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NATURAL SKELETAL PATHOLOGIES IN A POPULATION OF GRAY SQUIRRELS, *Sciurus carolinensis*, FROM PUTNAM COUNTY, GEORGIA

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ABSTRACT

Antemortem bone remodeling following severe trauma leads to bone disfigurement that serves as a skeletal record of the injury resulting from events such as nonfatal predator attacks, aggressive intraspecific interactions, or accidental injuries related to lifestyle hazards. In the current study, pathologic bone regrowth was analyzed in a sample of 91 eastern gray squirrel (*Sciurus carolinensis*) skeletons from Putnam County, Georgia. The occurrence, frequency, and position of bridging fracture calluses, bone misalignments, bone-surface perforations, and localized superficial calluses were recorded and compared to other terrestrial, semiarboreal, and arboreal mammalian species. Evidence of healed bone fractures was observed in 41% of individuals, with 26% of the skeletons displaying multiple healed fractures. Healed long bone fractures were noted in 19% of the skeletons. Pathologic ribs, caudal vertebrae, and metatarsals were most commonly observed and likely resulted from falls or nonfatal predator attacks.

Keywords: skeletal pathology, gray squirrel, *Sciurus carolinensis*, healed injuries

INTRODUCTION

Bone surface irregularities such as bridging fracture calluses, bone misalignments, and bone-surface perforations record severe bone trauma experienced by vertebrates. Healed fractures can serve as indicators of lifestyle characteristics, not only in extant populations, but also in extinct species. For example, Cubo et al. (2015) used healed bone fractures in nonavian dinosaurs to infer shifts from a bipedal to quadrupedal posture in extinct *Maiasura*. McCall et al. (2003) analyzed the presence of bone pathology in the extinct mammalian predator *Smilodon* to explore the question of sociality. Lingham-Soliar (2004) referenced healed mandibular fractures to propose possible prey items or intraspecific behaviors in extinct mosasaurs. It is evident that paleopathology studies rely on modern bone pathology studies and therefore need relevant bodies of data to be widely useful (Bartosiewicz 2008).

Large skeletal collections can be used to realistically estimate the frequency of skeletal pathologies in extant mammal populations. To date, the majority of skeletal pathology studies in nonhuman mammals has focused on primates (e.g. Bramblett 1967; Buikstra 1975; DeGusta and Milton 1998; Lovell 1990; Nakai 2003). However,

pathology studies of non-primate mammals are not as prevalent, despite their value in paleoecological studies. Some taxa which have been studied include viverrids (*Atilax*, *Bdeogal*, *Civettictis*, *Genetta*, *Helogale*, *Herpestes*, *Ichneumia*, *Mungos*, and *Nandinia*) from eastern Africa (Taylor 1971), water voles (*Arvicola terrestris monticola*) from Europe (Ventura and Gotzens 2005), squirrels (*Glaucomys sabrinus*, *Arborimus logicaudus*, *Tamiasciurus douglasii*, *Sciurus griseus*, and *Tamias* spp.) and woodrats (*Neotoma* spp.) from Oregon (Forsman and Otto 2006), and Virginia opossums (*Didelphis virginiana*) from Georgia (Mead and Patterson 2009).

In the present study, skeletal pathology was analyzed in a collection of eastern gray squirrel (*Sciurus carolinensis*) specimens. As summarized by Koprowski (1994), gray squirrels are medium sized (300-700 g) scansorial mammals with relatively long maximum lifespans (12 years in females, 9 years in males) compared to other comparably sized mammalian species. They are most common in mature woodlands and depend on tree nuts as their primary food source. There is no reported body mass or skeletal sexual dimorphism. Male home ranges are slightly larger than those of females, which is likely related to seasonal expansion during mate searching. Common predators in the southeastern United States include snakes, hawks, native mammalian carnivores, and domestic cats and dogs.

MATERIALS AND METHODS

The occurrence, frequency, and position of bridging fracture calluses, bone misalignments, bone-surface perforations, and localized superficial calluses indicating healed fractures were examined in skeletons of 91 eastern gray squirrels (54 female, 37 male) in the Georgia College recent mammal collection. The squirrels (adults and subadults) were collected from Putnam County, Georgia and had died as a result of domestic pet-kills, road-kills, hunter harvests, and, in at least one instance, apparent electrocution. All specimens were skeletonized using dermestid beetles and skeletons were surveyed under normal light. Suspected healed injuries were examined thoroughly using a compound light microscope. Sample size is indicated by *n*.

RESULTS

In this sample of 91 gray squirrels, evidence of healed bone fractures (Figure 1) was observed in 37 individuals (40.7%). Some of the skeletons (n = 24) exhibited multiple healed injuries resulting in a total of 76 healed injuries in these 37 individuals (Table I). Healed long bone fractures were noted in 17 skeletons (18.7%). The most commonly observed healed elements were ribs (n = 18), caudal vertebrae (n = 9), metatarsals (n = 8), femora (n = 5), tibiae (n = 5), fibulae (n = 4), radii (n = 4), ulnae (n = 4), and humeri (n = 3). Evidence of healed injuries was observed in 44.4% of females (24/54) and 35.1% of males (13/37). Of the 37 gray squirrels with evidence of healed injuries, 24 individuals exhibited evidence of multiple injuries. Figure 2 represents a living injured squirrel in Putnam County, Georgia.

DISCUSSION

This analysis of eastern gray squirrels provides comparative data for use in bone pathology studies in both extinct and extant taxa. The frequency of long bone fractures (18.7%) in the Putnam County sample is considerably higher (range = 4–46 times higher) than that observed in previously published studies which included squirrels. For

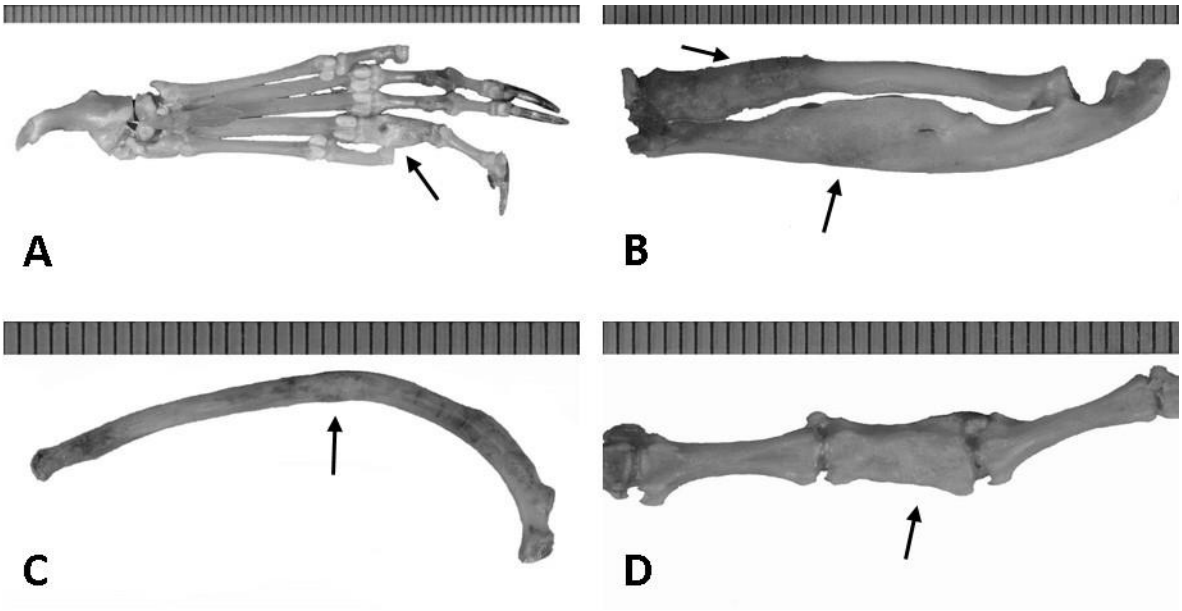

Figure 1. Examples of bridging fracture calluses indicating healed broken bones in gray squirrels (*Sciurus carolinensis*) from Putnam County, Georgia. A) proximal phalanx on the second digit in the right hindfoot (GCM 3084); B) right distal radius and medial ulna (GCM 3068); C) midshaft right rib (GCM 3030); D) caudal vertebra (GCM 3076). The scale is in millimeters. GCM, Georgia College recent mammal collection.

Table I. Anatomical positions of healed injuries in female (24/54) and male (13/37) gray squirrels (*Sciurus carolinensis*) from Putnam County, Georgia.

Gender/ Sample size	Skull/ mandible	Vertebrae	Ribs	Forelimbs	Hindlimbs	Pelvis
Female (n = 24)	2	8	13	9	13	3
Male (n = 13)	1	3	5	5	13	1
Total (n = 76)	3	11	18	14	26	4

example, Thorington (1972) recorded three individuals with healed long bone fractures in 65 specimens of eastern gray squirrels (4.6% of individuals). It appears that Thorington may have examined only long bones in his survey because he does not mention fractures on other skeletal elements. In a large sample of 15,455 arboreal or scansorial mammals collected from owl pellets in Oregon, Forsman and Otto (2006) recorded 41 healed fractures of long bones, innominates, or clavicles (0.3%). In their sample of 8,827 northern flying squirrels (*Glaucomys sabrinus*), 31 exhibited healed fractures (0.4%). For 3,301 woodrats (*Neotoma* spp.), eight were found with healed fractures (0.2%). For the Oregon owl pellet sample as a whole, healed tibiae and/or fibulae (n = 13), femora (n = 9), radii and/or ulnae (n = 9), and humeri (n = 5) were most commonly observed. Forsman and Otto (2006) concluded that these small mammals seldom break bones or they do not survive following bone breakage. They also

Figure 2. Example of a broken tail (white arrow) in a gray squirrel (*Sciurus carolinensis*) from Putnam County, Georgia. Photograph courtesy of Heidi Mead.

concluded that arboreal and scansorial mammals are more likely to encounter bone breakage than terrestrial species.

The frequency of long bone and pelvic factures (20.9%) in the Putnam County gray squirrel population is approximately the same as that found in the fossorial European water vole (*Arvicola terrestris*). Ventura and Gotzens (2005) reported 25 out of 110 specimens (22.7%) with healed fractures. In this species, healed innominates (n = 30), humeri (n = 23), femora (n = 22) and radii and ulnae (n = 17) were most common. The authors attributed the high frequency of healed fractures to aggressive intraspecific interactions, stresses imposed by burrowing, and pelvic trauma induced by parturition.

The occurrence of healed bone injuries in the Putnam County gray squirrel sample is much lower than that previously reported for the Virginia opossum (*Didelphis virginiana*). In a sample of 61 adult opossums from Georgia studied by Mead and Patterson (2009), 64% showed healed injuries primarily on ribs (54%), scapulae (23%), pelvises (21%), fibulae (18%) and vertebrae (18%). The authors suggested that the injuries were possibly due to trauma experienced while “playing opossum” or other predator interactions. It is possible that the more terrestrial habits or larger size of the Virginia opossum increases the likelihood of surviving bone breakage.

Based on an analysis of healed fractures in primates, Brandwood et al. (1986) concluded that healed fractures should be more common in arboreal species. In the gray

squirrel, intraspecific interactions, predator attacks, and falls are likely causes of injury. Koprowski (1994) reported broken tails (Figure 2) resulting from territorial disputes in this species. Falls do not appear to be common. Steele and Koprowski (2001) recorded only 56 falls from more than 10 m during 20,000 hours of gray and fox squirrel (*Sciurus niger*) observations. Although rarely fatal (Thompson 1976), in a species that may live close to 10 years, even a low overall frequency of falls may produce the number of healed fractures seen in the Putnam County gray squirrel sample.

The comparatively high frequency of healed fractures in the Putnam County sample is difficult to explain. It is not likely that injuries induced by a failed predator attack can be distinguished from those sustained in a fall. Most of the squirrels in this sample lived in high densities in close proximity to rural residences, many with bird-feeding stations that provided a year-round food source for squirrels. It is possible that more aggressive intraspecific interactions occur in these spaces around feeders as a result of dominance hierarchies that exist between males (Koprowski 1994). However, this may not explain entirely the higher frequency of healed fractures observed in females in the Putnam County sample. The area also has a high number of feral and free-ranging domestic cats that have been observed to "play" with their injured prey (including gray squirrels), which sometimes survive and escape. Loss et al. (2013) estimated that free-ranging domestic cats kill between 6.3 and 22.3 billion mammals annually in the United States. In their study, squirrels were the fourth most common mammalian prey recorded in rural areas. This predator-prey interaction likely contributes to the high frequency of healed injuries in this skeletal sample. Even though the causes of the injuries are unknown, this sample of gray squirrels provides comparative data for future bone pathology studies in both extant and extinct species. In addition, the high frequency of bone pathologies indicates that this species is capable of surviving serious trauma in which bone breakage occurs.

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