1 **Oral Health Correlates of Captivity**

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ABSTRACT

The predominant diet fed to captive carnivores in North America consists of ground meat formulated to provide full nutritional requirements. However, this ground meat diet completely lacks the mechanical properties (i.e., toughness and hardness) of the foods these animals would consume in the wild. The goal of this study is to evaluate the effect of captivity on oral health by comparing the prevalence of periodontal disease and dental calculus accumulation in wild and captive lions and tigers (*Panthera leo* and *P. tigris*), and to also correlate oral health with cranial morphology in these specimens.. To achieve this, 34 adult lion and 29 adult tiger skulls were scored for the presence and extent of dental calculus and periodontal disease. These oral health scores were also compared to cranial deformations examined in a previous study. We found that the occurrence and severity of calculus buildup and periodontal disease was significantly higher in captive felids compared to their wild counterparts. Further, higher calculus accumulation occurred on the posterior teeth when compared to the anterior teeth, while an opposite trend for periodontal disease was observed. We also found a significant correlation between oral health and cranial morphology of lions and tigers. The results suggest that food mechanical properties are significant factors contributing to oral health in felids.

KEY WORDS: *Panthera*, *P. leo*, *P. tigris*, gingivitis, gum disease, caries

INTRODUCTION

The composition of the diet of captive carnivores is of great interest to animal curators, keepers and veterinarians. However, this interest has focused almost entirely on the nutritional composition of the diet (e.g., Whitehouse-Tedd et al., 2015) and little consideration has been given to the mechanical properties of foods such as toughness and hardness. While the incorporation of bones as dietary supplements or as enrichment is a growing trend (McPhee, 2002; Skibieli et al., 2007), the predominant diet fed to captive carnivores in North America

consists of ground meat (Bechert et al., 2002; Kerr et al., 2013). While ground meat diets may contain all of the nutrients found in a natural diet, they does not simulate the ingestive or masticatory challenges that wild carnivores face (Haberstroh et al., 1984). In particular, the lack of bone and connective tissue in the captive diet may lead to dental health issues (Haberstroh et al., 1984; Lindburg, 1988). Numerous studies in domestic animals have demonstrated that mechanical attributes of the diet appear to affect dental calculus buildup and oral health in general (Antonelli et al., 2015; Logan, 2006; Vosburgh et al., 1982; Watson, 1994) however, thorough examination of the way in which the mechanical properties of foods affect oral health in large felids remains to be carried out. This study focuses on the correlation between dental health and captivity status in captive felids.

BACKGROUND

Experimental Studies

The mechanical properties of food have long been thought to affect the oral health of domestic dogs and cats as well as captive exotic carnivores (Fagan, 1980). Several studies have noted the correlation of soft diets with excessive calculus accumulation, gingivitis, and periodontal disease in dogs and cats (Logan, 2006; Watson, 1994) and exotic carnivores (Fagan, 1980). It is thought that a dry diet is associated with less gingival pathology because the abrasive action of dry/rough foods against the gingivae in effect acts as a toothbrush, cleaning the teeth and removing food particles trapped in the gingival sulcus (Haberstroh et al., 1984; Vosburgh et al., 1982)

Numerous studies have supported the hypothesis that mechanical properties of the diet are significant factors in the oral health of captive carnivores. A study conducted on captive wolves (*Canis lupus*) found that animals fed a hard, dry diet exhibited significantly lower levels of plaque accumulation after four months than those fed a soft, meat-based diet (Vosburgh et al., 1982). A study of captive Amur Tigers (*Panthera tigris altaica*) found that when animals being

fed a diet of commercially produced soft meat had their diets supplemented at least twice per week with beef bones (with muscle and connective tissue still attached) they showed lower incidence of gingivitis and periodontal disease (Haberstroh et al., 1984). Several studies of domestic beagles (*C. lupus familiaris*) have also found that those fed abrasive diets including commercial dry foods or biscuits showed lower rates of periodontal disease and tartar accumulation than those on soft diets (Brown and Park, 1968; Samuelson and Cutter, 1991; Watson, 1994). Another study showed that ferrets (*Mustela putorius furo*) fed a soft diet of bread and milk developed periodontal disease within 8-12 weeks. The addition of bones to their diet prevented periodontal disease and even caused a decrease in calculus accumulation (Verstraete, 2003).

Felid Dental Anatomy and Function

As in all mammals, carnivorans have four types of teeth: incisors, canines, premolars and molars. In most carnivores the incisors are used for grasping and tearing, though they are relatively vestigial in modern felids. Felid canines are used for capturing and killing prey, and the premolars and carnassials are used primarily for slicing flesh. Felids have no functional dental region distal to their carnassials – a molar region that many other carnivorans use for grinding tougher foods (Hartstone-Rose, 2008; Hartstone-Rose et al., 2012; Logan, 2006; Van Valkenburgh, 1989).

A typical adult felid has a total of 30 teeth with the following dental formula: I3/3, C1/1, P3/2, M1/1, where I, C, P and M represent Incisors, Canines, Premolars and Molars respectively, and the number on either side of the “/” signifies the number of teeth of that kind in each upper and lower quadrant respectively (Wiggs and Bloom, 2003). Teeth are anchored into the alveolar bone by the periodontal ligament. In healthy animals, gingival tissue covers the alveolar bone and tooth root to a level just below the area where enamel meets the root surface (Niemić, 2008a).

Dental Calculus and Periodontal Disease

Dental calculus, or tartar, can be defined as calcified or calcifying deposits of dental plaque (a microbial biofilm) attached to the enamel surface (Busscher et al., 2004). Calculus is primarily composed of inorganic compounds consisting of crystalline salts, but it is usually covered by an active layer of bacterial plaque. New calculus is formed as this active layer of bacterial plaque mineralizes (Deinzer et al., 2005; Marcenes and Sheiham, 1992). When plaque and calculus spread under the gingival line, it causes irritation leading to an inflammatory condition of the soft tissue known as gingivitis (Campbell, 2006). As calculus builds under the gingiva, the bacteria in the sub-gingival plaque set in motion a cycle of damage to the supporting tissues around the tooth, and a more severe form of periodontal disease known as periodontitis may develop (Pihlstrom et al., 2005). Periodontitis can lead to bone loss, tissue destruction, and ultimately tooth loss (Campbell, 2006).

Periodontal disease is the most prevalent disease in domestic carnivores and has been found in approximately 80% of adult dogs in one study (Niemic, 2008b). It is less common in wild carnivores (Wiggs and Bloom, 2003), possibly due to differences in the food consistency of wild and captive carnivores.

Captive Felid Diet

The most common diet provided to felids in captivity in North America consists almost entirely of commercially prepared meat supplemented with vitamins (Vester et al., 2008). While this ground meat diet attempts to ensure that an animal's nutritional needs are met (Kerr et al., 2013), it lacks the mechanical properties of the natural felid diet which consists of intact prey animal carcasses. In the wild, large felids consume flesh straight from the bone. In doing so, they also consume tough connective tissue and create contact between the surfaces of their teeth and bones from the carcass (Schaller, 1972; Sunquist and Sunquist, 2002). The presence of these natural dietary components is often ignored, if not discouraged in captive feeding. Milliken Meat

Products Ltd., one of the largest producers of carnivore meat diets (under the brand name “Toronto Zoo Carnivore Diets”), advertises that their meat product contains “no bones, cartilage, organs, skin or connective tissues” (Roberts and Gittleman, 1984). The primary reason for this aversion to other carcass parts is likely that these components present a choking hazard to the animals. Secondly, feeding captive carnivores fully intact carcasses can incite public relations problems, as was recently seen at the Copenhagen Zoo where one of the zoo’s giraffes was euthanized and fed to the zoo’s lions (Bowers, 2014; Schwarts, 2014). Commercially available ground meat diets with added vitamins meet the basic nutritional requirements of captive felids (Vester et al., 2008), but the lack of complete macro-structural elements leaves the captive diet devoid of the mechanical challenges found in the diets of wild carnivores.

Specific Aims and Hypotheses

The overall goal of this study is to assess the effect of captivity on the oral health of felids. Previous research has shown that captivity can negatively affect oral health in other carnivorans (Antonelli et al., 2015), likely due to a soft diet, and given that captive felids in North America are predominantly fed ground meat, we hypothesize that they will have higher incidences of dental calculus and periodontal disease compared to wild felids. Since tooth function differs across regions of the mouth, we also hypothesize that the prevalence of calculus and periodontal disease will also differ between the anterior and posterior teeth. Lastly, we hypothesize that oral health measures will correlate positively with an index of skull deformity that has been found to be a marker of captivity (Hartstone-Rose et al., 2014).

MATERIALS and METHODS

Sample

We collected data on 63 adult lion (*Panthera leo*) and tiger (*P. tigris*) skulls (Table 1) from the American Museum of Natural History (AMNH; New York), and the Smithsonian

Institution's National Museum of Natural History (NMNH¹ Washington DC) as well as several specimens in the comparative anatomy research collection at the University of South Carolina School of Medicine. Specimens were identified as adults by the presence of fully erupted permanent teeth. The wild specimens were collected throughout the natural range of each species and the captive animals were accessioned from The Barnum and Bailey Circus (traveling throughout the USA), the Carolina Tiger Rescue (Pittsboro, NC), National Zoological Park (Smithsonian, Washington DC), Toledo Zoological Society (Toledo, OH), and several historical zoos that now fall under the Wildlife Conservation Society (all around New York City): the Bronx Zoo, Central Park Zoo, New York Park Commission, New York Zoo, New York Zoo Gardens, New York Zoo Society, and the Prospect Park Zoo.

The sample population of specimens was sorted according to species and captivity status. For the sake of this paper, “wild” refers to individuals with known wild geographic origin and “captive” refers to individuals who resided in zoos or animal rescue facilities at the time of their deaths. Although captivity status at birth is unknown for most captive specimens in our sample, because importation of wild animals has historically been rare, it can safely be presumed that most if not all were born in captivity.

Insert Table 1 Here

All specimens were scored for calculus and periodontal disease by assessing the dental arcade in six sections (Fig. 1): upper and lower cheek teeth (premolars and molars) on the left and right side separately and upper and lower anterior teeth (canines and incisors). Each section was scored from 0 to 5 for calculus buildup and periodontal disease (see tables 2 and 3 for explanation of indices). Each score represents the average score for all teeth in each of the six sections. Using the average score for a section rather

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¹ Specimens from the NMNH are cataloged with the designation “USNM”.

than scoring each individual tooth eliminated the discrepancies that might arise, for example, due to individual missing or damaged teeth.

Insert Figure 1 Here

Calculus Scoring

The amount of calculus covering the crowns of all teeth in each of the six sections (Fig. 1) was observed and scored according to the calculus index outlined in Table 2. This index was created specifically for the goals of our analysis, but it is based on previously developed similar scales for scoring human dentition (Deinzer et al., 2005; Dog, 2005; Muhvic-Urek et al., 2007).

Insert Table 2 Here

Periodontal Disease Scoring

Specimens were scored for periodontal disease by assessing the presence and degree of bone porosity relative to the distance from the alveolar margin using a scale developed for the purposes of this analysis (Table 3). As in the scoring for calculus build up, the average score for all teeth in each section was taken.

Insert Table 3 Here

Cranial Deformation Score

Hartstone-Rose and colleagues (2014) used three-dimensional geometric morphometric analyses of the same specimens that we have used in the present study to assess the correlation between skull shape distortions and captivity status. In their principal component analysis of 43 cranial landmarks, the second greatest source of morphological variation across the population –

second only to the variation separating the two species – sorted the sample according to captivity status. This factor (the second principal component) accounted for 14.81% of the morphological variation in skull shape – almost twice as much of the variation as the axis that sorted these specimens by sex (which contributed 7.97% of the variation). Through this analysis and analyses of other specific measures, Hartstone-Rose and colleagues found that the degree of skull deformity is highly correlated with captivity status, and thus in the present study we use this second principal component score as a “captivity coefficient”. We compare this captivity coefficient to our periodontal disease and calculus scores to evaluate the correlation between the captivity-driven cranial deformation and oral health.

Statistical Analyses

Statistical analyses were conducted using JMP statistical software (version 10.0.2; SAS). Mean and maximum values for periodontal disease and calculus scores were used to examine correlations between oral health scores and captivity status, taxon, captivity coefficient, and variation between different regions of the mouth. One-way ANOVA tests were conducted to determine if captive animals have significantly higher periodontal and calculus scores than wild animals.

RESULTS

Effect of Captivity Status on Oral Health

The occurrence and magnitude of periodontal and calculus scores were significantly higher in captive animals compared to their wild counterparts.

To examine simply whether there was an increased presence or absence of substantial periodontal disease and calculus accumulation in captive animals, we calculated the total percentage of wild and captive specimens that have some or

moderate-to-extreme (score of >0 or >1 respectively) calculus and periodontal disease scores. While almost none of the wild felids exhibited moderate or severe periodontal disease and calculus, the opposite was true of the captive felids (Table 4 and figure 2).

Insert Table 4 Here

Insert Figure 2 Here

To examine not only the presence or absence of calculus and periodontal disease, but also the magnitude of these dental health variables, we conducted a one-way ANOVA test (Table 5). Results show that the mean and maximum periodontal score and mean and maximum calculus score statistically separate captive and wild populations, with captive animals showing significantly higher ($p = <.0001$) scores for both periodontal disease and calculus accumulation. Furthermore, the captive populations have wider standard deviations across these variables, demonstrating higher variability in these measures of oral health in captive felids.

Insert Table 5 Here

Calculus and periodontal disease were also analyzed exclusively in the two anterior sections (upper and lower). Results from these one-way ANOVA tests were significant for both calculus and periodontal disease in both upper and lower anterior teeth (Table 6), with the captive specimens scoring higher in every analysis. The results were particularly pronounced in regards to periodontal disease where the captive specimens scored an average of 2.60 and 2.11 for upper and lower anterior, respectively. Conversely, the wild specimens scored averages of 0.36 for upper and 0.71 for lower anterior teeth.

Correlation of Oral Health to Captivity-Associated Cranial Deformation

In order to examine the correlation between oral health and overall health, we compared the captivity coefficient scores from Hartstone-Rose and colleagues (2014) to mean/maximum periodontal disease, and mean/maximum calculus scores. Since neither the captivity coefficient nor the oral health scores are obviously “independent” variables (i.e., should be regarded with assumptions of error), to compare them, we used Reduced Major Axis regression (RMA) rather than Ordinary Least Square (OLS). Results showed a statistically significant relationship between oral health and cranial morphology (Table 7). Bivariate fits of mean and maximum periodontal score and mean and maximum dental calculus score against captivity coefficient showed a positive correlation. Higher captivity coefficient scores are correlated with higher periodontal disease and dental calculus scores. The relationship between the mean and maximum periodontal score and mean and maximum calculus score versus captivity coefficient is also statistically significant.

Insert Table 7 Here

Differences between Posterior vs. Anterior Dentition and Oral Health

There is a significant relationship between the oral health scores of anterior and posterior teeth (Table 8). However, the slopes of the anterior and posterior calculus and periodontal disease scores are not isometric; the periodontal disease score regression is negatively allometric and the calculus score regression is positively allometric. Thus, there is significantly more periodontal disease found in the anterior dentition, but significantly more calculus found in the posterior dentition.

Insert Table 8 Here

Influence of Sex and Species on Oral Health

In order to assess the influence of sex and species on periodontal and calculus scores, one-way ANOVA tests were conducted comparing species (tiger versus lion), and sex (male versus female) with mean and maximum periodontal disease and calculus scores. Only the comparison of maximum periodontal disease by species was statistically significant ($p=0.038$) with tigers having the greater score. To negate a sampling bias wherein the ratio of captive specimens to wild specimens was much higher in tigers (20:9) than in lions (15:19) and slightly in males (19:12) than in females (16:16), sex and species were divided by captivity status (wild tiger versus wild lion, captive tiger versus captive lion, wild males versus wild females, and captive males versus captive females) and then subjected to one-way ANOVA tests. Results from these tests found no significant differences in either species or sex.

DISCUSSION

Effect of Captivity on Oral Health

The goal of this study was to evaluate the occurrence of periodontal disease and the degree of calculus accumulation in wild and captive felids. Our results indicate that for felids held in North America, captivity has a strong effect on the oral health of lions and tigers. We predicted the incidence and magnitude of dental calculus and periodontal disease would be higher in captive felids, which are traditionally fed a soft diet in North America. As expected, a higher incidence of both was observed in the captive animals compared to their wild counterparts, and the magnitude of those markers of poor oral health was also significantly higher in captive animals.

Since the anterior teeth are particularly important for grasping and tearing in a nature felid diet, analyses were performed comparing just the anterior teeth of captive and wild felids. As with the other analyses, the findings were significant in regards to the captive specimens having higher calculus and periodontal scores (Table 6). The anterior teeth likely experience a high

amount of abrasion during hunting and also during consumption of tough tissue in whole carcasses (Hartstone-Rose, 2008). In the captive specimens, these acts are completely removed and the negative effect is clearly evident on the anterior teeth. While captivity has a negative effect on all sections of the oral cavity, it seems likely that anterior oral health in particular is worsened by the lack of tearing and grasping in a captive diet.

These results are likely due to the substantially different mechanical properties of the wild and captive diets. The high rates and levels of calculus and periodontal disease in captive animals are likely due to the lack of abrasion that accompanies chewing on bones or connective tissues. Further, soft diets tend to produce more bacterial plaque than firm diets resulting in an increased calculus accumulation and eventually gingivitis or periodontitis (Pearson et al., 2005).

Another potential cause of the higher incidences of dental calculus and periodontal disease could be stress from living in captivity. There is an extensive literature documenting that animals living in captivity experience significantly higher levels of stress indicators than their wild counterparts (Bayazit, 2009; Burgener et al., 2008; Morgan and Tromborg, 2007; Terio et al., 2004), and even further research that concludes that stress or captivity can affect an animal's health (Baker et al., 1998; Constable et al., 1998; Kilbourn et al., 2003; Terio, 2009; Whitehouse-Tedd et al., 2015). Yet, among all this research we were unable to find any that directly correlated captivity stress to oral health. There are however, studies that support stress as a causative agent for a deficiency in dental health in humans (Deinzer et al., 2005; Marcenes and Sheiham, 1992; Muhvic-Urek et al., 2007). Therefore, it is possible that the increase in calculus and periodontal disease in the captive specimens was a result of stress.

There are, of course, a variety of other factors that could potentially contribute to the change in oral health noted in captivity. For example, in black-footed ferrets (*Mustela nigripes*) concerns arose over the health effects of a lack of genetic diversity in the captive population resulting from near extinction of the species (Wisely et al., 2002a). A similar study to the one reported here found that oral health was worse among these captive black-footed ferrets (Antonelli et al., 2015). But, a separate study that found decreased cranial sizes in captive black-footed ferrets concluded that inbreeding was not statistically the cause of cranial morphological differences (Wisely et al., 2002b), although this may not be the case in felids. There are an array of factors that should be considered when looking at the effects of captivity on oral health, and multiple factors could contribute simultaneously. However, the findings of this study are in agreement with other literature (Fagan, 1980; Haberstroh et al., 1984; Logan, 2006; Watson, 1994) suggesting the mechanical properties of diet are a leading cause, if not the single greatest cause for the deterioration of oral health in captive felids.

Effect of Oral Health on Overall Health

The possibility of damage to other organs and tissues as a consequence of periodontal disease has been a topic of study for some time (Audet et al., 2002; McGrew, 1979). Although changes in nutritional aspects of the diet have arguably improved the health of domestic cats and dogs, periodontal disease remains a serious problem (Walton and Joly, 2003). Scientists and dental professionals have long suspected associations between oral health and systemic health. In humans, an association has been found between periodontal disease and diabetes, cardiovascular disease, and pregnancy complications (Logan, 2006). Although the nature of the relationship is not fully understood, studies thus far clearly point to a connection between periodontal health and systemic health (Campbell, 2006).

This study demonstrates a direct relationship between captivity status and oral health. Our comparison of periodontal disease and calculus occurrence to degree of cranial deformation –

which is also correlated with captivity status (Hartstone-Rose et al., 2014) – in the same specimens shows that an increase in cranial deformation is correlated to an increase in periodontal disease and calculus accumulation (Table 7). These findings support our hypothesis and provide valuable information to keepers of captive animals regarding possible side effects that can arise from oral health defects in captivity.

Health of Anterior versus Posterior Dentition

Because different regions of the dentition serve different functions during food acquisition and processing, one aim of this study was to determine if variation in oral health exists between the posterior and anterior dentition of captive and wild felids. Our results show a highly correlated relationship between the oral health scores of the posterior and anterior teeth (Table 8) – animals with poor anterior oral health also have poor posterior oral health. However, calculus buildup is greater in the posterior teeth when compared to the anterior teeth, but the opposite trend was seen for periodontal disease; higher prevalence of periodontal disease was noted in the anterior teeth when compared to the posterior teeth (Table 8). Because carnivores primarily use their anterior teeth for grasping and tearing, this action may damage the gingiva, leading to inflammation and if not treated could lead to periodontal disease. This could explain why periodontal disease is more prevalent on the anterior teeth. Higher prevalence of calculus accumulation on the posterior teeth could be explained by the previous finding that plaque tends to accumulate at the openings of parotid salivary ducts which are located near the cheek teeth (Vosburgh et al., 1982).

Effects of Age, Sex and Species

One of the limitations of this study was that while the prevalence and severity of oral health issues are age-related (Albuquerque et al., 2012; Gawor et al., 2006; Patterson et al., 2003; Watson, 1994), the exact ages of the specimens in our study were unknown. However, a study by

Gawor and colleagues (2006) on the influence of diet on oral health of cats and dogs showed that even after they adjusted for age, the mean oral health index was significantly higher in cats and dogs fed soft food compared with those fed dry or mixed food. These results clearly indicate that feeding a dry food diet has a positive influence on oral health (Walton and Joly, 2003). Furthermore, we have found juvenile captive specimens with advanced oral health diseases (Fig. 3), demonstrating that although age might be a confounding factor in this study, it is not necessarily the main correlate of dental disease. Regardless, only adult specimens were included in our study.

Insert Figure 3 Here

Results of one-way ANOVA tests showed no significant influence of sex and species on oral health. The one statistical exception – tigers having significantly higher maximum periodontal disease scores – is likely a statistical sample artifact since there is no obvious biological reason that this should be true. This difference in maximum periodontal disease score probably arose because of the large number of captive tigers compared to wild tigers driving the mean scores of the tigers higher than those of the lions which had a more equal distribution between captive and wild specimens. This is supported by our further analysis comparing wild tigers to wild lions and captive tigers to captive lions. When captivity status is adjusted for, there were no significant differences between the two species. This not only implies that there is no notable difference between the species, but also further supports our previous hypothesis that captivity is the causative agent for oral health problems in both lions and tigers.

Future Directions

Although ground meat, soft diets are the standard among North American captivity centers, this diet is not the predominant one fed in all global regions. Specifically, European captivity centers tend to favor whole carcass feeding both for the nutritional value of a natural diet, and also for the enrichment of the animals (Pearson et al., 2005). An expansion of this study to examine oral health and cranial morphology among specimens fed a whole carcass diet would provide strong comparative data between the differences in effect on oral health among the two diet types. Additionally, a comparison of specimens fed similar diets, but in different global areas (i.e. North America and Europe), could help clarify whether the previously seen oral health issues are truly diet induced or rather a factor of other zoo keeping characteristics prevalent in North America.

The exact diet of the captive specimens could not be ascertained prior to the study. Given that all the specimens are from North American captivity centers, however, it is reasonable to surmise that the diet was indeed a ground meat diet. While this cannot be stated with absolute certainty, a similar study of black-footed ferrets found the same result – worse oral health in captive animals (Antonelli et al., 2015). Further still, experimental data exist that point directly to diet composition as the cause of oral health problems in captive timber wolves and even captive Amur tigers (Haberstroh et al., 1984; Vosburgh et al., 1982). Further studies could be performed with the use of live specimens to generate a more specific understanding of the exact effects of diet composition and oral health in these large felid species.

Another direction in which to continue this work will be to examine the effects of stress on oral health among captive animals. As previously mentioned, evidence supports that captivity has negative health effects on animals, but there is no literature directed specifically at oral health. An examination of live animals' dentition, as well as markers

of stress such as behavioral abnormalities or levels of cortisol, could provide information on the relationship between the stresses of captivity and oral health.

Broader Impacts

The results of this study strongly suggest that the mechanical properties of diet are important to oral health in felids. The wild felid diet, which allows more abrasive material (such as bone, tendon, and skin) to contact the teeth, is correlated with a lower incidence of oral disease. These data support recommendations for improvement in North American captive carnivore diets from a mechanical perspective (Hartstone-Rose et al., 2014). Management of dental disorders provides animals with a higher quality of life, extends their life span and improves breeding capabilities (Van Foreest, 1993).

This study also demonstrates a link between oral health and cranial deformation. Further understanding of the possible relationship between periodontal health and other systemic conditions will allow zoo and veterinary professionals to provide the best overall health care for captive carnivores.

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Figure Captions

Figure 1. Analytical sections for the mandibular (A.) and maxillary (right) teeth.

Figure 2. Percent of specimens exhibiting some (score > 0) and moderate-to-extreme (score > 1) of mean and maximum calculus and periodontal disease scores. Gray bars = wild specimens; black bars = captive specimens.

Figure 3. Severe calculus (and moderate periodontal disease) on maxillary premolars of a juvenile tiger (USNM 396272). Note the deciduous premolar being replaced by the permanent premolar. As only adult specimens were included in the statistical analyses, this specimen is used here only for illustrative purposes.

577 **Table 1. Number of specimens in this sample broken down by species, captivity status, and**
 578 **sex (n=63)**

Common Name	Species	Captive (Zoo)	Wild	Male	Female
Lion	<i>Panthera leo</i>	15	19	17	17
Tiger	<i>Panthera tigris</i>	20	9	14	15
	TOTAL	35	28	31	32

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581 **Table 2. Calculus Index**

Calculus	Observations
Scores	
0	No evidence of calculus
1	1 – 10% of tooth crown is covered by calculus
2	10 – 25% of tooth crown is covered by calculus
3	25 – 50% of tooth crown is covered by calculus
4	50 – 75% of tooth crown is covered by calculus and/or minor caries
5	75 – 100% of tooth crown is covered by calculus OR thickened calculus and/or major caries

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584 **Table 3. Periodontal Disease Index**

Periodontal	Observations
Disease	
Scores	
0	The bone within 5mm of gum line has no visible porosity
1	The bone within 5mm of gum line has noticeable porosity
2	The bone within 5mm of gum line has excessive porosity OR the bone within 1cm of the gum line has noticeable porosity
3	The bone within 1cm of the gum line has excessive porosity OR bone remodeling without excessive porosity
4	Openings in the alveolar bone >1mm, but <2mm and/or evidence of abscess with bone remodeling
5	Multi-millimeter openings in the alveolar bone and/or tooth loss

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Table 4. Presence and absence of calculus and periodontal disease in wild and captive felids.

Variables	Wild % Score > 0	Captive % Score > 0	Wild % Score > 1	Captive % Score > 1
Mean Calculus Score	18%	97%	4%	46%
Maximum Calculus Score	18%	97%	4%	34%
Mean Periodontal Score	64%	97%	11%	88%
Maximum Periodontal Score	64%	97%	25%	83%

591 **Table 5. One-way ANOVA Analysis of Oral Health and Captivity Status.**

Variable	Mean ^a (SD)	Mean ^a (SD)	p-Value
	Zoo	Wild	
Mean ^b Periodontal Disease	1.62 (0.75)	0.39 (0.53)	<.0001
Maximum ^c Periodontal Disease	3.08 (1.40)	1.00 (1.09)	<.0001
Mean ^b Calculus	1.05 (0.66)	0.08 (0.21)	<.0001
Maximum ^c Calculus	1.77 (1.33)	0.21 (0.49)	<.0001

592 ^aAverage score across all specimens.593 ^bAverage score of all six dental sections in each specimen.594 ^cHighest score of the six dental sections per specimen.

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596 **Table 6. One-way ANOVA Analysis of Anterior Oral Health and Captivity Status.**

Variable	Mean ^a (SD)	Mean ^a (SD)	p-Value
	Zoo	Wild	
Upper Anterior Periodontal Disease	2.60 (0.18)	0.36 (0.21)	<.0001
Lower Anterior Periodontal Disease	2.11 (0.15)	0.71 (0.17)	<.0001
Upper Anterior Calculus	0.71 (0.11)	0.11 (0.13)	.0008
Lower Anterior Calculus	0.46 (0.07)	0.04 (0.08)	<.0001

597 ^aAverage score across all specimens.

Table 7. Descriptive statistics for RMA regressions of dental scores against the captivity coefficient.

Dependent variable	Slope	y-intercept	r ²	Lower CL	Upper CL	p-Value
Mean Periodontal	34.04	1.09	0.42	18.22	63.61	>0.0006
Maximum Periodontal	61.84	2.19	0.48	37.52	101.94	>0.0001
Mean Calculus	26.65	0.63	0.41	13.84	51.33	>0.0009
Maximum Calculus	49.03	1.11	0.33	19.59	122.71	>0.0076

Table 8. Descriptive statistics for RMA regressions of the anterior (independent) and posterior (dependent) regions by dental score.

Variable	Slope	y-intercept	r ²	Lower CL	Upper CL	p-Value
Periodontal Disease	0.70	-0.24	0.38	0.50	0.98	<.0001
Scores						
Calculus Scores	1.64	0.14	0.35	1.14	2.366	<.0001

Figure 1

Figure 2

Figure 3