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PERIODONTAL AND DENTAL LESIONS IN RACCOONS FROM A FARMING AND A RECREATIONAL AREA IN ILLINOIS

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ABSTRACT: Dental health was evaluated in two populations of raccoons (*Procyon lotor*) in western Illinois (USA); one was from a rural agricultural area with low human density and the other from a nearby state park heavily used by humans and raccoons. From 1989 through 1993, 300 raccoons were live-trapped in the agricultural area and 246 raccoons were live-trapped in the park. Oral health was assessed using gingival and calculi indices and by measuring loss of attachment and tooth wear. Raccoons from the park were significantly older and smaller, but not thinner, than raccoons from the farmed area. Gingival and periodontal indices, tooth wear, tooth loss, and caries increased significantly from juveniles to yearlings to adults, at both sites. Males had higher levels of gingivitis and loss of periodontal attachment than females, but were similar on other dental measures. There were no seasonal differences between raccoons in dental indices. Animals with high scores for one oral measure tended to have high values for all indices. Dental health was generally good for juveniles and yearlings from both sites. Among adults, periodontal indices and the prevalence of caries were significantly higher in the park, but prevalence of broken or missing teeth was similar for both populations. There was no association between body condition, and a higher dental score or more missing or broken teeth.

Key words: Dental health, peridontal disease, *Procyon lotor*, raccoon, teeth, veterinary dentistry.

INTRODUCTION

The raccoon (*Procyon lotor*) is widely distributed throughout North America (Kaufmann, 1982) and also has been introduced into Europe (Fatullaevich-Aliev and Sanderson, 1966). The natural diet of this opportunistic omnivore includes plant material, crayfish, and insects, but raccoons also have adapted to human environments and food sources (Hoffmeister, 1989). For example, suburban raccoons will utilize human garbage even when a traditionally preferred food source, such as corn, is closer to their denning areas (Slate, 1985).

Increased levels of dental disease, in a variety of animal species, have been attributed to human-associated diets. Dental caries and periodontal disease were both more prevalent in captive primates and other mammals than in their wild counterparts of similar ages (Robinson, 1979). Increased dental disease in wild chimpanzees (*Pan troglodytes*) was associated with use of farm crops and refuse heaps (Jones and Cave, 1960). Prevalence of periodontal disease and caries in bears (*Ursus americanus*) varied between study areas (Manville, 1992). Dental disease has been related to factors such as age, hygiene, general nutrition, specific dietary imbalances and food consistency (Vosburgh et al., 1982; Hamp et al., 1984). No one has compared effects among adjacent wild populations differing in levels of exposure to human food refuse.

As part of a study of raccoon ecology and health in western Illinois (USA), dental disease was evaluated in two raccoon populations; one from a rural agricultural area with limited availability of human food and garbage, and the other from a nearby state recreational area offering raccoons much greater access to human-associated foods. Our objectives were to compare raccoon dental health between these two populations and to assess relationships between the presence of gingival, dental and periodontal lesions, and raccoon age, sex, and body size.

MATERIALS AND METHODS

Noncontiguous sites with close geographic proximity were selected to minimize potential differences in raccoon populations, such as genetics, climate or ecological parameters, not related to human activities. The rural agricultural study site was a 2,310 ha forested and extensively farmed area (AG; 39°57′N, 90°53′W) with 59% row crops, 15% pasture/forage and 25% shrub forest. Minimum raccoon density was estimated to be 4.5 raccoons/km^2 (Nixon et al., 1994). Cattle, horses, swine, and sheep were grazed within the study area. Raccoons had year-round, unrestricted access to livestock feeds, garbage from individual farm households, and other trash piles. The public recreation area was a nearby 644 ha state park (SP; 39°53′N, 90°56′W) with a substantial raccoon and nuisance raccoon population, estimated to be at least 13.5 raccoons/km^2 (Nixon et al., 1994). Land cover was 75% oak-hickory forest, 6% row crops and 11% pasture/forage. Public attendance at this park was approximately 205,000 visits per year, almost entirely from late spring through early fall. During times of heavy use, the contact potential between raccoons and campers was great, with reports of raccoons eating garbage from bags and cans, food left on picnic tables, in tents or in trailers and accepting food from campers' hands. Raccoons also chewed on coolers and opened containers that were not strapped shut (L. Hungerford, unpubl. data). Raccoons in the park had access to abundant human food wastes, spring-to-fall, but not during other months.

Raccoons were live-trapped using box traps constructed of wood and hardware cloth (29.2 cm × 36.4 cm × 81.3 cm). Both study sites were sampled during the spring (March to June) and fall (August to October) from 1989 through 1993. Each animal was weighed and sedated with tiletamine+zolazepam (Telazol®, Fort Dodge Laboratories, Inc., Fort Dodge, Iowa, USA) given intramuscularly at 5 mg/kg, measured and given a thorough physical examination. The oral cavity was examined and photographed. A premolar was extracted from animals ≥1-yr-old to determine age based on tooth cementum annuli (Grau et al., 1970). Numbered, rotatable ear tags were placed as permanent identification and some animals received radio collars (Advanced Telemetry Systems, Isanti, Minnesota, USA). Following recovery from sedation in a dark, quiet area, raccoons were released at the site of capture.

Five measures were used to assess oral health (Table 1). All were modified from measures developed for human and domestic animal dental epidemiology (Spolsky, 1990). Gingival Index (GI) was used to score the redness and friability of the gingiva (Table 1). Calculi Index (CI) was used to grade the amount of calculus on the teeth. Tooth wear (TW) was categorized as light, moderate or severe in each animal. Attachment Loss (AL) was a measure

TABLE 1. Measures used to evaluate dental health in raccoons from Illinois.

Measure	Scales and definitions
Gingival index (GI)	0 = Normal 1 = Mild inflammation, characterized by slight change in color, slight edema; no bleeding on palpation. 2 = Moderate inflammation characterized by redness, edema and glazing; bleeding on palpation. 3 = Severe inflammation with marked redness, edema and ulcerations; tendency to spontaneous bleeding
Calculi index (CI)	0 = Absent 1 = Supragingival only with no or slight (≤ 1 mm) extension below the gingival margin 2 = Moderate amount of calculus on teeth with both supragingival and subgingival calculus present on at least one tooth 3 = Abundant supragingival and subgingival calculus on several teeth
Tooth wear (TW)	1 = Light with no changes or mild blunting of tooth profiles 2 = Moderate as characterized by wear present but crests of molars still evident 3 = Heavy as characterized by teeth in one or more quadrants worn close to the gingival margin
Attachment loss (AL)	Depth of periodontal pocket, measured in millimeters and averaged separately for canine teeth (CAL) and for all other teeth (AL)

of the distance, in millimeters, between the cemento-enamel junction and the bottom of the periodontal pocket between the gingiva and the tooth. Measurements were made using a Williams round single end periodontal probe (Henry Schein, Inc., Port Washington, New York, USA) and averaged for all teeth excluding the canine teeth. Canine Attachment Loss (CAL) was a measure of the average periodontal pocket depth for all canine teeth. Major injuries to the mouth, damage to or loss of teeth and presence of dental caries were separately recorded on each field sheet using a diagram of the upper and lower raccoon dentition (dental formula—$2 \times (3/3, 1/1, 4/4, 2/2) = 40$). Based on these diagrams, each animal was classified as having broken and/or missing teeth or not, as having dental caries or not and the number of affected teeth was totaled.

Animals were classified into age groups based on appearance, tooth eruption, and body weight (Nixon et al., 1994). Ages were grouped as juveniles (<1-yr-old), yearlings (≥1- but <2-yr-old), or adults (≥2-yr-old). Adults were subclassified into four age groups of similar size, based on cementum annuli (2-yr, 3-yr, 4-yr, and >4-yr). An index of body condition was computed as the ratio of the animal's actual weight to a reference weight, calculated for each animal using the relationship weight (in kg) = $80 \times (\text{length in cm})^{2.7}$ (Radinsky, 1978).

The complete database contained information on all captures for each raccoon. For raccoons captured more than once, one record was randomly selected from among those with complete dental information. Potentially confounding effects of sex, age, and size were assessed between the total AG and SP populations and between the adults in both populations. Proportions of animals in each category of GI, CI, and tooth wear and AL and CAL measurements were compared among age groups and then between sites, controlling for age. Means of dental scores were graphed. Because juveniles and many yearlings lacked complete permanent dentition, subsequent analyses included only adults. Dental scores for adults were compared between sites, controlling for age. Adults with different levels of dental lesions were compared for differences in weight, length and thinness. The proportion of animals with broken teeth and with dental caries were compared between sites and evaluated for relationships with the other dental health indices.

Analyses of population and health data were performed using a Windows-based statistical package (SAS Institute Inc., 1990, 1996). Summary data were entered into a spreadsheet for graphing (Microsoft® Excel, Microsoft Corporation, Seattle, Washington, USA). For simple comparisons, Fisher exact test (FE) was used when both dependent and independent variables were dichotomous (Zar, 1996) and a Cochran-Mantel-Haenszel test for trend (CMH) when the independent variable was ordinal (Rothman and Greenland, 1998). Logistic regression (LR) was used for other categorical data to test for differences between groups or trends controlling for confounders (Rothman and Greenland, 1998). The distributions of continuous data were tested for normality and homogeneity of variance. Analysis of variance (ANOVA) was used when assumptions were met. An ANOVA of data ranked within levels of potential confounders (rANOVA) was used in other cases (Zar, 1996). Least-square means (LSM) were calculated from multivariate analyses to estimate effect sizes (Zar, 1996). A value of $P < 0.05$ was used to establish statistical significance.

RESULTS

In the agricultural area, data were collected on 300 raccoons, of which 117 were captured in the spring and 183 in the fall. There were 176 males and 124 females composed of 105 juveniles, 97 yearlings, and 98 adults. In the recreational area, 246 raccoons were examined, of which 88 were captured in the spring and 158 in the fall. There were 102 males and 144 females composed of 69 juveniles, 60 yearlings and 117 adults.

The sex and age distributions and physical size of raccoons differed between sites. The proportion of females among captured animals was higher in the park (58% of 246) than in the farmed area (41% of 300; FE, $P < 0.01$). More adults and fewer juvenile raccoons were captured in the recreational area (CMH, $P < 0.01$) and park adults were older than those in the farmed area (rANOVA, $P < 0.001$). The oldest animal in the AG group was 6.5–yr–old while the SP sample contained 14 animals between 7 and 11.5 yr of age. There were no differences in weight, length, or body condition between adults aged 2 yr, 3 yr, 4 yr, and > 4 yr of age (rANOVA, $P > 0.10$ for each). Controlling for sex and season, adult raccoons in the recreational area weighed less (SP LSM = 5.4 kg; AG LSM = 5.8 kg; rANOVA, $P < 0.001$) and

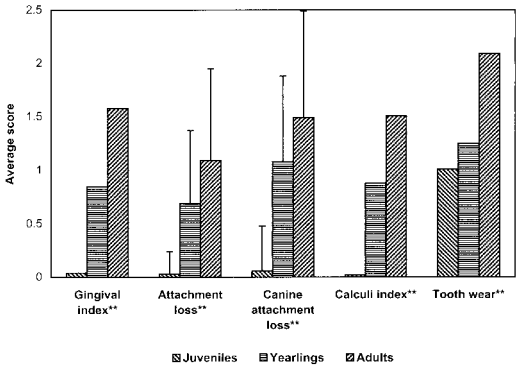

FIGURE 1. Mean scores and measurements for oral health measures of juvenile, yearling and adult raccoons from western Illinois, 1989 to 1993. ** marks age differences where $P < 0.001$.

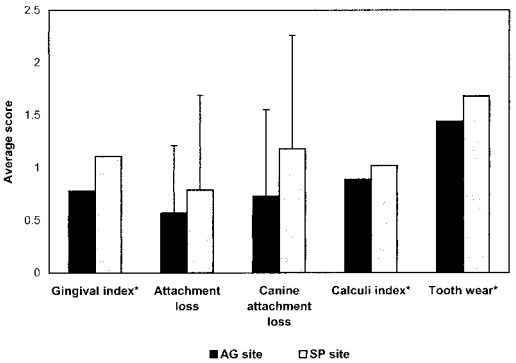

FIGURE 2. Mean scores and measurements for oral health measures of raccoons from an agricultural area (AG site) and nearby state park (SP site) in western Illinois, 1989 to 1993. * marks site differences where $P < 0.01$.

were shorter (SP LSM = 55 cm; AG LSM = 57 cm; ANOVA, $P < 0.001$) than those in the farmed area, but they did not differ significantly in body condition (SP LSM = 1.2; AG LSM = 1.2; ANOVA, $P = 0.10$).

There were significant increases in GI, CI, and TW scores as age group increased (Fig. 1; CMH, $P < 0.001$ for each). Ranked AL and CAL measurements also were higher in older age groups (rANOVA, $P < 0.001$ for each). Between sites, GI, CI, and TW were significantly different (Fig. 2; CMH, $P < 0.01$ for each), while AL and CAL were not (rANOVA, $P > 0.05$ for each). Among juveniles and yearlings, most animals were scored as normal and healthy on all these measures. There were no significant differences between sites in the dental measures for raccoons in either of these age groups. Among adults, all dental indices (GI, CI, TW, AL, and CAL) increased with age (CMH, $P < 0.01$; rANOVA, $P < 0.05$). Adult males had significantly higher GI and AL measures than females (LR, $P < 0.001$; rANOVA, $P < 0.01$), while CI, TW, and CAL did not differ between the sexes, controlling for age (grouped as 2-yr, 3-yr, 4-yr, and >4 yr of age). When adults were compared between sites, controlling for age, GI, CI, and TW were greater in the recreational area (LR, $P < 0.01$) but AL and CAL did not vary significantly (rANOVA, $P > 0.10$). Among adult raccoons, body condition increased with tooth wear (light wear LSM = 1.15; moderate wear LSM = 1.17; severe wear LSM = 1.26; rANOVA, $P < 0.001$) but body condition did not differ with other dental parameters (rANOVA, $P > 0.20$ for all), after controlling for site.

Overall, 107 (20%) of the 546 raccoons had broken or missing teeth with the number of broken or missing teeth ranging from one to 11, with a median of two. The most frequently affected teeth were the canines. Of the 546 raccoons, 12% had damage to canines alone, 3% had canines and premolars or molars affected, and 4% had only premolars or molars affected. Incisor teeth were not included in these analyses. There were no significant differences in the number of broken or missing teeth between males and females or between study sites (FE, $P > 0.15$ for each). The proportions with tooth damage increased with age group (Fig. 3; CMH, $P < 0.001$) and increased with age among adults (CMH, $P < 0.001$). There was no difference in body condition scores among adult animals with and without broken teeth (rANOVA, $P > 0.10$). The proportion of adult raccoons with broken or missing teeth increased as GI, CI, TW, AL and CAL increased (LR, $P < 0.05$ for all), controlling for age.

Dental caries was observed in only 37

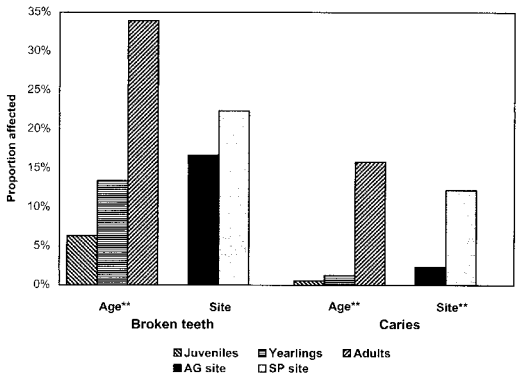

FIGURE 3. Comparison of percentage of raccoons with broken teeth and dental caries for raccoons classified by age class (juvenile, yearling and adult) and site (an agricultural area (AG) and nearby state park (SP)) in western Illinois, 1989 to 1993. ** marks age or site differences where $P < 0.001$.

FIGURE 4. Oral cavity of an adult female raccoon from the state park population in western Illinois, spring 1990. Scores for this raccoon were GI = 3, AL = 2 mm, CAL = 3 mm, CI = 3, Tooth wear = 3, with missing and fractured upper incisors, 3 broken canines, broken and missing upper premolars, gum erosion and gingival hyperplasia.

(7%) of 546 animals. The teeth primarily affected were the molars and last premolars. The number of animals with caries was similar between sexes. The proportion of raccoons with dental caries was higher in adults than yearlings or juveniles (Fig. 3; CMH, $P < 0.001$) and increased with age among adults (CMH, $P < 0.001$). There were five times more animals with caries in the recreational than the agricultural site (Fig. 3; FE, $P < 0.001$). There was no difference in body condition index between animals with and without dental caries. The proportion of animals with caries, among adults controlling for age and site, increased with GI, CI, and TW (LR, $P < 0.03$ for all), but not with AL or CAL (LR, $P > 0.20$ for each). Adult raccoons with broken teeth were four times more likely to have dental caries than those without (FE, $P < 0.001$), controlling for age and site.

DISCUSSION

Dental lesions can have varying impacts in wild populations. For most species, dental health has not been evaluated in the wild. For Darajani baboons (*Papio cynocephalus*) and Weddell's seal (*Leptonychotes weddelli*), dental pathology and tooth loss have been reported to limit adult lifespan (Robinson, 1979). A similar effect has been postulated in feral cats (Verstraete et al., 1996). Among raccoons in this study, striking dental changes (Fig. 4) and poor oral health were more prevalent in the park than in the farmed area. Yet animals in the park population lived significantly longer, despite a higher prevalence of dental problems across all age classes of adults. Raccoons with missing teeth or substantial periodontal changes were not thinner than raccoons with healthier mouths. Further, adult animals with greater tooth wear, which never reached complete loss of occlusal surfaces, showed increased rather than decreased body condition. More tooth wear in animals of similar ages can occur with harder dietary substrates (Verstraete, 1996). Oral disease and tooth wear may have less severe consequences for raccoons, which can grasp food with either teeth or paws, and can utilize a wide variety of food sources. In the park, where the population was older and where dental health was the most compromised, availability of human food refuse might have minimized effects of a decreased ability to catch and chew naturally occurring prey items.

Although adult male raccoons were not more likely to have broken teeth or caries than females, they had higher GI and AL scores. A similar sex difference has been reported in baboons (Robinson, 1979) and humans (Spolsky, 1990) but was attributed to better oral hygiene, in the later. This relationship was present in both sites and in both fall and spring captures, adjusted for age. Raccoons do not show sexual dental dimorphism, but behavioral differences do occur.

Periodontal changes may occur following tooth damage or may be an inciting factor for tooth loss. Although periodontal disease was more prevalent and severe in the park, there were no differences in the number of broken teeth between locations. Thus, we believe that the higher level of disease in the park was not due merely to physical trauma from using teeth to open cans and garbage containers. Specific nutritional deficiencies may lead to gingival and periodontal disease (Spolsky, 1990). Also, the consistency and carbohydrate composition of food (Vosburgh et al., 1982) and the presence of increased bacterial levels in decaying food (Robinson, 1979) may lead to periodontal disease in animals. Caries, which has been associated with increased oral carbohydrate fermentation in humans (Sanz et al., 1990), also was more prevalent among SP raccoons, supporting this theory.

In both populations, gingival and periodontal changes, tooth wear, tooth damage/loss and caries increased from juveniles to yearlings to adults. Among adults, tooth wear increased with age, as has been previously reported (Johnson, 1970; Kaufmann, 1982), but gingival and dental health also worsened in older animals. In humans, gingivitis peaks in puberty, then drops sharply to remain almost constant or increase slowly with age (Spolsky, 1990). Periodontal disease, in humans (Spolsky, 1990) and dogs (Hamp et al., 1984), increases in both prevalence and severity with age. Among adult bears (*Ursus americanus*), there was no relationship between periodontal disease and age; however, caries increased with age (Manville, 1992). Increases in periodontal measures and tooth loss were positively correlated among raccoons, as has also been reported for humans (Spolsky, 1990). In all but one animal, the tooth damage appeared traumatic in origin, with secondary periodontal changes. One older male in the recreational area had high scores on periodontal indices, loss of several premolars and molars and loosening of other teeth.

The unexpected differences in lengths and weights between our neighboring study sites, especially in conjunction with the similarity in relative body condition, may have also been a product of the differing access to human-associated diets. In domestic species, diminished adult body size is a recognized consequence of inadequate nutrition of young animals, while body fat reflects more recent nutritional status (Church and Pond, 1988). Intermittent access to human foods of high caloric content may have led to decreased winter growth of young animals in the park with spring/summer compensatory gains sustaining relative body mass and condition.

Human-raccoon interaction can provide an enriching experience for humans, although the potential exists for negative consequences, such as bites, zoonotic infection or property damage. Visitors to the park studied here were almost unanimously pleased with the presence of raccoons at the site. One trail was informally designated the "Raccoon Path" because visitors, especially those with children, found it a convenient place to consistently observe raccoons. But while encouraging public interest in wildlife, the benefits and consequences for wild populations, including the effect of supplemental feed sources on growth, longevity, and dental health, should be considered. Quantitative measures of oral health may be valuable tools for evaluating human-induced effects on wild populations. Further work on the nature and prevalence of oral disease in raccoons and other wild species is needed to

allow inclusion of dental health in assessment of effects of human activity.

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