Shape and Size of Teeth of Dogs and Cats-Relevance to Studies of Plaque and Calculus Accumulation

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Summary:

Crown width, height and buccal surface areas were measured on heads or skulls of four dogs and four cats, and were compared with similar measurements on models of human dentition. Buccal surface area variability was greater in dogs and cats than in humans, and teeth of cats were smaller. Horizontal (gingival and occlusal halves) and vertical (mesial, middle, and distal thirds) buccal surface area variability was also greater in canine and feline teeth compared with human teeth. This increased variability suggests the need for testing of reliability and repeatability of scoring when using plaque and calculus indices based on horizontal or vertical segmentation. Buccal surface area variability between teeth also prompts questioning the validity of equal weighting of smaller, irregularly-shaped teeth when calculating a mean mouth score. Whether equal or more reliable results would be obtained from scores of whole teeth in comparison with segmentation indices used currently has yet to be determined. ***J Vet Dent 19(4); 186 - 195, 2002***

Introduction

Indices are used in canine and feline dental trials to permit statistical analysis of the extent of accumulation of plaque and calculus. They are based on indices used previously in human and laboratory beagle studies.[1-6] These indices generate scores for each tooth that are then summed and divided by the number of teeth scored to produce a "mean mouth score" for analysis. Compared with human teeth, carnivore teeth appear to vary widely in coronal height, width, and buccal surface shape and area, although the extent of this variability has not been documented previously. Some indexing systems use vertical or horizontal segments of the buccal surface to increase the range of the plaque or calculus score.[7,8] If a segment of the crown area is used, scoring the extent of dental substrate using a visually-assessed index requires use of a 'frame' to delineate the area scored. Inclusion of teeth that are irregularly shaped (not a simple rectangle or oval), and that have widely variable surface areas, may be difficult to 'frame' consistently, producing mean mouth scores that are not representative. The purpose of this study was to quantify the similarities and differences among the crowns of teeth used to generate plaque and calculus scores in dogs and cats and to stimulate discussion of the methodology used in canine and feline plaque and calculus studies.

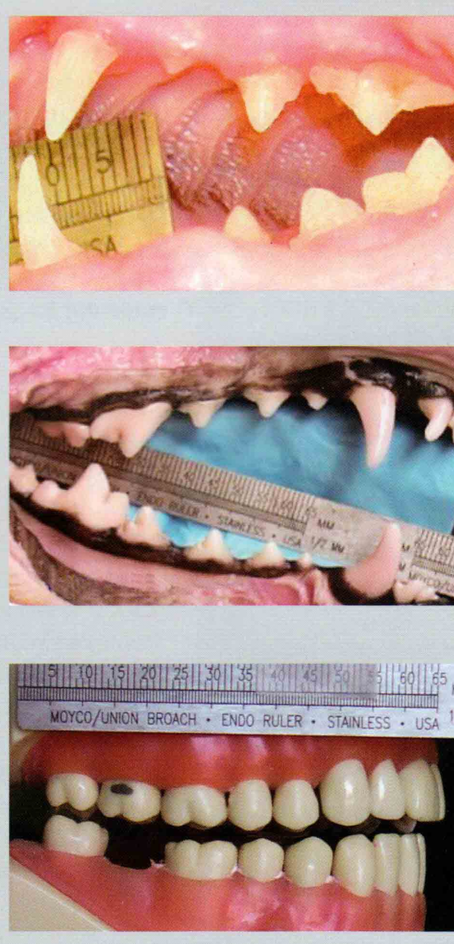
Materials and Methods

Teeth typically used in studies of plaque and calculus accumulation in dogs and cats were photographed using a digital camera, and the calibrated images were used to determine the maximum coronal width, height, and buccal surface area of individual teeth and of the surface area of specific coronal segments of these teeth.

Lateral views of the buccal surfaces of the teeth in skulls or heads of 7 dogs and 5 cats were photographed (Fig. 1).

Figure 1

Lateral oral views of feline, canine, and human teeth (model) with a ruler to show relative scale.



Photographs of one side of the mouth in three skulls and one head of dogs (3 beagles and 1 mixed-breed), and two skulls and two heads of domestic short-haired cats were selected for subsequent measurement, based on the following criteria:

- The specimens were not obviously brachygnathic (no rotated or overlapped teeth except for the small distal cusp of the mandibular fourth premolar tooth slightly overlapping the first molar tooth), and all had no grossly obvious gingival hyperplasia.
- All of the following teeth were present and evaluated:
    - in dogs–maxillary third incisor, canine, third and fourth premolar; mandibular canine, third and fourth premolar, and first molar teeth.
    - in cats–maxillary canine, third and fourth premolar; mandibular canine, third and fourth premolar, and first molar teeth.

Although the canine specimens were from dogs of unknown body weight, all four specimens had skulls of medium size based on the distance from the distal edge of mandibular canine tooth (at the cementoenamel junction [CEJ] or gingival margin) to the distal edge of the mandibular first molar tooth (range = 63.5 mm to 79.3 mm, mean = 71.8 mm).

No apparatus was used to fix the position of the camera lens relative to the specimens although a visual 'best-fit' of the canine-molar dental arch perpendicular to the lens axis was used. The dental arch formed by the rostral teeth is not in the same plane as that of caudal teeth, thus some rotational distortion of the images of the third incisor tooth in canine specimens and the second incisor tooth in human models was expected when using a single image. No correction for rotational distortion of the incisor teeth was attempted.

Only one side of each specimen was evaluated when taking the measurements. An endodontic ruler marked in 0.5 mm increments was included in the images to permit calibration of linear and area tooth measurements. The ruler was placed adjacent to the mandibular canine and first molar teeth and parallel to the long axis of the body of the mandible (Fig. 1).

For comparison purposes and to support accuracy of the methodologies described here, 2 models of human dentition were photographed, and maxillary second incisor, canine, first and second premolar, first molar; and, mandibular canine, first and second premolar, and first molar teeth were measured. Measurements of large numbers of extracted human teeth reported previously were compared with the measurements of human models photographed in this study.[9,10]

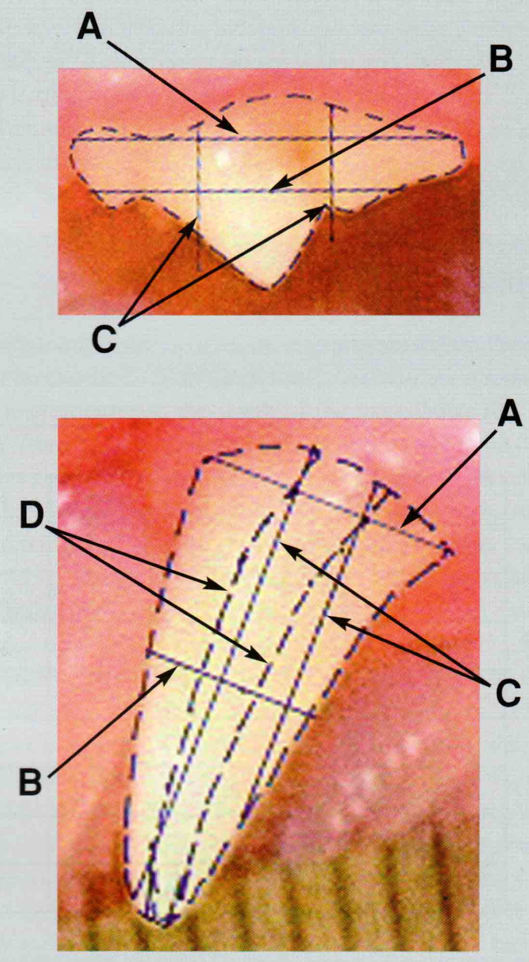
On prints of the digital images, the mesial and distal CEJ in skulls or mesial and distal gingival margin points in heads were identified, and a straight line connecting these mesial and distal points was drawn ("CEJ straight line"). A second line, curved as necessary, was drawn following the buccal CEJ (on images of skulls) or the gingival margin (on images of heads). The CEJ straight line was used to measure the width of the crown, and the buccal curved CEJ or gingival margin line was used to measure the buccal surface area of the crown.

Also on the print, the maximum mesial-distal width of the crown was divided into thirds. From the points marking each 1/3 of the maximum width, a line was drawn perpendicular to the CEJ straight line from the CEJ to the most occlusal aspect of the crown. These lines divided the crown into 3 vertical segments (mesial, middle, distal) for area measurements. For canine teeth (cat) and canine and maxillary third incisor teeth (dog), marks were made at several points along the height of the crown, dividing the width into thirds, then two curved lines were drawn connecting these width points to create 3 curved vertical segments (mesial, middle, distal) [Figs. 2 and 3].

Finally, the "crown height" from the gingival margin to the tip of the highest occlusal cusp (maximum distance, perpendicular to the "CEJ straight line") was divided in half,

Figure 2

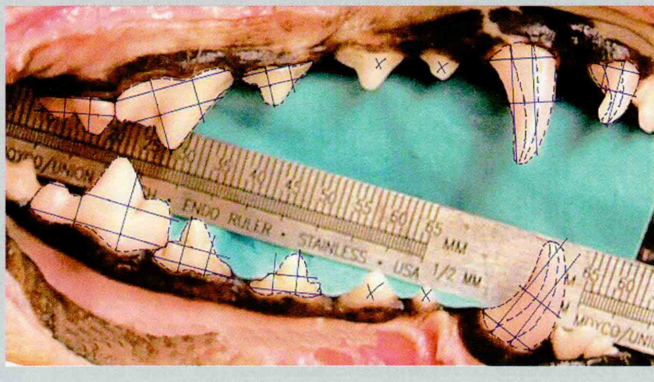
Lines drawn on printed images of teeth to provide frames for crown width, height, and buccal surface area measurements.



A = cementoenamel junction (CEJ) straight line; B = line dividing horizontal surface area into gingival and occlusal halves; C = lines dividing vertical surface area into mesial, middle, and distal thirds; D = lines dividing curved vertical surface area into mesial, middle, and distal thirds

Figure 3

Typical canine image prepared for buccal surface area measurements using measurement software.



and a straight line at this point was drawn parallel to the original "CEJ straight line". This created occlusal and gingival segments of the crown for buccal surface area measurements (Figs. 2 and 3).

The marked prints were then scanned and measured using image analysis software[a]. Each image was calibrated using the endodontic ruler as a reference and measurements performed (mm or mm^2) using the measurement software and expressed as a mean and range. The following measurements were made and recorded: **crown width** (maximum mesial-distal width of crown parallel to CEJ straight line); **crown height** (maximum height from the CEJ or gingival margin [perpendicular to the CEJ straight line] to the maximum height of the crown); **horizontal buccal surface area** (both occlusal and gingival segments); and, **vertical buccal surface area** (each vertical segment and, for the third incisor and canine teeth, each curved vertical segment).

The following calculations were made based on the aforementioned measurements: **buccal surface area** (sum of gingival and occlusal segments; sum of vertical segments) of each tooth of all scored teeth in that specimen; **horizontal buccal surface area** segments of each tooth and of all scored teeth in that specimen; **vertical and curved vertical buccal surface area** segments of each tooth and of all scored teeth in that specimen.

Horizontal and vertical buccal surface areas were

Table 1

Width (mm) of crowns of teeth in dogs, cats, and humans.

	Maxillary					Mandibular			
	I2/3	C	P3/1	P4/2	M1	C	P3/1	P4/2	M1
Dog[a]	7.5	11.0	11.6	19.4	12.7	10.6	11.0	12.7	23.4
%[d]	*32*	*47*	*50*	*83*	*54*	*45*	*47*	*54*	*100*
Cat[a]	-	5.0	6.2	11.2	-	4.8	5.7	7.1	7.7
%[d]	-	*45*	*55*	*100*	-	*43*	*51*	*63*	*69*
Human[b]	5.3	7.6	7.5	7.1	10.6	6.7	7.2	7.3	11.5
%[d]	*46*	*66*	*65*	*62*	*92*	*58*	*63*	*63*	*100*
Human[c]	6.6	7.6	7.1	6.8	10.5	6.9	7.0	7.1	11.2
%[d]	*59*	*68*	*63*	*61*	*94*	*62*	*63*	*63*	*100*

I = Incisor (2nd in humans, 3rd in canine), C = Canine, P = Premolar (1st and 2nd in human, 3rd and 4th in canine and feline), M = Molar.

[a] Mean of measurements from images of four specimens.

[b] Mean of measurements from two human dentition models.

[c] Mean of measurements from references 9 and 10.

[d] Width of crown as percentage compared with widest crown, rounded to nearest whole number.

Table 2

Height (mm) of crowns of teeth in dogs, cats, and humans.

	Maxillary					Mandibular			
	I2/3	C	P3/1	P4/2	M1	C	P3/1	P4/2	M1
Dog[a]	10.8	20.8	7.6	11.7	5.9	19.6	9.2	9.1	14.1
% [d]	*52*	*100*	*37*	*56*	*28*	*94*	*44*	*43*	*68*
Cat[a]	-	11.0	4.6	4.6	-	9.1	4.3	5.2	5.2
% [d]	-	*100*	*42*	*42*	-	*83*	*39*	*47*	*47*
Human[b]	8.7	10.0	8.3	7.9	6.9	9.9	8.2	7.0	6.7
% [d]	*87*	*100*	*83*	*79*	*69*	*99*	*82*	*70*	*67*
Human[c]	9.4	10.3	8.6	8.1	7.5	11.0	8.7	8.1	7.6
% [d]	*85*	*94*	*78*	*74*	*68*	*100*	*79*	*74*	*69*

I = Incisor (2nd in humans, 3rd in canine), C = Canine, P = Premolar (1st and 2nd in human, 3rd and 4th in canine and feline), M = Molar.

[a] Mean of measurements from images of four specimens.

[b] Mean of measurements from two human dentition models.

[c] Mean of measurements from references 9 and 10.

[d] Height of crown as percentage compared with highest crown, rounded to nearest whole number.

compared, to assess the repeatability of the area measurement system. In subsequent calculations, the sum of the occlusal and gingival segments was used as the total buccal surface area. No attempt was made to perform statistical analysis of the data reported here. Coronal width, height, and buccal surface area measurements were compared to provide proportional percentage data.

Results

The mean difference (range) between total buccal surface area measurements using vertical and horizontal buccal surface area segments on any one tooth was 2.0 ± 1.5 (0.1 - 5.9), 1.7 ± 1.2 (0 - 4.1), and 1.6 ± 1.5 (0 - 5.5) %, respectively, in dogs, cats, and human models. On the human models, except for the second incisor tooth (which differed by 1.3 mm or 25.0 %), the widths of the crowns of the scored teeth were all within 0.4 mm (maximum difference = 6.0 %) of the mean occlusal widths recorded in previous reports of direct measurements of large numbers of extracted human teeth (Table 1).[9,10] Seven of 9 human teeth were the same as or slightly wider in the models than in extracted teeth. The 2 teeth that were narrower as measured from images of the models were the mandibular canine (3.0 %) and the second incisor (20.0 %), perhaps due to the progressive curve of the arch narrowing the view of these crowns on the two-dimensional image. The heights of scored human crowns in the models were each within 16.0 % of the mean coronal heights recorded in previous reports of direct measurement of large numbers of extracted human teeth.[9,10] The coronal height was consistently less in the models than in the extracted teeth.

In the dog, the mandibular first molar tooth had the widest crown at 23.4 mm (20.3 - 26.7 mm). The coronal width of the other teeth relative to the width of the mandibular first molar ranged from 32.0 % for the maxillary third incisor to 83.0 % for the maxillary fourth premolar in dogs (Table 1). In cats, the maxillary fourth premolar tooth had the widest tooth crown at 11.2 mm (10.8 -11.7 mm). The coronal width of other cat teeth were 43.0 - 69.0 % of the maxillary fourth premolar. The mandibular first molar had the widest crown in both the extracted human teeth[9,10] (11.2 mm) and the models (11.5 mm). The coronal width of other teeth ranged from 46.0 - 92.0 % of the mandibular first molar in the models, and 58.0 - 92.0 % if the second incisor tooth was eliminated because of the dental arch distortion (Table 1).

The canine teeth had the highest crowns in all three species (Table 2). All teeth in the human models had crowns that were at least 67.0 % the height of the canine teeth. In dogs, 4 of the 9 teeth had coronal heights that were lower than 50.0 % of the canine tooth (minimum 28.0 %). In cats, 5 of 7 teeth had coronal heights that were less than 50.0 % of the canine tooth (minimum 39.0 %).

Coronal buccal surface areas of teeth varied greatly among tooth locations, more so in dogs than in cats (Table 3). Coronal buccal surface area of specific teeth ranged from a mean of 49.0

Table 3

Buccal surface area (mm²) of crowns of teeth in dogs, cats, and humans.

	Maxillary					Mandibular			
	I2/3	C	P3/1	P4/2	M1	C	P3/1	P4/2	M1
Dog[a]	61.4	156.4	51.7	139.7	52.5	146.7	49.0	70.1	198.8
% [c]	*31*	*79*	*26*	*70*	*26*	*74*	*25*	*35*	*100*
Cat[a]	-	37.3	15.2	27	-	26.9	12.8	21.2	27.7
% [c]	-	*100*	*41*	*72*	-	*72*	*34*	*57*	*74*
Human[b]	40.6	64.1	49.9	47.8	64.8	54.9	49.5	44.1	66.5
% [c]	*61*	*96*	*75*	*72*	*97*	*83*	*74*	*66*	*100*

I = Incisor (2nd in humans, 3rd in canine), C = Canine, P = Premolar (1st and 2nd in human, 3rd and 4th in canine and feline), M = Molar.

[a] Mean of measurements from images of four specimens, calculated by summing gingival and occlusal segments.

[b] Mean of measurements from two human dentition models.

[c] Mean of measurements from references 9 and 10.

[d] Surface area of tooth as percentage compared with tooth having greatest surface area, rounded to nearest whole number.

mm² (maxillary third premolar tooth) to 198.8 mm² (mandibular first molar tooth) in dogs, and from 12.8 mm² (mandibular third premolar) to 37.3 mm² (maxillary canine) in cats. In dogs, 5 of 9 teeth had less than 36.0 % (minimum 25.0 %) of the coronal buccal surface area of the mandibular first molar tooth. In cats, one tooth had 34.0 % and another 41 % of the coronal buccal surface area of the maxillary fourth premolar tooth. Coronal buccal surface areas ranged from 40.6 mm² (maxillary second incisor) to 66.5 mm² (mandibular first molar) in the human dentition models, with the smallest tooth having 61.0 % of the coronal buccal surface area of the mandibular first molar.

Differences were more apparent when the vertical and horizontal coronal buccal surface areas were compared between teeth and species (Tables 4 and 5). In dogs, the smallest vertical buccal surface area segment (mesial segment of maxillary third premolar tooth) was 12.4 mm², which was 14.0 % of the area of the largest vertical segment (middle third of the mandibular first molar tooth) and 1.3 % of the summed surface areas of all vertical segments. In cats, the smallest vertical buccal surface area segment (distal third of mandibular third premolar tooth) was 2.7 mm², which was 20.0 % of the area of the largest vertical segment (middle third of maxillary fourth premolar tooth) and 1.6 % of the summed surface areas of all vertical segments. The smallest vertical buccal surface area segment in the human models (distal third of the mandibular first premolar) was 12.3 mm², which was 45.0 % of the largest vertical segment (middle third of maxillary canine tooth) and 2.5 % of the summed surface areas of all vertical segments. When comparing curved vertical buccal surface areas in both dogs and cats, the smallest was 75.0 % - 99.0 % of the largest area. The overall contribution to vertical buccal surface area by mesial, middle, and distal segments was 30.8 %, 39.9 % and 29.3 %, respectively in dogs; 29.2 %, 41.4 % and 29.4 % respectively in cats; and 32.6 %, 38.1 % and 29.3 % respectively in the human models (Table 4).

In dogs, the area of the smallest occlusal or gingival horizontal segment was 15.2 mm² (occlusal half of the mandibular third premolar tooth), which was only 11.0 % of the area of the largest horizontal segment and 1.7 % of the summed surface areas of all horizontal segments (Tables 6 and 7). In cats, the smallest horizontal buccal surface area segment (occlusal half of the mandibular third premolar tooth) was 4.0 mm², which was 17.0 % of the largest horizontal segment (gingival half of the maxillary canine tooth) and 2.4 % of the summed surface areas of all horizontal segments. The smallest horizontal buccal surface area segment in the human models (gingival half of the maxillary second incisor tooth) was 19.8 mm², which was 61.0 % of the largest horizontal segment (gingival half of the maxillary canine, maxillary first molar and mandibular first molar teeth) and 4.2 % of the summed surface areas of all horizontal segments. The overall horizontal buccal surface area contribution for the occlusal segment was only 35.8 % in dogs and 34.3 % in cats. However, the horizontal buccal surface area contribution for the occlusal segment was 49.8 % in the human models (Table 6).

Table 4

Vertical buccal surface area (mesial, middle, and distal vertical crown segments) of teeth in dogs, cats, and humans as a percentage of the total buccal surface area of scored teeth.

	Maxillary					Mandibular			
	I2/3	C	P3/1	P4/2	M1	C	P3/1	P4/2	M1
MESIAL									
Dog[a]	2.3	5.4	1.3	3.8	2.2	5.1	1.6	1.7	7.4
Cat[a]	-	7.2	1.8	4.0	-	5.2	2.2	3.5	5.3
Human[b]	2.6	4.4	3.1	3.1	4.4	3.9	3.6	2.9	4.6
MIDDLE									
Dog[a]	2.4	5.9	2.6	6.8	1.9	5.6	2.4	3.6	9.3
Cat[a]	-	7.8	4.5	8.1	-	5.5	3.8	6.1	5.9
Human[b]	3.2	5.5	4.3	4.0	4.7	4.3	4.1	3.6	5.1
DISTAL									
Dog[a]	2.2	5.6	1.6	4.6	1.6	5.1	1.4	2.3	4.9
Cat[a]	-	7.2	2.7	4.3	-	5.3	1.6	3.0	5.3
Human[b]	2.7	3.6	3.1	3.0	4.4	3.1	2.5	2.8	4.1

I = Incisor (2nd in humans, 3rd in canine), C = Canine, P = Premolar (1st and 2nd in human, 3rd and 4th in canine and feline), M = Molar.

[a] Mean of designated surface areas of teeth on four specimens, calculated as each mesial, middle, and distal vertical segment as percentage of summed areas of gingival and occlusal segments.

[b] Mean of designated surface areas of two human dentition models, calculated as each mesial, middle, and distal vertical segment as percentage of summed areas of gingival and occlusal segments.

Table 5

Largest and smallest vertical buccal surface area segments of crowns of teeth in dogs, cats, and humans.

	Largest vertical segment (%)	Smallest vertical segment (%)	%[c]
Dog[a]	9.3 (Middle Man M1)	1.3 (Mesial Max P3)	14 %
Cat[a]	8.1 (Middle Max P4)	1.6 (Distal Man P3)	20 %
Human[b]	5.5 (Middle Max C)	2.5 (Distal Man P1)	45 %

C = Canine, P = Premolar (1st, 2nd in humans; 3rd, 4th in canine and feline), M = Molar, Man = mandibular; Max = maxillary.

[a] Mean of designated surface areas of teeth on four specimens, calculated as percentage of mean buccal surface area of all teeth.

[b] Mean of designated surface areas of teeth on two human dentition models, calculated as percentage of mean buccal surface area of all teeth.

[c] Smallest vertical segment surface area as percentage of largest vertical segment surface area.

Table 6

Horizontal buccal surface area (occlusal and gingival crown segments) of teeth in dogs, cats, and humans as a percentage of the total buccal surface area of scored teeth.

	Maxillary					Mandibular			
	I2/3	C	P3/1	P4/2	M1	C	P3/1	P4/2	M1
GINGIVAL									
Dog[a]	4.0	10.4	3.9	10.3	3.6	9.4	3.7	5.2	15.0
Cat[a]	-	14.2	6.1	12.6	-	9.7	5.2	8.9	9.3
Human[b]	4.2	6.9	5.4	5.3	6.9	5.9	5.1	4.6	6.5
OCCLUSAL									
Dog[a]	2.7	6.2	1.7	5.9	2.2	6.3	1.7	2.4	6.7
Cat[a]	-	7.9	2.8	4.0	-	6.1	2.4	3.9	7.2
Human[b]	4.4	6.6	5.1	4.7	6.7	5.6	5.2	4.6	6.9

I = Incisor (2nd in humans, 3rd in canine), C = Canine, P = Premolar (1st and 2nd in human, 3rd and 4th in canine and feline), M = Molar.

[a] Mean of designated areas of teeth on four specimens, as percentage of summed surface areas of the gingival and occlusal segments of all teeth.

[b] Mean of designated surface areas of two human dentition models, as percentage of summed areas of gingival and occlusal segments of all teeth.

Table 7

Largest and smallest horizontal buccal surface area segments of crowns of teeth in dogs, cats, and humans.

	Largest horizontal segment (%)	Smallest horizontal segment (%)	% [c]
Dog[a]	15.0 (Gingival Man M1)	1.7 (Occlusal Man P3)	11 %
Cat[a]	14.2 (Gingival Max C)	2.4 (Occlusal Man P3)	17 %
Human[b]	6.9 (Gin Max C, Max M1, Man M1)	4.2 (Gingival Max I3)	61 %

C = Canine, P = Premolar (1st, 2nd in humans; 3rd, 4th in canine and feline), M = Molar, Man = mandibular; Max = maxillary.

[a] Mean of designated surface areas of teeth on four specimens, calculated as percentage of mean buccal surface area of all teeth.

[b] Mean of designated surface areas of teeth on two human dentition models, calculated as percentage of mean buccal surface area of all teeth.

[c] Smallest vertical segment surface area as percentage of largest vertical segment surface area.

Discussion

Plaque indices described originally in human trials have been used extensively in dogs, including several longitudinal trials of 18-months or more that support the now well-accepted conclusion that plaque accumulation causes periodontal disease.[5,6,11-13] The appropriate application of indices described previously, but modified for use in dogs and cats, has been questioned recently.[20] Since adoption of plaque scoring systems based on assessment of plaque coverage of the visible buccal surface of the tooth in the 1960's, there have been three major changes in indices:

1. Examination of thickness as well as extent of coverage. Although rarely stated, the "thickness" is presumably maximum plaque or calculus thickness even if confined to a relatively small area of tooth surface. This concept was initially applied to dental stain in dogs.[2,14] Authors of one study concluded that scoring stain intensity is more sensitive than scoring extent of coverage in dogs.[2] A single scoring system that combined intensity and coverage was found to be more sensitive than extent of coverage alone.[2] A combination of coverage and thickness scoring was applied to calculus in dogs and to plaque in dogs and cats.[7,8,15,16] Another report recommended against separate scoring of thickness and coverage, at least in longer-term studies, because of changes due to mechanical loss of pieces of calculus.[17] It was noted that an *area x thickness* scoring system did not contribute to the information provided by the index.[17]

2. Scoring of multiple segments of teeth (gingival-occlusal halves or vertical thirds). Using these methods, each segment contributes equally to the mean score for that tooth, and the mean of all teeth scores is considered the mean mouth score. [7,18]

3. Combining thickness scoring and segmentation scoring. The effect of this method is to increase the maximum possible score on a single tooth from 3 to 24 for plaque, represented by a 0 - 4 area score multiplied by a 0 - 3 intensity score multiplied by both halves of the tooth; or, from 3 to 36 for calculus, represented by a 0 - 4 area score multiplied by a 0 - 3 thickness score multiplied by three 1/3 segments.[1,7,8,16,19]

Division of the teeth into gingival and occlusal halves was suggested in 1961 for scoring disclosed plaque in human teeth in a study of efficacy of tooth-brushing, for the stated purpose of assessing small differences that were unlikely to be identified by then-existing techniques.[1] Only the gingival half of the tooth was scored for plaque, and the scoring was based on extent of coverage (0 = none; 1 = < 1/3; 2 = 1/3 - 2/3; 3 = > 2/3) of the buccal surface.[1] A similar system, based on scoring the whole tooth, was used in beagle dogs in 1967.[13] A human plaque index proposed in 1962 and slightly modified in 1970 used a 0-5 scoring system, with scores 1-3 indicating stages of less than 1/3 coverage.[3,4]

Although often described as "modifications", segmented combination plaque and calculus indices are sufficiently different from the original indices[3,4] that referring to them as separate indices has been proposed for calculus (Warrick-Gorrel Index) and for plaque (Logan-Boyce Index).[8,20] Use of these segmented combination scores is now common in dogs[7,21-26] and cats[27-29], and data validating the sensitivity of the entire scoring system using positive and negative controls for plaque have been presented.[30] However, these validation studies did not report validity or sensitivity of individual components (segmentations; area *vs.* thickness).

Visual assessment of the extent of dental substrate coverage requires a "frame" within which coverage can be quantified. The frame should be repeatable if the crown is divided into segments. To ensure consistency, the horizontal and vertical frames measured in this study were all developed from the "CEJ straight line." Although the crown halves and thirds were mathematically correct as defined and simple to map on the area-measuring software, they did not follow anatomic landmarks. The curved vertical buccal surface area measurements in canine teeth resulted in more equivalent segmentation scores but the anatomic nature of these areas would seem to make scoring difficult on a consistent basis. Data reported here suggest that segmentation would be difficult to apply consistently and may result in disproportionate representation of many segmented areas. This may off-set any sensitivity (ability to determine statistical differences) gained by having additional data points for analysis.

Reliance upon evaluating segmented buccal surface areas raises concerns about accurate determination and repeatability of horizontal and vertical segment mapping, evaluator scoring consistency, score duplication or overlap between segments, inclusion of small incisor and premolar cusps in vertical segments, change in scoring sensitivity based on scoring segments, and accuracy of segmented scoring to indicate actual differences between groups.

Horizontal buccal surface area assessment may show decreased plaque and calculus accumulation of the occlusal half based on mechanical dental substrate removal, however the occlusal aspect is less relevant to periodontal health. Segmented combination scores have been used in long-term trials that include disease criteria, which help to establish clinical relevance.[31,32] As noted previously, one study evaluating stain in dogs found that increased sensitivity resulted from indices that combined, in a single observation, both thickness and extent of coverage compared with a multiplied (*thickness x coverage*) score.[2] A study of calculus accumulation in dogs showed increased sensitivity when a segmented, multiplied (*thickness x coverage*) score was used compared with a segmented coverage index only.[8] Although correlation of decreased gingivitis with reduced plaque and calculus deposition has been shown in dogs on a long-term basis, no correlations with periodontitis have been reported except in studies comparing water with chlorhexidine.[31,33,34] Sensitivity of whole tooth scores compared with horizontal or vertical segmented tooth scores has not been reported in dogs and cats. Clinical significance of differences identified by using these segmented indices has yet to be fully established.[35] Segmented evaluation may be beneficial if it increases scoring sensitivity that can be accurately correlated with gingival health.

The clinical significance of plaque is that its accumulation at the gingival margin causes inflammation. One long-standing and commonly used plaque index in human and veterinary trials concentrates on the extent of coverage around the gingival margin.[19] An early, human plaque coverage index included only the gingival halves of the crowns.[1] In humans, the natural shape of the tooth provides similar buccal surface areas for the occlusal and gingival horizontal segments. The results reported here support this observation with the gingival horizontal buccal surface area comprising 50.2 % of the total mean buccal surface area. Dogs and cats do not have similar occlusal and gingival buccal surface area distribution as documented in this study. Therefore, equal weighting when scoring occlusal and gingival horizontal segments may be misleading. The most extreme example is that the gingival segment of the mandibular first molar (a large, wide and functionally important tooth in the dog) contributes the same weight to the mean mouth score as the occlusal segment of the maxillary third premolar tooth. The occlusal segment of the maxillary third premolar tooth is only 11 % of the buccal surface area of the gingival segment of the mandibular first molar tooth and is well away from the gingival margin. Plaque and calculus accumulate more rapidly at the gingival margin than on the occlusal aspect of teeth in dogs.[12] The likely result of equal weighting of scores of occlusal and gingival horizontal segments in dogs and cats is that the mean mouth score will under-represent the extent of plaque accumulation present at the gingival margin, but may enhance statistical analysis. Such equal emphasis may provide more data at the expense of clinical relevancy.

Division into vertical 1/3 segments was used in a study of mouth-washes in humans[18] and has been used extensively in dogs and cats.[8,21,22,24-26,28,32] The possible differential effect on mesial and distal (*i.e.* closer to interdental) segments compared with the mid-buccal area has been stated as justification for this method in human tooth-brushing trials.[2] As reported here, aggregate mesial, middle, and distal buccal surface areas of dogs (30.8 %, 39.9 %, 29.3 %), cats (29.2 %, 41.4 %, 29.4 %), and humans (32.6 %, 38.1 %, 29.3 %) are similar. However, variation among individual teeth is greater in the dog and cat compared with human teeth, and the interdental spaces are less likely to be closed triangles. The effect of overlapping teeth (*e.g.* brachygnathic dogs and cats) on ability to score individual teeth has not been studied. Although validation of vertical segmentation in dogs is mentioned in one description of periodontal assessment indices[7], reports that provide data and analysis that segmentation itself is valid or increases sensitivity in dogs or cats could not be identified.

This study suggests that canine and feline teeth are irregular and the coronal surfaces differ more in width, height, and area compared with human teeth. Human teeth have generally bell-shaped buccal surfaces with a single cusp or approximately symmetrical cusps of even height whereas some canine and feline teeth have multiple, non-symmetrical cusps (Fig. 1). As a result, guidelines for occlusal and vertical buccal surface area segments do not line up with specific cusps or grooves on multi-cusped teeth in dogs and cats (Figs. 2 and 3).

The maxillary fourth premolar and first molar teeth in dogs are wide and prone to the accumulation of dental substrates compared with other teeth.[12,36] When comparing the smallest and largest teeth in the species reported in this study, the smallest tooth had 11.0 %, 17.0 %, and 61.0 % of the coronal buccal surface area of the largest tooth in dogs, cats, and humans, respectively. The buccal surface area of teeth varied more in dogs than in cats, and there was substantially more variation compared with humans. All cat teeth were smaller than the smallest dog or human model tooth. The smallest coronal buccal surface area measurement was 12.8 mm^2, 49.0 mm^2, and 40.6 mm^2 in cats, dogs, and human models, respectively. Since the mean mouth score system currently in general use gives equal weight to the scores for each tooth, the contribution of larger, wider teeth may be under-represented. Since periodontal disease develops as a result of accumulation of plaque at the gingival margin and in the gingival sulcus,[5,6] it might be appropriate to factor in the contribution of individual teeth to total gingival width when using methodology that employs the mean mouth score for different indices. Based on the maximum crown width data reported here, the equation for a mean mouth score incorporating weighting factors for crown width would be:

Dog: maxillary [I3 x 0.06] + [C x 0.09]* + [P3 x 0.10] + [P4 x 0.16] + [M1 x 0.11] plus mandibular [C x 0.09] + [P3 x 0.09] + [P4 x 0.11] + [M1 x 0.20].

Cat: maxillary [C x 0.10] + [P3 x 0.13] + [P4 x 0.21] plus mandibular [C x 0.10] + [P3 x 0.12] + [P4 x 0.15] + [M1 x 0.16].

* [C x 0.09] = canine tooth score x weighting factor (tooth width ÷ total width of scored teeth).

Body weight and skeletal size, occlusal pattern, and product usage are other factors that should be considered when designing periodontal research studies. The height of the mandibular first molar tooth in dogs relative to mandibular height is inversely proportional to body weight.[37] There are no data available examining variability of crown width or area of specific teeth relative to body weight in dogs or cats. Although most reported studies were done on dogs with medium- or large-sized heads, plaque and calculus scoring studies showing a statistical difference between oral hygiene groups in small and toy breed dogs have been reported.[21,22] However, a previous report indicated that changes in gingival sulcus fluid measurements, as an indicator of gingival inflammation, were the same in both large and small dogs following the same diet changes.[38] It is not known whether the equation for a mean mouth scoring system based on crown width factors for medium skulled dogs would be appropriate for small and toy breed dogs. In trials examining calculus in dogs, there is a pronounced difference in results for specific teeth if the calculus retarding agent is mechanical (*i.e.* associated with chewing behavior), and less so if the agent is chemical.[39] The occlusal pattern and the pattern of periodontal disease in the species under consideration, especially when considering the type of product being evaluated, should have a bearing on which teeth are selected for evaluation.

One reason given for use of segmentation is that it permits study of the effects of the product's proposed mechanism of action.[17] Reported segmentation studies in dogs and cats use horizontal division for plaque and vertical division for calculus, often in the same study.[21,22,24-26,28,32] A consistent segmentation protocol for both plaque and calculus with each segment including part of the gingival margin would allow direct examination of associations between these dental substrates and their impact on gingival health.

In conclusion, scoring systems that use segments should describe in detail the segmentation system, or refer to a more detailed description than is currently available.[7] Further, in the absence of studies that show that increased statistical sensitivity results from segmentation, and that demonstrate the relevance of this increased statistical sensitivity to plaque-induced gingivitis or periodontitis in dogs and cats, segmentation should not be used. As the merits of plaque and calculus scoring methodology are debated, it is important not to lose track of the major concern in dental trials: the key to accurately representing what happens in the mouth is a fully-reported, randomized, blinded study, using a valid and ethical study design conducted by trained and calibrated graders. Use of these principles in repeated trials of the same hypothesis would result in the same conclusion.

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[a] Sigma Scan Pro, version 4.01, SPSS Inc., Chicago, IL (www.spss.com)

† Author Disclaimer: This paper is not written on behalf of the Veterinary Oral Health Council (VOHC®), and any recommendations made in this paper are not VOHC® policy.

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References

1 Shick RA, Ash MM. Evaluation of the vertical method of tooth brushing. *J Periodontal* 1961; 32: 356-353.

2. Schemehorn BR, McDonald JL, Stookey GK. Use of the beagle dog as a dental stain model. *J Dent Res* 1982; 61: 1028-1030.

3. Turesky SD, Gilmore ND, Glickman I. Reduced plaque formation by the chloromethyl analogue of victamine C. *J Periodontol* 1970; 41:41-43.

4. Quigley GA, Hein JW. Comparative cleansing efficiency of manual and power brushing. *J Am Dent Assoc* 1962; 65: 26-29.

5. Lindhe J, Hamp Se, Loe H. Experimental periodontitis in the beagle dog. *J Perio Res* 1973; 8: 1-10.

6. Lindhe J, Hamp SE, Loe H. Plaque-induced periodontal disease in beagle dogs. *J Perio Res* 1975; 10: 243-255.

7. Logan EI, Boyce EN. Oral health assessment in dogs: parameters and methods. *J Vet Dent* 1994; 11: 58-63.

8. Warrick J, Gorrel C. A more objective method of scoring calculus. *Proceedings of the 5th World Veterinary Dental Congress.* Birmingham:England, 1997: 40-42.

9. Berkowitz BKB, Holland GR, Moxham BJ. *Color atlas and textbook of oral anatomy.* Year Book Medical Publishers, 1978.

10. Woeful JB. Measurements of 4572 human teeth; 1979. Quoted in Woeful JB, Scheid RC. *Dental anatomy: its relevance to disease.* Williams and Wilkins: Baltimore, 1997.

11. Kaplan ML, Davis MA, Aschaffenburg PH, et al. Clinical radiographic and scintigraphic findings in experimental periodontal disease in dogs. *Arch Oral Biol* 1978; 23: 273-280.

12. Rosenburg HM, Rehfeld CE, Emmering TE. A method for the epidemiologic assessment of periodontal health-disease state in a beagle hound colony. *J Periodontol* 1966; 37: 208-213.

13. Saxe SR, Greene JC, Bohannan HM, et al. Oral debris, calculus and periodontal disease in the beagle dog. *Periodontics* 1967; 5: 217-225.

14. Leonard GH, Witt JJ, Underwood RA. The enhancement of chlorhexidine stain in dogs. Int Assoc Dent Res Program Abst 1980; 58: 27.

15. Stookey GK, Warrick JM, Miller LL, et al. Hexametaphosphate-coated snack biscuits significantly reduce calculus formation in dogs. *J Vet Dent* 1996: 13; 27-30.

16. Lage A, Lausen N, Tracy R, et al. Effect of chewing rawhide and cereal biscuit on removal of calculus in dogs. *J Am Vet Med Assoc* 1990; 213-219.

17. Hefferren JJ, Schiff TJ, Smith MR. Assessment methods and clinical outcomes. Chemical and microbial composition, formation and maturation dynamics of pellicle, plaque and calculus. *J Vet Dent* 1994; 11: 75-79.

18. Shaver,KJ, Schiff T. Oral clinical functionality of enzyme AP used as a mouthwash. *J Periodontal* 1970; 41: 333-336.

19. Silness J, Loe H. Periodontal disease in pregnancy. II Correlation between oral hygiene and periodontal condition. *Acto Odont Scand* 1964; 22: 121-135.

20. Hennet P. Review of studies assessing plaque accumulation and gingival inflammation in dogs. *J Vet Dent* 1999;16: 23-29.

21. Rawlings JM, Gorrel C, Markwell PJ. Effect on canine oral health of adding chlorhexidine to a dental hygiene chew. *J Vet Dent* 1998; 15: 129-134.

22. Gorrel C, Rawlings JM. The role of tooth brushing and diet in the maintenance of periodontal health in dogs. *J Vet Dent* 1996;13:139-143.

23. Jensen L, Logan E, Finney O. Reduction in accumulation of plaque, stain, and calculus in dogs by dietary means. *J Vet Dent* 1995; 12: 161-164.

24. Rawlings JM, Gorrel C, Markwell PI. Effect of two dietary regimens on gingivitis in the dog. *J Small Anim Pract* 1997; 38: 147-151.

25. Gorrel C, Rawlings JM. The role of a dental hygiene chew in maintaining periodontal health in dogs. *J Vet Dent* 1996; 13: 31-34.

26. Gorrel C, Warwick J, Bierer TL. Effect of a new dental hygiene chew on periodontal health in dogs. *J Vet Dent* 1999; 16: 77-81.

27. Boyce EN. Feline experimental models for control of periodontal disease. *Vet Clin Nor Am Small Anim Pract* 1992; 22:1309-1322.

28. Gorrel C, Inskeep G, Inskeep T. Benefits of a dental hygiene chew on the periodontal health of cats. *J Vet Dent* 1998; 15: 135-138.

29. Logan EI. Oral cleansing by dietary means: feline methodology and study results. *Proceedings Conference Companion Animal Oral Health,* University of Kansas, March, 1996: 31-34.

30. Boyce EN, Logan EI. Oral health assessment in dogs: study design and results. *J Vet Dent* 1994; 11: 64-70.

31. Logan EI. Oral cleansing by dietary means: results of six-month studies. *Proceedings Conference Companion Animal Oral Health,* University of Kansas, March, 1996: 11-15.

32. Gorrel C, Bierer TL: Long-term effects of a dental hygiene chew on the periodontal health of dogs. *J Vet Dent* 1999;16: 109-113.

33. Briner WW, Gibberman BP, Leonard GJ, et al. Effect of chlorhexidine on plaque, gingivitis and alveolar bone loss in beagle dogs after seven years of treatment. *J Perio Res* 1980; 15: 390-394.

34. Tepe JH, Leonard GJ, Singer RE, Gray JJ, Gibberman BP, Mulvihill JE: Long-term effect of chlorhexidine on plaque, gingivitis, sulcus depth, gingival recession and loss of attachment in beagle dogs. *J Perio Res* 1983; 18: 452-458.

35. Hujoel PP, Armitage GC, Garcia RI. A perspective on clinical significance. *J Periodontol 2000*; 71: 1515-1518.

36. Harvey CE, Shofer F, Laster L. Association of age and body weight with periodontal disease in North American dogs. *J Vet Dent* 1994; 11:94-105.

37. Gioso M, Shofer F, Barros PSM, et al. Mandible and mandibular first molar tooth measurements in dogs: relationship of radiographic height to body weight. *J Vet Dent* 2001;18: 65-68.

38. Egelberg J: Local effect of diet on plaque formation and development of gingivitis in dogs. I: Effect of hard and soft diets. *Odontologisk Revy* 1965; 16: 31-41.

39. Ewing TH, Warrick JM, Kantmann CL, et al. Effect of tooth selection on results obtained with a clinical calculus index in dogs. *Proceedings of the 2000 Veterinary Dental Forum,* 2000; 115-118.