Pulp cavity-tooth width ratios from known-age and wild-caught coyotes determined by radiography

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Abstract Although the relative sizes of pulp cavities in teeth are used frequently to identify various age classes of carnivores, validation of the technique has received little attention. We measured the pulp cavities and tooth widths based on radiographs of canine and premolar teeth from a large sample of known-age, pen-reared coyotes (*Canis latrans*) and from samples of wild-caught coyotes of unknown age. The ratio of pulp cavity to tooth width decreased rapidly through the first year of life. Although canine tooth ratios of juvenile, yearling, and adult coyotes differed, variations within yearling and adult groups precluded accurate assignment of individual coyotes to other than juvenile and mature age categories. A value of 0.45 in this ratio appeared to reasonably delineate the 2 groups among wild coyotes from northern Utah between November and February. Pulp cavity–tooth width ratios of upper canines and premolars were larger than ratios from lower canines and premolars from the same coyotes. Females had slightly smaller tooth ratios than males of the same age.

Key words age determination, *Canis latrans*, coyote, known age, pulp cavity, radiography

A reduction in the relative size of the pulp cavity of canine teeth associated with increasing age has been reported for red foxes (*Vulpes vulpes*, Churcher 1960, Grue and Jensen 1973, Simon and Frydendall 1981), coyotes (*Canis latrans*, Knudsen 1976), bobcats (*Lynx rufus*, Mahan 1979), and other species. Churcher (1960) used radiographs to determine relative pulp cavity size in red fox teeth. The technique was used subsequently with other carnivores, including arctic foxes (*Alopex lagopus*, Grue and Jensen 1976, Bradley et al. 1981,), gray foxes (*Urocyon cinereoargenteus*, Tumlison and McDaniel 1984), fishers (*Martes pennanti*, Kuehn and Berg 1981, Jenks et al. 1984, 1986), otters (*Lutra canadensis*, Kuehn and Berg 1983), martens (*M. americana*, Dix and Strickland 1986*a*, Nagorsen et al. 1988), badgers (*Taxidea taxus*) and striped skunks (*Mephitis mephitis*, Frederickson 1983), European badgers (*Meles meles*, Graf and Wandeler 1982), and bobcats (Johnson et al. 1981), but it has not been reported for coyotes.

Utility of pulp cavity-tooth width ratios to assess relative ages of animals, as well as use of radiographic techniques to determine such ratios, has generally been "validated" by using specimens that were assigned ages based on other physical attributes associated with changes in age (e.g., cementum annuli) but seldom from characteristics of animals of known age. Most reports suggest that juvenile animals can be readily distinguished from older animals, but authors disagree about whether additional age classes can be identified realistically. Although differences in relative pulp cavity size among several older age classes can be demon-

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strated statistically (Jenks et al. 1984), assignment of individual animals among older age groupings cannot be made with certainty because pulp cavity ratios are not exclusive among age groups (Dix and Strickland 1986*b*, Nagorsen 1988).

We examined tooth specimens from a colony of captive coyotes of known age and evaluated pulp cavity-tooth width ratios as an indicator of relative age, as well as using radiographic techniques to describe these tooth characteristics. Carcasses acquired from local fur trappers permitted comparisons between captive and wild coyotes.

Methods

We had access to skulls from coyotes that had been reared in captivity at a research facility near Millville, Utah. Because the month and year of birth and death of each coyote was available from records maintained at the facility, we calculated the age, in months, of each coyote in our sample. When possible, we extracted an upper and a lower canine tooth as well as an upper and a lower first premolar tooth from each skull. Sample sizes within tooth types varied, but collectively the coyotes within our sample ranged from 8 to 118 months of age. We selected left upper and lower canines or premolars when available. A few other premolars were surgically extracted from live, captive individuals that had been anesthetized (intramuscular injection of a mixture of 100 mg ketamine hydrochloride and 1.0 mg acepromazine), including juveniles (0-11 months), yearlings (12-23 months), and adults (>24 months). We used canines (mostly lower but including an undetermined number of upper) from 697 wild coyotes of unknown age captured by fur trappers in northern Utah and southern Idaho between November 1978 and February 1981 to compare tooth characteristics between wild and captive coyotes.

We glued extracted teeth to 20 × 25-cm posterboard cards (33 teeth/card) and had radiographs made at Logan Regional Hospital in Logan, Utah, using Kodak Min-R film. Exposures were made at 100 cm using a 2.5-mm aluminum filter and settings of 50 ma at a 50-kv peak for 0.2 sec.

We standardized measurements of each canine by drawing lines on the radiograph perpendicular to the concave surface of each tooth 15 mm from the tip of the root (Figure 1). We standardized measurements of premolars by drawing a line 3.0 mm below, and parallel to, the gum line on the tooth. In each case we measured tooth and pulp cavity widths along these lines to the nearest 0.05 mm with dial calipers.

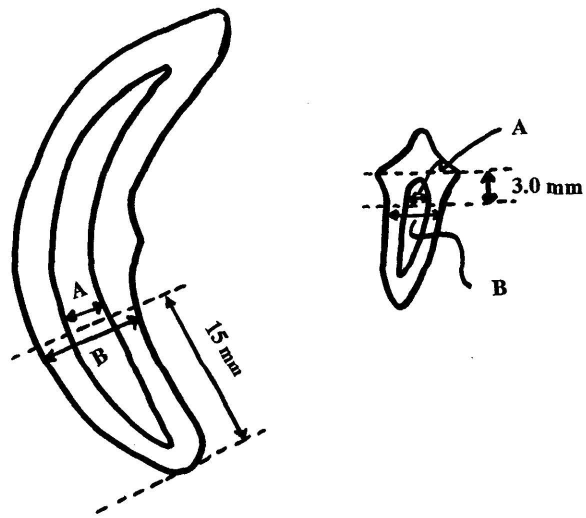

Figure 1. Pulp cavity (A) and tooth width (B) measurement locations for canine and premolar coyote teeth. Standardized measurements of canines were achieved by drawing a line on the radiograph perpendicular to the concave surface of the tooth 15 mm from the tip of the root. Premolar measurements were standardized by drawing a line 3.0 mm below, but parallel to, the gum line of the tooth.

We calculated ratios of pulp cavity to tooth width for upper and lower canines and premolars. We conducted analyses of upper and lower premolars and canines separately because preliminary analyses suggested they were not similar. We used a *t*-test to determine whether canine tooth ratios of yearling and adults differed significantly (the sample of canine teeth available from known-age juveniles was inadequate for statistical testing) and a one-way ANOVA and Least Significant Difference tests to determine whether premolar ratios differed among the 3 age classes. We used one-way ANOVA for paired comparisons of pulp cavity-tooth width ratios between upper and lower canines and upper and lower premolars, as well as teeth from male and female coyotes. We used computer program CurveExpert 1.3 (Hyams 1997) to fit nonlinear regression equations to data sets for upper and lower canines and premolars.

We categorized canine teeth from wild-caught coyotes by month of capture (Nov-Feb) for each of 3 consecutive years with the aggregate sample sizes/month ranging from 54 to 363 ($\bar{x}$=174) and then calculated the percentage frequency distributions of pulp cavity-tooth width ratios as unweighted means for each of the 4 months.

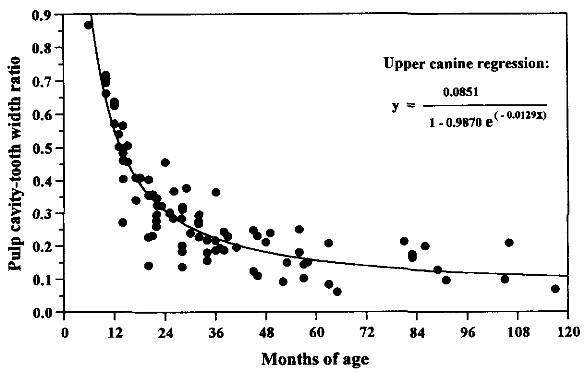

Figure 2. Pulp cavity–tooth width ratios determined from radiographs of upper canine teeth from 87 captive coyotes of known age, along with a calculated curvilinear regression.

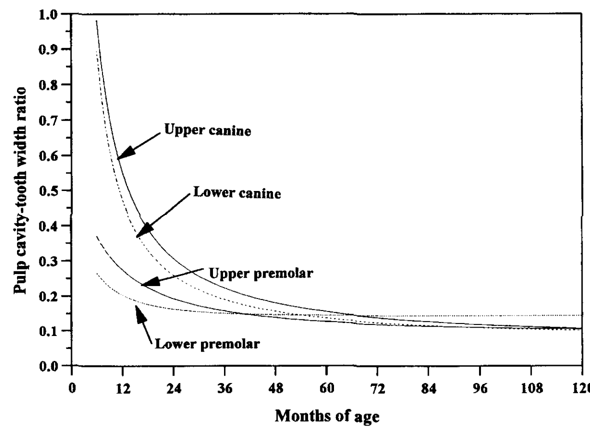

Figure 3. Comparison of nonlinear regressions (model: $y = a / (1 - b\, e^{(-cx)})$ of pulp cavity–tooth width ratios from coyotes of known age (months) for upper canines (n=87, r^2=0.86), lower canines (n=45, r^2=0.81), upper premolars (n=103, r^2=0.66), and lower premolars (n=104, r^2=0.36).

Results

Pulp cavity-tooth width ratios among adults were smaller ($P<0.01$) than those of yearlings for upper ($t_{78}=8.11$) and lower ($t_{43}=8.35$) canines (Table 1). Overall, premolar ratios differed ($P<0.01$) among age classes for upper ($F_{2,\,102}=63.83$) and lower ($F_{2,\,102}=22.70$) premolars (Table 1). However, while each individual comparison among juvenile, yearling, and adult age classes for upper premolar ratios differed ($P<0.01$), for lower premolars, only juveniles differed ($P<0.01$) from the 2 other age classes. Ratios among lower premolars were larger ($P<0.10$) among yearlings than adults.

Inspection of tooth measurement ratios from upper canines indicated a rapid reduction in the pulp cavity-tooth width ratio during the first year of life, with a marked reduction in subsequent annual decrements (Figure 2). Ambiguity in ratios among age classes of coyotes exceeding one year of age was apparent. The regression equations we calculated for the ratios of upper and lower canines, as well as upper and lower premolars (Figure 3, Table 2), suggest that ratios for mandibular teeth were smaller than comparable teeth in the maxilla for coyotes of similar age. We corroborated this interpretation by paired comparisons of ratios among coyotes for which teeth from upper and lower jaws were measured. Among 36 coyotes from 12 to 83 months old for which both upper and lower canines were measured, upper canine ratios were larger ($t_{34}=6.96$, $P<0.001$) than lower canine ratios. Among 41 coyotes for which both upper and lower premolars were measured, ratios from upper premolars were larger ($t_{39}=4.76$, $P<0.001$) than ratios from lower premolars. Among 11 coyotes of each sex of the same age (month), our data suggest that upper canine tooth ratios may be larger among males than females ($t_9=-1.52$, $P=0.08$).

Histograms of relative pulp cavity-tooth width ratios among canine teeth for wild coyotes caught between November and February (Figure 4) revealed distinct clusters of values around the calculated regression value for lower canines (arrows) derived from captive juvenile coyotes. These clusters drift systematically toward lower ratios as the months progress from November through February, as do the regression values calculated from known-age captive coyotes (Figure 4). A more diffuse group with smaller pulp cavity-tooth width ratios is present but no distinct subgroupings were evident within the histograms. We interpret these results to indicate that the pulp cavity-tooth width ratios of captive

Table 1. Sample sizes (n), mean pulp cavity–tooth width ratios ($\bar{x}$), and standard deviations (SD) for 3 age classes of known-age coyotes.

	Juvenile			Yearling			Adult		
Tooth	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD
Upper canine				28	0.41	±0.13	52	0.21	±0.08
Lower canine				14	0.37	±0.08	31	0.18	±0.07
Upper premolar	17	0.30	±0.07	36	0.23	±0.04	51	0.15	±0.05
Lower premolar	24	0.23	±0.05	49	0.17	±0.04	31	0.16	±0.04

Table 2. Sample sizes (n), nonlinear regression coefficients (a, b, and c), and correlation coefficients (r^2) associated with the model $y=a/(1-b\,e^{(-cx)})$ calculated for pulp cavity–tooth width ratios for 4 types of teeth from captive coyotes of known age.

Tooth	n	a	b	c	r^2
Upper canine	87	0.0851	0.9870	0.0129	0.86
Lower canine	45	0.0895	0.9997	0.0175	0.81
Upper premolar	103	0.1006	0.8376	0.0230	0.66
Lower premolar	104	0.1447	0.7213	0.0755	0.36

and wild caught samples were similar, pulp cavities close rapidly during coyotes' first fall and winter, and classifying population samples via this technique should be limited to juvenile and mature categories.

Discussion

The issue of whether pulp cavity-tooth width ratios are similar between recently excised teeth and those from skulls that may have desiccated for several years should be considered. Because ratios from our wild-caught juvenile animals appear to cluster around the regression values calculated from our captive sample, we suspect this is not a major concern. An appropriate study of such affects may be warranted. Our data indicate that increased precision might be gained by rigidly adhering to separate analyses for upper and lower teeth, as well as among males and females, but we suspect any such advantage will likely be meager and masked by the inherent variability of pulp cavity-tooth width ratios among coyotes of the same age.

Our results corroborate interpretations of other investigators who report that tooth pulp cavity sizes of canine and premolar teeth become progressively smaller with age. Decrements in pulp cavity size also become progressively smaller with increasing age. Although the mean pulp cavity-tooth width ratios among yearling and adult coyotes were different, variation within each group precludes accurate assignment of year class among coyotes in these age groups. Working with radiographs of canine teeth is easier than premolars, and correlation coefficients between age and relative pulp cavity size are substantially greater. Although increased precision can possibly be attained by working separately with teeth from upper or lower jaws, we concur with the interpretations of Dix and Strickland (1986b) and discourage use of relative pulp cavity size to classify coyotes into more than juvenile and mature categories. Based on the percentage frequency histograms of pulp cavity-tooth width ratios of wild-caught coyotes from northern Utah and southern Idaho (Figure 4), we think a pulp cavity-tooth width ratio of 0.45, measured 15 mm from the tip of the root of the canine teeth, seems to reasonably discriminate between juvenile and mature coyotes between November and February. Pulp cavity-tooth width ratios from known-age coyotes are generally supportive of this interpretation.

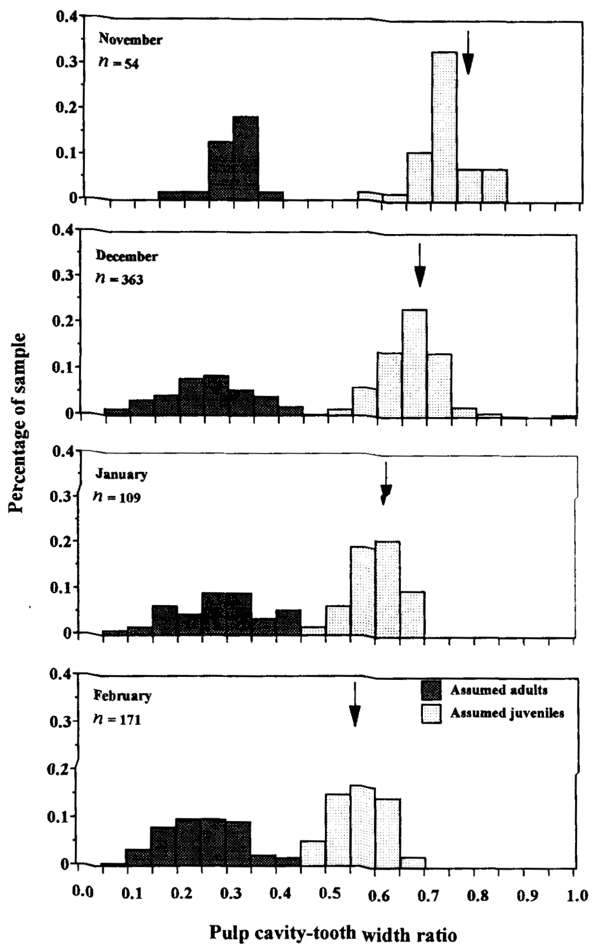

Figure 4. Percentage frequency histograms, by month, of the pulp cavity–tooth width ratios of 697 lower canine teeth from wild coyotes captured in northern Utah and southern Idaho between November and February. Assuming a 15 April mean whelping date, the 7–10 month nonlinear regression values for pulp cavity–tooth width ratios of lower canine teeth from known-age captive coyotes (Figure 3) are represented by arrow.

We also suggest that juvenile and mature categories of coyotes can be assessed as accurately by visual inspection of radiographs as by measurements and calculations. Among 697 teeth from wild-caught coyotes for which age was determined by both procedures, we noted only 7 discrepancies. In these instances, we were more confident of the classifications by visual inspection than measured variables because the former integrates characteristics along the entire length of the pulp cavity and was less subject to abnormal characteristics at a single specific measuring location. Personnel unfamiliar with interpretation of relative pulp cavity characteristics are advised to examine samples collected early in the collection period when differences are more striking, in order to become familiar with characteristics of juvenile and adult animals.

Including upper and lower canines within our sample of wild-caught coyotes undoubtedly reduced precision in the resulting pulp cavity-tooth width ratio histograms (Figure 4). Unfortunately, we were unable to segregate the 2 during our analyses. We concur with most other published reports in concluding that relative pulp cavity- tooth width ratio, as determined radiographically, is a relatively inexpensive and useful technique to assess the proportion of juveniles among coyote population samples. Perhaps the greatest advantage to radiographic analyses of pulp cavity-tooth widths ratios is in providing an inexpensive method to identify and exclude juveniles from samples intended for more time-consuming and expensive techniques of assessing age, such as tooth sectioning to determine number of cementum annuli.

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Literature cited

Bradley, J. A., D. Secord, and L. Prins. 1981. Age determination in the arctic fox (*Alopex lagopus*). Canadian Journal of Zoology 59: 1976–1979.

Churcher, C. S. 1960. Cranial variation in the North American red fox. Journal of Mammalogy 41: 349–360.

Dix, L. M., and M. A. Strickland. 1986*a*. Use of tooth radiographs to classify martens by sex and age. Wildlife Society Bulletin 14: 275–279.

Dix, L. M., and M. A. Strickland. 1986*b*. Sex and age determination for fisher using radiographs of canine teeth: a critique. Journal of Wildlife Management 50: 275–276.

Frederickson, L. F. 1983. Use of radiographs to age badger and striped skunk. Wildlife Society Bulletin 11: 297–299.

Graf, M., and A. I. Wandeler. 1982. Age determination in badgers (*Meles meles* L.) Review of Suisse Zoology 89: 1017–1023.

Grue, H., and B. Jensen. 1973. Annular structures in canine tooth cementum in red foxes (*Vulpes fulva* L.) of known age. Danish Review of Game Biology 8: 1–12.

Grue, H., and B. Jensen. 1976. Annual cementum structures in canine teeth in arctic foxes (*Alopex lagopus* L.) from Greenland and Denmark. Danish Review of Game Biology 10: 1–12.

Hyams, D. 1997. CurveExpert 1.34: A comprehensive curve fitting system for Windows. Shareware. Starkville, Mississippi. Http://www.ebicom.net/~dhyams/cvxpt.htm.

Jenks, J. A., R. T. Bowyer, and A. G. Clark. 1984. Sex and age-class determination for fisher using radiographs of canine teeth. Journal of Wildlife Management 48: 626–627.

Jenks, J. A., A. G. Clark, and R. T. Bowyer. 1986. Sex and age determination for fisher using radiographs of canine teeth: a response. Journal of Wildlife Management 50: 277–278.

Johnson, N. F., B. A. Brown, and J. C. Bosomworth. 1981. Age and sex characteristics of bobcat canines and their use in population assessment. Wildlife Society Bulletin 9: 203–206.

Knudsen, J. 1976. Demographic analysis of a Utah-Idaho coyote population. Thesis, Utah State University, Logan, USA.

Kuehn, D. W., and W. E. Berg. 1981. Use of radiographs to identify age-classes of fisher. Journal of Wildlife Management 45: 1009–1010.

Kuehn, D. W., and W. E. Berg. 1983. Use of radiographs to age otters. Wildlife Society Bulletin 11: 68–70.

Mahan, C. J. 1979. Age determination of bobcats (*Lynx rufus*) by means of canine pulp cavity ratios. Pages 126–129 *in* Blum and Escherich, Conference organizers. Bobcat Research Conference Proceedings: Current Research on Biology and Management of Lynx rufus. National Wildlife Federation, 16–18 October 1979, Science and Technical Series 6, Front Royal, Virginia, USA.

Nagorsen, D. W., J. Forsberg, and G. R. Giannico. 1988. An evaluation of canine radiographs for sexing and aging pacific coast martens. Wildlife Society Bulletin 16: 421–426.

Simon, D. E., and M. J. Frydendall. 1981. Age study of Minnesota red fox using cementum annulae counts and tooth x-rays. Journal of the Minnesota Academy of Science 46: 2–5.

Tumlinson, R., and V. R. McDaniel. 1984. Gray fox age classification by canine tooth pulp cavity radiographs. Journal of Wildlife Management 48: 228–230.

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