k tested.

It is apparent from this analysis that the model is not suitable for the data presented in Fig. 2. It is not possible to attribute this discrepancy to any of the errors described above and it is therefore suggested that Spinage's model is inapplicable to this sample of Roman cattle. It is interesting to note that Klein et al (1983) in Fig. 5.2 in which they plot the residuals for true age minus the quadratic prediction of age against true age for the M1 show there is a tendency for the quadratic regression to overestimate in younger animals and underestimate in middle aged animals. This figure suggests that the quadratic model derived from Spinage (1971) does not quite fit the data, and interestingly contrasts with the group understudy by reversing the pattern noted above. Visual observation of Fig. 2 suggests that the wear on the M1 may speed up during the early wear period, an aspect not accounted for by the model. This is not unexpected since the rate of wear on the

M1 immediately after its eruption is to some extent limited by the rate of wear on the larger deciduous premolar 4 just anterior in the jaw, and until this tooth is lost diminution of the occlusal surface will be restricted by its rate of wear although the M1 will continue to erupt after initiation of wear. Similarly, by the time the M1 CRHT is reduced to 10-15 mms all the permanent molars are in full wear and CRHT reduction on the M1 is limited by the overall rate of wear on the whole occlusal surface of the cheek teeth when this is at its maximum surface area. It may therefore be that wear on the M1 is related to age in a sinoidal manner. It is not possible from this set of data to test this since it has already been noted above that the data allows too much latitude permitting a number of different constants to give 'reasonably good' fits. An accurate estimate for mean unworn CRHT and mean Age at which the M1 wears to zero CRHT in these Roman cattle would simplify the development of a curvilinear model to describe the rate of wear in relation to annulus counts. However in the absence of these data an empirical curvilinear regression is unlikely to accurately describe the biological events. Further discussion is therefore limited to considering the nature of the data rather than producing a predictive model that can be used to age jaws from either CRHT or MWS.

Figure 2 illustrates the curvilinear relationship between the number of annuli and CRHT. The filled symbols are specimens in which the posterior cusp of the Molar 3 (M3) is absent or reduced. This reduces the area of occluding surface and may therefore lead to a slight increase in the rate of wear. The sample is small but in the four specimens in which the M3 is fully in wear three certainly have a lower CRHT in relation to annulus count than other examples. The triangles in Fig. 2 represent M1's in which there was some evidence to suggest that the annulus count may be an underestimate. If this was true we would expect them to congregate along the bottom edge of the data. Although this has not been tested statistically it would appear that these counts were not appreciably different from that part of the data set felt to be accurately counted and any error introduced is presumably fairly small.

In Fig. 4 number of annuli has been plotted against MWS. These two variables have a positive curvilinear relationship although the scatter is quite wide in the later age categories. This confirms the expected pattern that the larger MWSs represent considerably longer periods than the smaller MWSs. The considerable increase in scatter of data in the older animals indicates that this data is not suitable for regression.

The negative relationship between CRHT and MWS (Fig. 5) in contrast to the above figures (2 & 4) is essentially linear. The concentration in this figure of a large

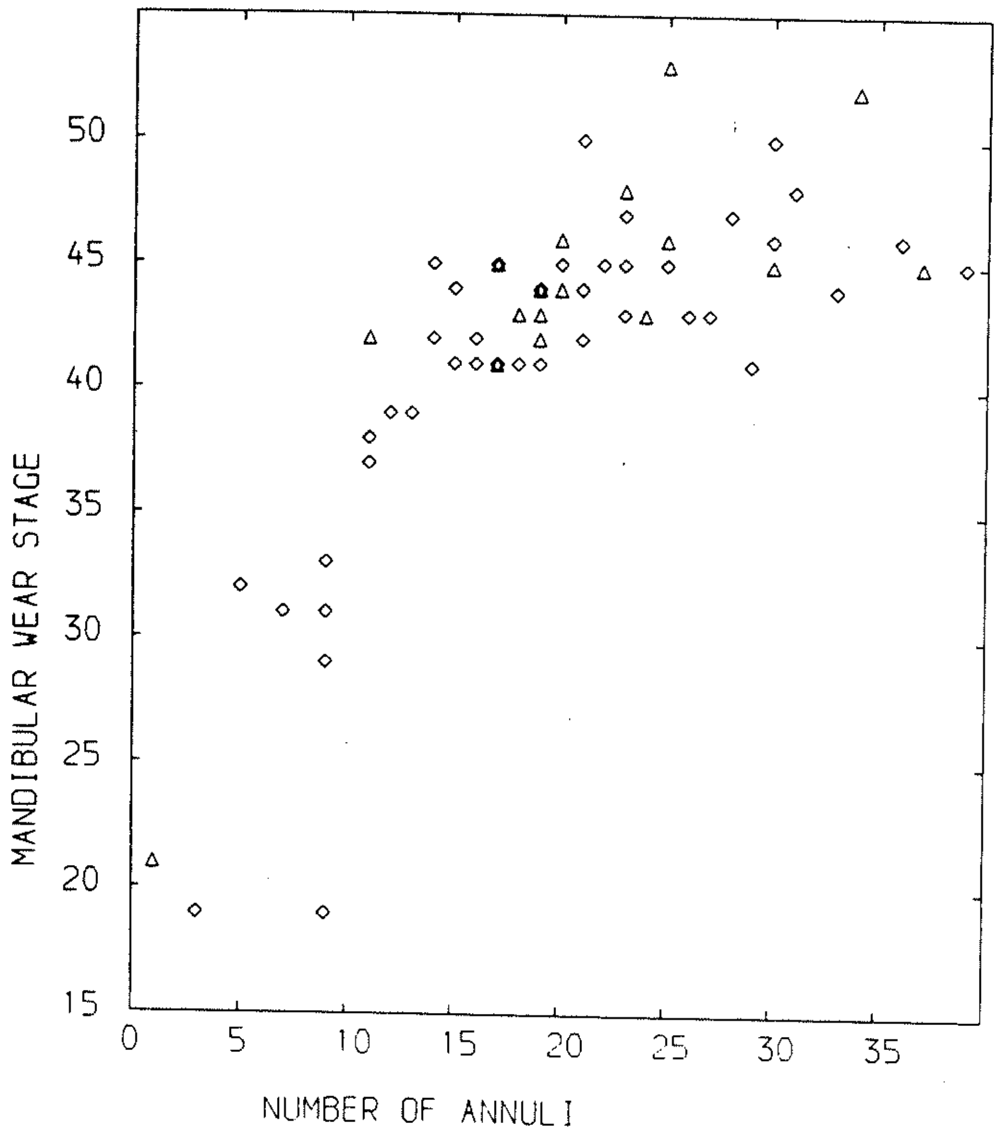


figure 4. scattergram of mandibular wear stage against ml annulus count for 1st ^ 2nd century cattle mandibles from [illegible]

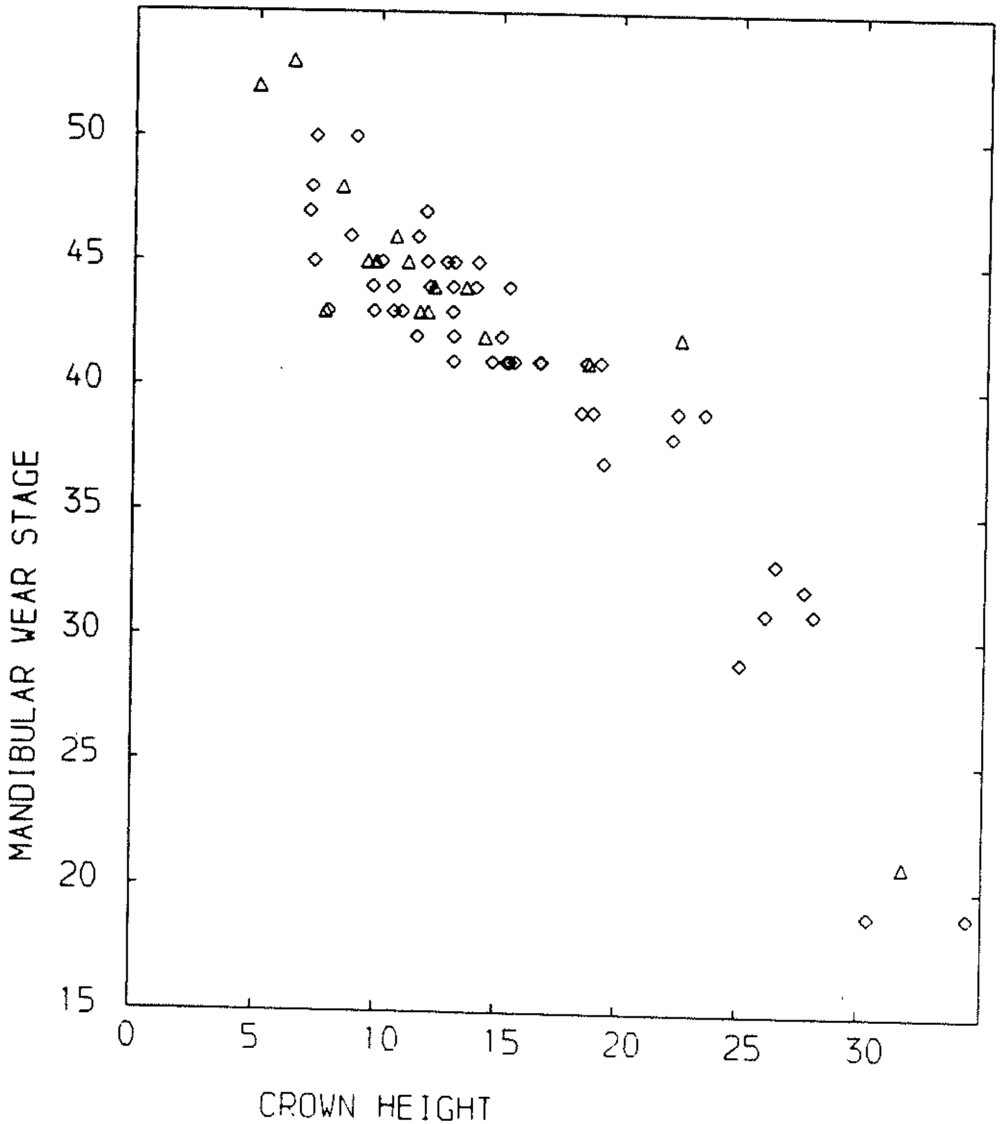


figure 5. scattergram of mandibular wear stage
against ml crown height for 1st and 2nd
century cattle mandibles from [illegible]

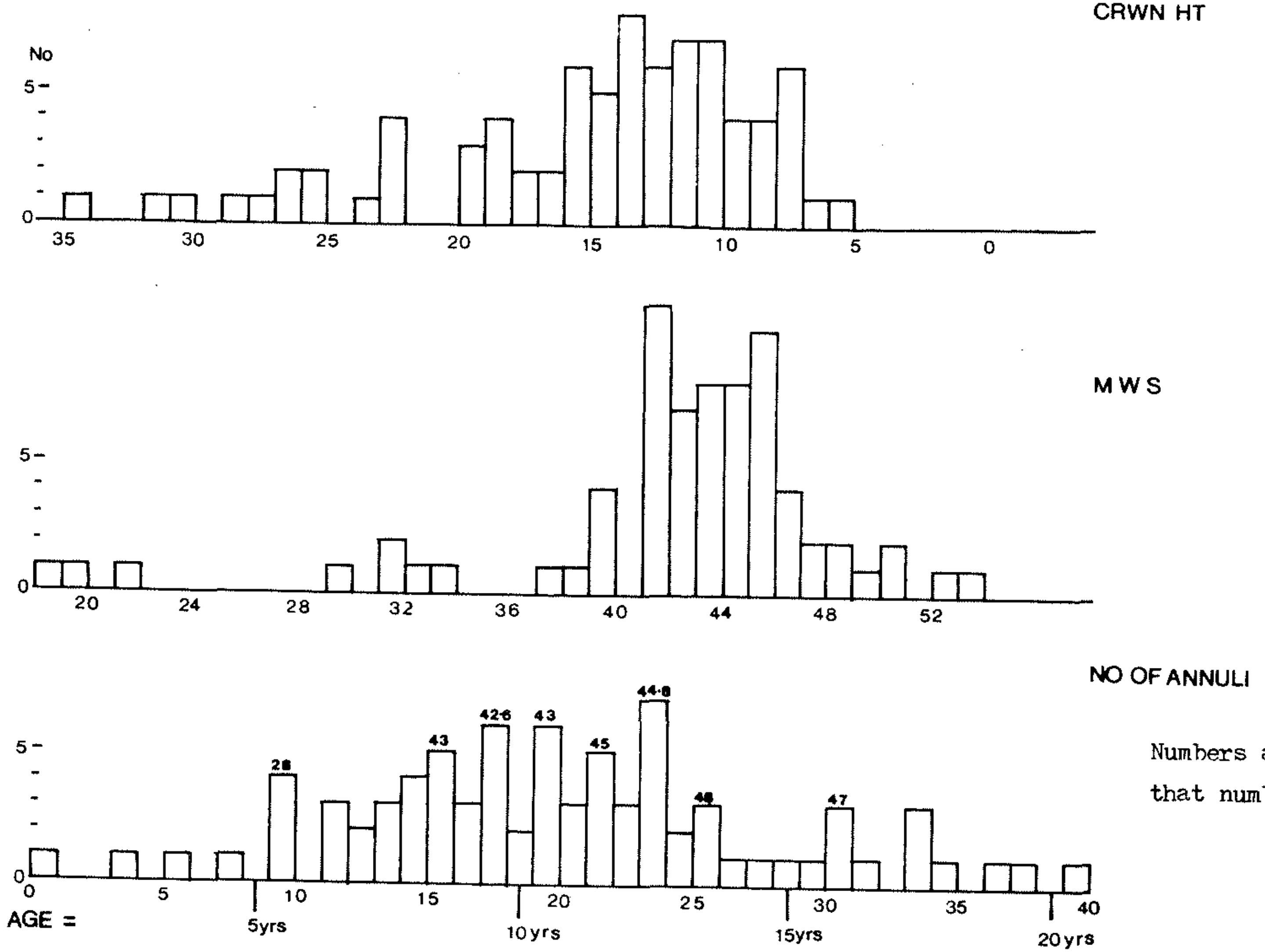
proportion of the cases into relatively few MWSs and CRHTs contrasts with the pattern observable in Figs. 2, 4 and 6. The scale of the variation (in estimated age) of both MWS and CRHT is such that both measures are relatively unreliable as estimates of age after approximately 8 years old. In this sample for example (see Fig. 4) an MWS of 45 was recorded for a number of jaws from which the annulus counts gave an estimated age range of 8 years to 20.5 years with a mean age of 12.5 and a standard deviation of 3.62- ie two in every three jaws with an MWS of 45 will lie within an estimated age range of 8.88 and 16.12 years. A similar example may be given for CRHT. A CRHT of 10.11 mm is recorded for a jaw with an estimated age of 11 years, and a CRHT of 10.33 mm for a jaw of 17.5 years.The mean age for M1s with CRHTs between 10.0 and 10.99 mm is 13.07 with a sd. of 2.18- ie two in every three jaws with a CRHT between 10-10.99 mms will lie between 10.89 and 15.25 years. The variablity in CRHT in these later wear stages appears to be somewhat less than that for MWS (Figs. 2 & 4) and would indicate that CRHT is a more reliable estimate of age in these stages. When considering the pastoral exploitation patterns of prehistoric and early historic populations these errors are considerable and except where large samples are available, age or even age categories cannot be realistically assigned in the later 50-60% of the potential lifespan of these cattle. This is unfortunate particularly since many samples in this country (Grant, 1982; Grant, 1984; Maltby, 1981). show that the majority of the cattle are slaughtered within this period of the lifespan or at least when their MWS is in excess of 40.

While the slaughter pattern determined in the manner of Klein and Cruze-Uribe (1984) is not strictly so useful when dealing with pastoral rather than hunting and scavenging economies it is interesting to compare the results using their formula (in this sample taking k=0.5, Y0=36 & N=25) and the results from annulus counts in 10% units of lifespan (Fig. 7). The effect of the underestimate in the early and later stages of the M1 wear can be seen in Fig. 7 where the first two age categories contain a considerably larger proportion of individuals and the later categories contain fewer individuals. The discrepancy is of sufficient magnitude for some mis-interpretation.

This study suggests a number of problems in the analysis of the age structure of archaeological samples of domestic species from CRHTs and MWSs. If we can rely on the results of the annulus counts as a realistic measure of true age then little reliablity can be attached to age predictions based upon CRHT or MWS after about 8 years of age even when using the model exploited by Klein and Cruz-Uribe (1984). The later wear stages and low CRHTs are subject to such large errors that only large samples may be expected to average out incorrect predictions. Interestingly the range of error found by Klein et al (1983) and Spinage (1972) was also

Fig. 6

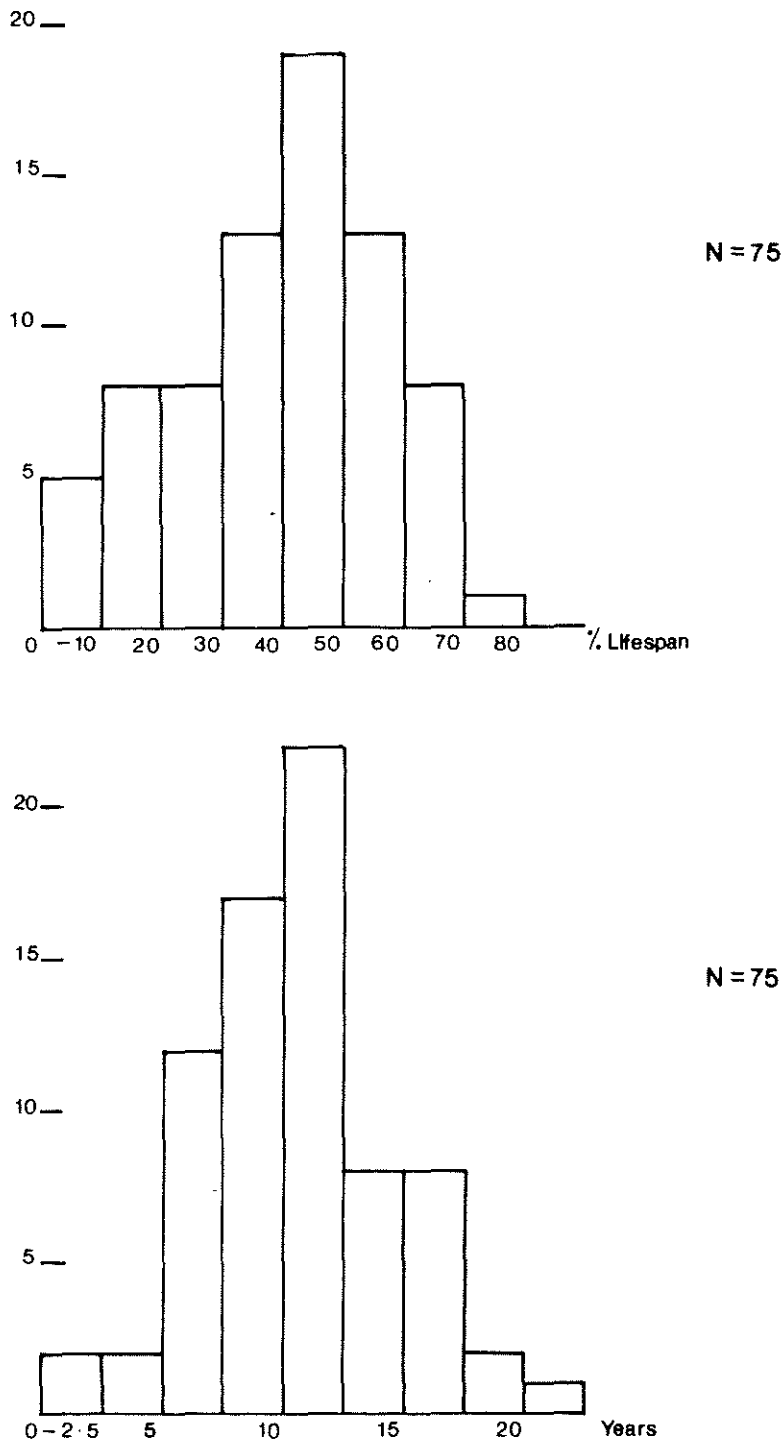
Histograms of three different measures used to estimate age, only that of annulus counts is calibrated according to years of age.



Numbers above bars = mean MWS for that number of annuli.

Fig. 7

Histogram of 10% lifespan units calculated after Klein and Cruze-Uribe (1984) and using annulus counts as a measure of age.



Estimated Age From Annulus Counts

great. Klein et al (1983) admitted that the results could only realistically be used in 10% of lifespan units. Ducos (1968) found fairly wide variability in an index of CRHT and thickness at the base of the crown in a group of modern known age N'Dama cattle. Figure 6 illustrates the nature of the variation in these tooth measures and illustrates that information could easily be lost by relying on CRHT or MWS. The results suggest that every opportunity should be taken to study the cementum annuli in samples where preservation is very good if realistic assessment of the age structure is required. Such studies will inevitably assist the interpretation of the MWS and CRHT data for sites where preservation is not good enough for study of the microstructure of the cementum and may result in the development of a more reliable model of Molar 1 wear. This study has somewhat tacitly accepted that cementum annuli represent annual increments, further supporting work should be carried out on modern domestic material to substantiate this conclusion before results of work such as this are used for indiscriminate interpretation.

Acknowledgements

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Figure captions for 'Age determination from Mandibular dentition'.

Figure 1. Diagram of the longitudinal section of a cattle mandibular Molar 1 illustrating the measurements used.

Figure 6. Frequency diagram of the occurrence of CRHTs, MWSs and annulus counts for a sample of 1st and 2nd century cattle from Carlisle. The figures on the diagram for annulus count indicate the mean MWS for that count.

Figure 7. Frequency histograms of the age structure of a 1st and 2nd century sample of cattle mandibles from Carlisle in 10% units of lifespan (after Klein and Cruz-Uribe, 1984) and in 10% units of estimated age from annulus counts using a maximum age of 25 years.