Use of crown height of the maxillary first molar tooth to approximate the age of horses

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OBJECTIVE
To identify whether age, sex, or breed is associated with crown height of the left and right maxillary first molar tooth (M1) measured on CT images, to develop a mathematical model to determine age of horses by use of M1 crown height, and to determine the correlation between M1 crown height measured on radiographic and CT images.

SAMPLE
CT (n = 735) and radiographic images (35) of the heads of horses.

PROCEDURES
Crown height of left and right M1 was digitally measured on axial CT views. Height was measured on a lateral radiographic image when available. Linear regression analysis was used to identify factors associated with crown height. Half the data set was subsequently used to generate a regression model to predict age on the basis of M1 crown height, and the other half was used to validate accuracy of the predictions.

RESULTS
M1 crown height decreased with increasing age, but the rate of decrease slowed with increasing age. Height also differed by sex and breed. The model most accurately reflected age of horses < 10 years old, although age was overestimated by a mean of 0.1 years. The correlation between radiographic and CT crown height of M1 was 0.91; the mean for radiographic measurements was 2.5 mm greater than for CT measurements.

CONCLUSIONS AND CLINICAL RELEVANCE
M1 crown height can be used to predict age of horses. Results for CT images correlated well with those for radiographic images. Studies are needed to develop a comparable model with results for radiographic images. (*Am J Vet Res* 2018;79:867–873)

Determining the age of horses by use of their teeth is an ancient practice[1] that Chinese records date back to at least 600 BC.[2] Regardless of the era, estimating the age of horses is important for the determination of perceived value, disease prognosis, nutritional decisions, and working life.[3]

Historically, emphasis has been placed on the use of incisor morphology to determine age. However, studies[4,5] indicate that the use of incisor morphology is accurate only for horses up to 5 years of age and is based on eruption of the permanent dentition.[4,5] Incisor characteristics typically used to determine age of horses (eg, occlusal surface shape, Galvayne's groove, and presence or absence of infundibula) have wide variation, which suggests that these features are not reliable indicators of age.[4–6]

Investigators of a 2008 study,[7] which was conducted on the basis of the suggestion in an 1882 study[8] that cheek teeth may be used to accurately estimate age in horses, determined a mathematical model for estimating the age of horses that was based on morphology of the occlusal surface of the cheek teeth. However, challenges associated with obtaining occlusal images via dental impressions or intraoral endoscopy limited the applicability of this method for determining horse age.

The first permanent cheek teeth (excluding the first premolar teeth) to erupt are the first molar teeth, which appear when horses are approximately 1 year old. They are followed by the second premolar and second molar teeth at approximately 2 years of age, third premolar teeth at approximately 3 years of age, third molar teeth at approximately 3 to 4 years of age, and the fourth premolar teeth at approximately 4 years of age.[9] As such, the first molar teeth are subject to wear at a relatively early age and can be useful for inclusion in mathematical models of aging because those models can incorporate results for young horses.[7] As mandibular teeth wear, crown height decreases by 2.2 to 4.0 mm each year.[a] The range in the attrition rate may be attributable to differences in dental hardness among breeds (as suggested in re-

ABBREVIATIONS
CI Confidence interval
M1 Maxillary first molar tooth

ports of breed differences for incisor shortening[3,10]), environmental differences (eg, type of pasture soil and abrasiveness of forage[3,11,12]), and stereotypic behaviors that typically affect the incisor teeth.[13]

The objective of the study reported here was to determine whether age, breed, sex, or head width had an effect on crown height (that portion of a tooth covered by enamel) of horses and to investigate whether the age of horses could be accurately determined by measuring the crown height of the left and right M1 on CT images. A second objective was to use a subset of horses for which there were CT images and a lateral radiographic image of the head to determine whether crown height of M1 on radiographic images was correlated with crown height of M1 on CT images.

Materials and Methods

Sample

The CT images of 1,365 equids that had been collected for another study[14] were obtained for the study reported here. Complete data regarding breed, sex, and age (calculated from horse passports or breed papers) were available for 735 horses. There was no history available pertaining to dental care, including that of recent odontoplasty or floating. In addition, radiographic images of the head of 35 of these horses were obtained.

Procedures

The CT images were viewed in the axial and sagittal planes within multiplanar reconstruction. Left and right M1 were identified, and the total crown height (clinical [visible portion] and reserve [portion under the gingiva]) was measured digitally by 1 investigator (KVH). Crown height was measured from the bifurcation of the mesial and distal roots to the most coronal prominence of the occlusal surface of the tooth in the axial plane image **(Figure 1)**. Crown height was measured 3 times on images of the first 50 teeth, and the mean value was calculated and statistically compared with the first of the measurements. There was no significant difference. Thus, given the logistics of measuring images for > 700 horses, only a single measurement was obtained for each image thereafter.

Missing teeth or teeth that were malpositioned (as determined by assessment in the axial, coronal, and sagittal planes) or malerupted were not measured. Similarly, teeth that had CT-evident dental pathological changes or were involved in dental sinusitis were not included in the study. The mean height for the left and right M1 was calculated for each horse included in the study. For 93 horses, 1 tooth was missing or was not measured because of the aforementioned reasons; thus, the value for the single available M1 was used in place of the mean. Additionally, head width at the bifurcation of the mesial and distal roots of M1 was measured by drawing a line between the bony limits of the facial crest.

Radiographic crown height of M1 was measured on appropriately positioned lateral digital radiographic images. Appropriate positioning was determined by ensuring that there was no rostrocaudal angulation of the incident beam (ie, only radiographic im-

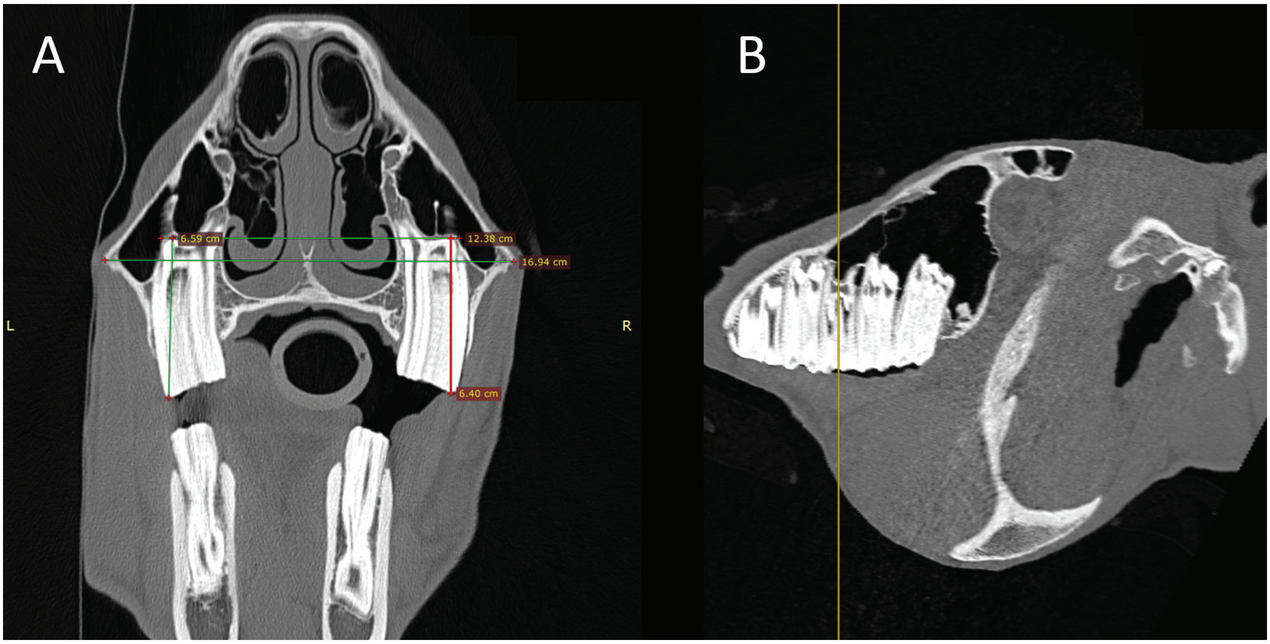

Figure 1—Axial (A) and sagittal (B) CT images within multiplanar reconstruction of the head of a horse. Crown height of the left and right M1 (6.59 and 6.40 cm, respectively) and head width (distance between the bony limits of the facial crest; 16.94 cm) were measured on the axial image. The line parallel to that used for measurement of the bony limits of the facial crest (between the left and right M1 [12.38 cm]) was used to ensure consistency of measurement between left and right sides of the head. The midportion of M1 is indicated (vertical yellow line) in the sagittal image. L = Left. R = Right.

ages in which the left and right maxillary second premolar teeth were superimposed on the mesial edge were used) and that there was no dorsoventral obliquity as determined by assessment of the superimposition of the nasoincisive notches. Only the M1 closest to the image capture device was measured to limit magnification artifact. A radiographic marker was not included; thus, there was no correction for magnification associated with the radiographic technique. Radiographic crown height was determined from the bifurcation of the mesial and distal roots to the most coronal prominence of the occlusal surface of the tooth, similar to the method used for CT measurements. All data were entered into a spreadsheet program.[b]

Statistical analysis

Analysis was performed with a commercial statistics package.[c] Twenty-six breeds of horses were represented; horses were classified into 9 breed groups, as described elsewhere.[14] Linear regression analysis was used to examine the effect of age, breed group, and sex on crown height (combined height of the clinical and reserve crown) as measured on CT images of the equine head. Unconditional analysis was used to screen variables; those with a value of $P < 0.2$ were submitted for consideration in building the final multivariable model.[15] Continuous risk factors were assessed to ensure that they met linearity assumptions. Final models were built by use of manual backward elimination, and variables that were not significant were assessed as potential confounders. When ≥ 2 variables were significant, biologically plausible 2-way interactions were assessed; significant interactions were retained in the final model ($P < 0.05$).

Linear regression analysis was then used to estimate age on the basis of crown height of M1, breed group, and sex. A random number generator was used to generate a number between 0 and 1 within each breed group. Horses with a number < 0.5 were used to create a model (training data set), which was validated by predicting the age of horses with a number ≥ 0.5 and then examining accuracy of the prediction (testing data set). When a particular breed group contained < 10 horses, all animals in that breed group were retained in the training data set. A statistical program[d] was used to calculate the Lin concordance correlation coefficient to measure agreement between the actual and predicted age for both the training and testing data sets. Differences between observed and predicted outcomes were also examined by use of a limits of agreement plot (Bland-Altman plot).[e] Similarly, agreement between the crown height of M1 measured on CT and radiographic images (n = 35) was examined.

Results

The sample comprised CT images for 735 horses (426 males and 309 females). Mean ± SD age of the horses was 11.7 ± 5.8 years (range, 1.0 to 39.8 years). The horses represented 26 breeds, which were classified into 9 breed groups **(Table 1)**.

An unconditional analysis of factors potentially associated with crown height of M1 was conducted (Table 1). The final multivariable model for crown height of M1 was determined **(Table 2)**. Crown height decreased with increasing age, but the rate of decrease slowed with every additional year of age, as described by the following equation: crown height of M1 = ([–4 mm X age] + [0.007 mm X age^2]). For example, after accounting for breed and sex, the mean difference in crown height of M1 between 1- and

Table 1—Results of unconditional analysis of potential risk factors on crown height of M1 measured on CT images of 735 horses.

Risk factor	No. of horses	β (95% CI)
Sex*		
Male	426	–0.48 (–0.71 to –0.26)
Female	309	NA
Age (y)*	735	–0.23 (–0.24 to –0.22)
Breed group*†		
Standardbred	14	–1.13 (–2.57 to 0.31)
Quarter Horse	66	–0.97 (–2.23 to 0.28)
Thoroughbred	52	–1.58 (–2.86 to –0.32)
Pony	38	–1.32 (–2.26 to –0.02)
Warmblood	459	–0.81 (–2.02 to 0.40)
Coldblood	50	–0.51 (–1.78 to 0.77)
Icelandic Horse	24	–1.71 (–3.05 to –0.36)
Arabian	26	–1.51 (–2.86 to –0.18)
Miniature Horse	6	NA
Head width (cm)‡	735	0.001 (–0.02 to 0.02)

Breeds in each breed group are as follows: Quarter Horse = Quarter Horse, Paint, and Appaloosa; Pony = Welsh, Shetland, and uncategorized; Warmblood = Hanoverian, Holsteiner, Noriker, Oldenburg, Trakehner, Westphalian, and Furioso–North Star; and Coldblood = Friesian, Freiberger, Tinker, Noriker, Haflinger, Belgian, Clydesdale, and Percheron.

*Effect is significant ($P < 0.001$). †The *P* value is based on > 10 animals/breed group. ‡Effect is not significant ($P = 0.95$).

β = Regression coefficient (amount by which the factor is altered for an incremental change in the outcome variable). NA = Not applicable (referent).

Table 2—Results for the final multivariable model of factors used to predict crown height of M1 for 729 horses by use of breed groups represented by > 10 animals.

Factor	β	95% CI	*P* value*
Sex			
Female	0.41	0.31 to 0.51	< 0.001
Male	NA	NA	NA
Breed group			
Standardbred	0.30	–0.14 to 0.74	0.18
Quarter Horse	0.24	–0.07 to 0.55	0.13
Thoroughbred	–0.02	–0.34 to 0.30	0.90
Pony	0.06	–0.28 to 0.40	0.72
Warmblood	0.41	0.15 to 0.69	0.002
Coldblood	0.49	0.17 to 0.81	0.003
Icelandic Horse	0.22	–0.16 to 0.59	0.26
Arabian	NA	NA	NA
Age (y)	–0.40	–0.43 to –0.38	< 0.001
Age^2 (y)	0.007	0.006 to 0.008	< 0.001

*Values are considered significant at $P < 0.05$.
See Table 1 for remainder of key.

Table 3—Pairwise comparisons of crown height of M1 between breed groups of horses (n = 729) represented by > 10 animals/breed group.

Breed group	Mean	95% CI
Coldblood[a,b]	5.41	5.22–5.60
Warmblood[b]	5.34	5.29–5.40
Standardbred[a,b,c,d]	5.22	4.87–5.57
Quarter Horse[a,c]	5.16	5.00–5.32
Icelandic Horse[a,b,c,d]	5.13	4.86–5.41
Pony[c,d]	4.98	4.77–5.19
Arabian[c,d]	4.92	4.66–5.18
Thoroughbred[d]	4.90	4.71–5.08

Values for breed groups with different superscript letters differ significantly ($P < 0.05$).

See Table 1 for remainder of key.

Table 4—Results for the final multivariable model of factors used to predict age of horses (n = 378) by use of a training data set.

Factor	β	95% CI	*P* value*
Intercept	30.11	26.28 to 33.94	< 0.001
Sex			
Female	1.18	0.60 to 1.75	< 0.001
Male	NA	NA	NA
Breed group			
Standardbred	–0.92	–2.95 to 1.09	0.37
Quarter Horse	–0.86	–1.82 to 0.09	0.08
Thoroughbred	–1.24	–2.37 to –0.13	0.03
Pony	–1.67	–3.04 to –0.31	0.02
Coldblood	0.28	–1.12 to 1.69	0.69
Icelandic Horse	–0.13	–1.77 to 1.51	0.87
Arabian	–1.64	–3.17 to –0.12	0.03
Warmblood	NA	NA	NA
Crown height of M1 (mm)	–4.56	–5.63 to –3.48	< 0.001
Crown height of M1^2 (mm)	0.12	0.02 to 0.22	0.014

See Tables 1 and 2 for key.

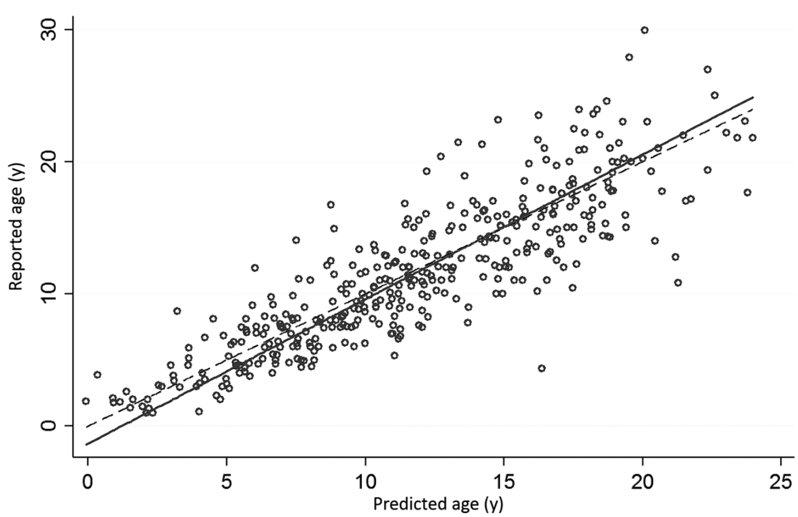

Figure 2—Dot plot of predicted age (calculated by use of the crown height of M1) versus reported age (calculated from horse passports or breed papers) of horses (n = 378) in a training data set. Each symbol represents results for 1 horse. The line of observed concordance (solid line) and line of perfect concordance (dashed line) are indicated.

2-year-old horses would be ([–4 mm X 2] + [0.007 X 2^2]) – ([–4 mm X 1] + [0.007 X 1^2]) = –3.97 mm, whereas the mean difference between 5- and 6-year-old horses would be –3.92 mm, and the mean difference between 15- and 16-year old horses would be –3.78 mm.

After accounting for age and breed, crown height of females was greater than that of males (regression coefficient = 0.41 mm; 95% CI, 0.31 to 0.51 mm). Pairwise comparisons of the predicted value of mean height between breed groups, after accounting for age and sex and using only those breed groups represented by > 10 horses, indicated that Warmblood and Coldblood breed groups had a crown height of M1 that was significantly greater than that of Thoroughbreds, Ponies, and Arabians **(Table 3)**. Other differences among breed groups were also identified.

Another final multivariable model of factors that could potentially be used to predict age was created by use of data only from the training data set **(Table 4)**. The Lin concordance coefficient between predicted and actual age for the training data set was 0.86 (95% CI, 0.83 to 0.88; **Figure 2**); mean predicted age was 0.22 years greater than actual age (SD, ± 2.9 years; 95% limits of agreement, –6.0 to 5.5 years).

Application of the prediction model to the testing data set resulted in a concordance correlation coefficient between observed and predicted values of 0.85 (95% CI, 0.82 to 0.88; **Figure 3**). Assessment of limits of agreement plots indicated that the model overestimated age by a mean of 0.1 years (SD, ± 3 years; 95% limit of agreement, –6.0 to 5.8 years) and best predicted age of horses < 10 years old **(Figure 4)**.

Comparison of measured radiographic and CT crown height of M1 height (n = 35) yielded a concordance correlation coefficient of 0.91 (95% CI, 0.85 to 0.96). Measurements of radiographic images were greater (mean, 2.5 mm; 95% limits of agreement, –8.9 to 14.0 mm) than those of CT images **(Figure 5)**.

Discussion

The first objective of the study reported here was to identify factors (age, breed, sex, and head width) associated with crown height of M1 as measured on CT images. This originated from the fact that on a dorsoventral radiographic projection, there is an obvious difference in density between M1 and the fourth premolar tooth as horses age. This difference is attributable to the disparity between the remaining crown heights of the cheek teeth. Computed tomography was the imaging modality selected because of the ability to manipulate high-quality images in a retrospective manner. Interestingly, results for the present study indicated a strong correlation be-

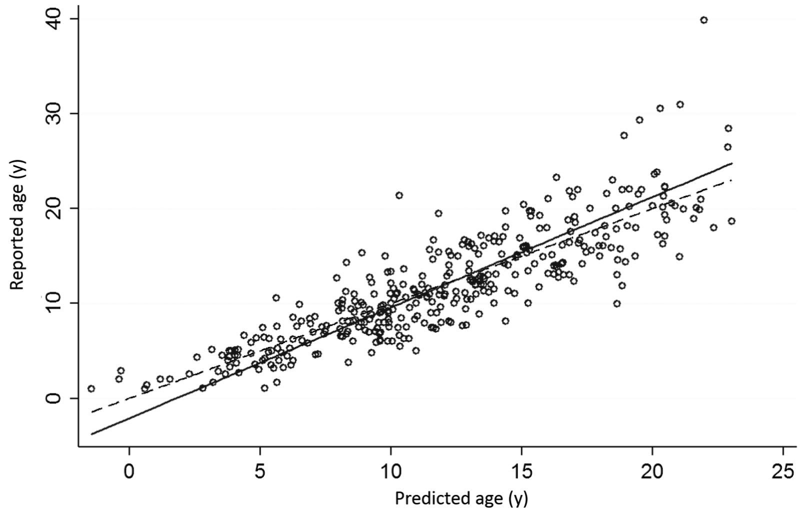

Figure 3—Dot plot of predicted age (calculated by use of the crown height of M1) versus reported age (calculated from horse passports or breed papers) of horses (n = 378) in a testing data set. ***See*** Figure 2 for key.

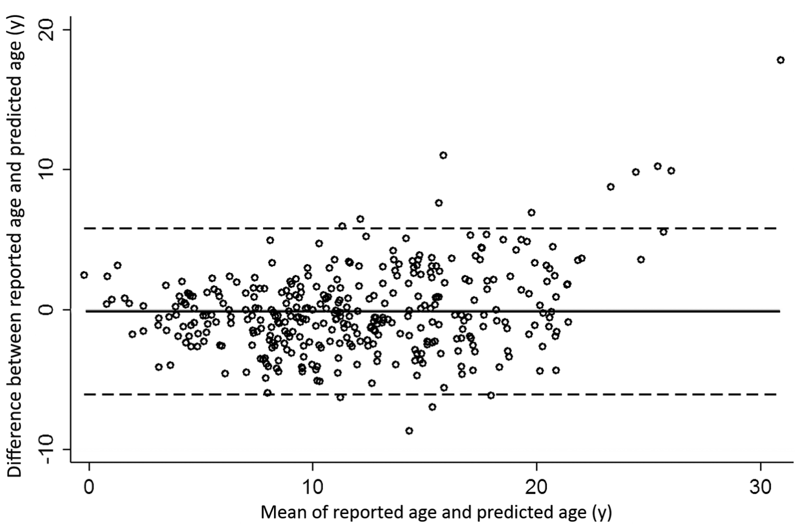

Figure 4—Bland-Altman plot between reported and predicted age of horses (n = 378) in a testing data set. Each symbol represents results for 1 horse. The mean observed agreement (solid line) and 95% limits of agreement (dashed lines) are indicated.

tween crown height of M1 and age, with effects of both sex and breed.

A mathematical model for predicting the age of horses by use of the crown height of M1 as measured on CT images was developed and tested. In another study,[16] investigators used 13 variables for incisors to generate a mathematical model to predict age of horses. The Pearson correlation coefficient generated by comparing known to predicted age for the model in that study[16] was 0.9, which is only marginally better than the age that can be derived by examination by 4 experienced veterinarians. In that study,[16] investigators used horses with a minimum age of 5 years and rounded the age of a horse to the nearest whole number, such that a reported age of 6 years would encompass 5.51 to 6.50 years.

In the absence of an officially implanted microchip, use of the cheek teeth rather than the incisors may be a more accurate method of age determination simply because the cheek teeth are not subject to the vagaries of stereotypic behavior. This problem was addressed in the aforementioned study[16] on incisor teeth, the results of which were not altered when horses with stereotypic behavior were removed from the analysis. However, this should not be interpreted to mean that stereotypic behavior does not affect age determination.

Unfortunately, no history pertaining to the dental care of the horses in the present study population was available. It is possible that dental intervention performed on the occlusal surface and buccal edges of M1 may have affected measurements (ie, made them shorter). However, we found that the loss of crown height of M1 actually slowed with increasing age. In addition, it was possible that the large study population may have diluted the effects of forage, soil, and other environmental variables that impact dental abrasion.

The mathematical model generated in the present study was not the first model to be generated by use of values for the cheek teeth. We chose to use the left and right M1 on the basis of studies conducted with zebras[17] and domestic horses[7] in which it was suggested that results for M1 appeared to correlate better with age than did results for mandibular molars. The crown height of M1 was originally used to predict age of zebras by use of cadaver skulls.[17] However, given that the age of these wild animals was not accurately known, the age derived by use of M1 was tested against the proposed age determined by use of incisor morphology.[18] The model reported here was substantially better than previous models because the concordance coefficient was higher and it was the result of a multivariable analysis of a much larger number of horses.

The model for all horses in the present study suggested that the rate of loss in the crown height of M1 decreased by a lesser amount with each year of age. The reduction of 3.97 mm between 1 and 2 years of age is equivalent to the upper limit of values reported elsewhere.[a] However, we found in the present study that as horses aged, the rate of height reduction decreased, which supports clinical findings that the rate of clinical crown eruption appears

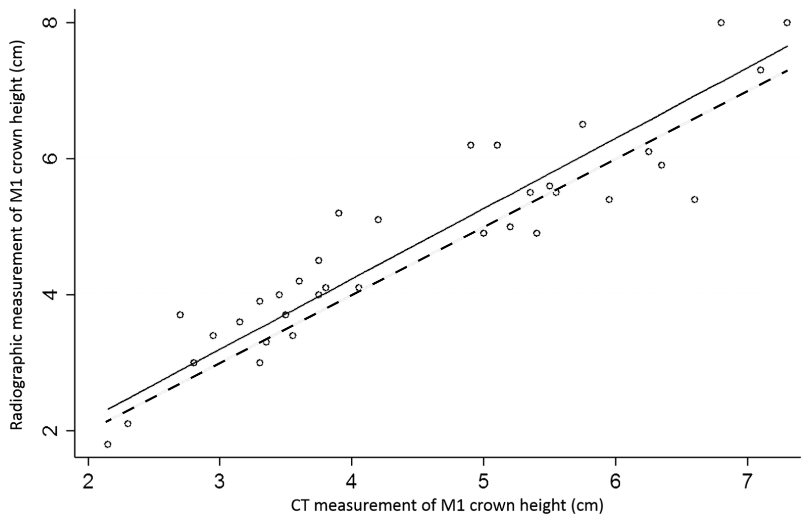

Figure 5—Dot plot of crown height of M1 measured on radiographic and CT images of 35 horses. ***See*** Figure 2 for key.

to slow as horses age. However, that observation is true only until tooth senescence. At that point, the roots are covered only in cementum, which is substantially less resistant to erosion; thus, the rate of loss of crown height would increase. There were not enough horses of advanced age in the present study to enable us to create a mathematical model for the increased old-age attrition of M1.

Analysis of data for the study reported here also indicated effects of sex and breed. Females had a greater crown height of M1 than did males (accounting for age and breed). The importance of this finding is not known, but it corroborates the sexual dichotomy reported in another study[19] for which investigators found that deciduous premolar teeth were shed at a later age in females than males. It is possible that the greater crown height (ie, longer teeth) in females is a function of reduced attrition, which may explain the delay in exfoliation of deciduous premolar teeth. However, it also could be simply a sex-specific variation.

Breed significantly impacted measurements of the crown height of M1 in the present study. For example, crown height of M1 was significantly greater for Coldblood horses than Arabians. There was no difference in crown height between Coldbloods and Standardbreds and between Arabians and Standardbreds. This finding was contrary to results of previous studies,[6,10] for which investigators compared subjective changes in incisor morphology among Arabians, Trotters, and Belgians. In those studies,[6,10] the rate of dental wear was slower in Arabians than Trotters and Belgians. In addition, sequential subjective changes occurred earlier in draft horses than Trotters. These subjective differences were attributed to objective differences in microhardness of the enamel and dentin among the 3 breed groups, with the dental structure of Arabians being significantly harder than that of draft horses or Trotters.[10]

For the study reported here, analysis of results for the mathematical model indicated significant differences in crown height of M1 among breeds that must be considered when predicting age of horses. Horses with bigger heads had a greater crown height of M1. This effect has been reported previously[7]; however, horses of larger breeds also have a different rate of attrition than do horses of other breeds. To account for this, we also measured width of the head of every horse (as a surrogate for head size); however, this measurement was not a significant factor in any of the multivariable models.

The Lin concordance correlation coefficient is similar to the Pearson correlation coefficient, but it better reflects the level of agreement between 2 data sets because it takes the scale of the observations into account and not just the degree of linear association.[20] The concordance coefficient between the actual and predicted age was 0.85, which represented a good fit of the data. However, assessment of the SD (± 3 years) and 95% CI (–6.0 to 5.8 years) for the limits of agreement indicated that it clearly was not the perfect model for determining age of all horses. Despite this fact, results for the model of the present study were within 3 years of actual age in most 20-year-old horses, which represented a substantial improvement on previous methods. It is possible that crown height of M1, in addition to incisor-based methods, may be used to create a more accurate estimate of age.

Results of the study reported here enabled generation of a mathematical model that can be used with CT images or with forensic data to predict horse age by use of the following equation: age in years = 30.11 – (4.56 X crown height of M1 in mm) + (0.12 X [crown height in mm]^2). This equation can be modified with a sex correction (+1.18 years if the horse is a female) or with corrections for breed group for non-Warmblood horses (+0.28 years for Coldbloods and –0.13 years for Icelandic Horses, –0.86 years for Quarter Horses, –0.92 years for Standardbreds, –1.24 years for Thoroughbreds, –1.64 years for Arabians, and –1.67 years for Ponies).

The model will be of limited practical use unless it can be related to a modality that is routinely used in general practice, namely radiography. The concordance correlation coefficient (0.91) between crown height of M1 as measured on CT and radiographic images was good. Crown height of M1 measured on radiographic images was greater by a mean of only 2 mm than the height measured on CT images. This difference was expected because of the effect of magnification associated with the fact that the radiographic image capture device was located a distance from the tooth. Unfortunately, the low number of horses for which there were quality radiographic images for interpretation precluded development of a mathematical model for radiographic images; therefore, further studies are needed to determine whether the model generated by use of the CT data set will be applicable for radiographic images obtained for a larger number of horses.

Acknowledgments

The authors declare that there were no conflicts of interest.

Footnotes

a. Kirkland KD. *The morphology of the endodontic system, reserve crown and roots of equine mandibular cheek teeth*. MS thesis, University of Illinois, Urbana, Ill, 1995.
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