Title: Taphonomic bone trauma caused by Southern African scavengers

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Abstract

Forensic anthropologists in Southern Africa are often confronted with post-mortem modifications of human skeletal remains caused by animal scavenging. This is troublesome as the post-mortem pseudo-trauma could be misinterpreted. This study aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest. The scavenging animals selected for this study included wild dog, spotted hyena, lion, leopard, black-backed jackal, caracal, and porcupine housed at the National Zoological Gardens of South Africa. Sparsely fleshed and articulated bovine front and hind limbs as well as ribs were placed in each animal enclosure and collected after two days for cleaning and analysis. Felids (lion, leopard, and caracal) gnawed away the greater trochanter of the humerus leaving deep, parallel furrows. Hyena caused massive trauma to bone with one third of the tibia shaft surviving with jagged fracture edges. Porcupines left distinctive fan-like parallel scores; and large, oval depressions with an eroded, polished appearance. Wild dogs and jackals did not leave any distinctive patterns. Light scavenging trauma is distinct from other bone taphonomy but cannot be used to determine the species. Heavy scavenging trauma patterns can be used to determine the general type of perpetrating animal however the exact taxa or species cannot be determined.

Keywords:

Forensic anthropology, taphonomic trauma, scavenging, animals, Southern Africa

Introduction

Animal scavenging often causes post-mortem modifications of human skeletal remains. In a forensic context this is troublesome as the post-mortem pseudo-trauma could be misinterpreted by forensic specialists (1-3). Competent analysis of post-mortem trauma should discriminate between damage and trauma inflicted by an animal, a human perpetrator, and other taphonomic influences. The ability to identify a scavenger by the trauma it causes to bone could also assist in the implementation of more reliable search methods for locating scattered remains and other evidence (2).

Scavenging animals considered to be of forensic importance in North America include wolves (Canis lupus), coyotes (Canis latrans), rodents, racoons (A.arathkone), foxes (V. vulpes), opossums (D. marsupialis), striped skunks (M. mephitis), crows (Corvus brachyrhynchos), and a variety of vultures (Cathartidae) such as the turkey vulture (C. aura) (1, 4). Vultures are the avian scavengers most often discussed in forensic studies (1) and are commonly found in North America, the Mediterranean, Eastern Europe, Asia, and Africa. Internationally, in more rural regions, large felids such as lions (Panthera leo), leopards (Panthera pardus), tigers (Panthera tigris), and cougars (Felis concolor) have been known to occasionally scavenge on human remains (5). In abnormal situations, herbivorous animals, such as deer, have also been observed scavenging on dry bones. This behaviour is termed osteophagia and is caused by a phosphorous deficiency resulting from a nutritional dysfunction (6). In urbanised cities, domesticated pets (particularly dogs) have often resorted to feeding upon the soft tissues and skeletal remains of their deceased owners when locked indoors – even if there are alternative food sources available (7, 8).

Descriptions of bone trauma caused by animal bite marks have been categorised into four categories: pits, furrows, punctures, and scores (2, 9). Pits are described as indentations that do not penetrate the cortical surface of the bone. These pits are caused by individual tooth cusps. Punctures are penetrating marks through the cortical bone with an irregular shape. Punctures can be caused by canine and carnassial teeth. Avian scavengers can also form punctures that are conical in appearance on the surfaces of bones, usually caused by a pecking motion when eating soft tissues (10). Furrows are longitudinal marks commonly found near the epiphyseal ends of bones. These are created by premolars and molars and are the result of scavengers trying to gain access to the bone marrow. A score is a broad term describing any mark in the bone surface where the length is greater than the breadth (11). This is often caused by a tooth sliding after a pit has been created (2). Rodent gnaw marks appear as scores on the superficial surfaces of bones. These are often exhibited as parallel striations with uneven margins (2). Generally, the size of these respective marks (pits, punctures, furrows, and scores) can indicate the relative size of the animal (2).

Bite marks are not the only marks caused by scavenging animals to bone. Claw marks are often found in conjunction with bite marks when the animal attempts to grasp the bone (12). Claw marks appear similar to tooth-made scores, since the claw marks are also longer than they are wide. However, scores made by claws can be differentiated from tooth marks because the diameter of claw marks are too thin to be confused as tooth marks and the claw marks are often in parallel rows (12).

The extent of the bite marks on bone can vary depending on the animal species and individual animal. The relative amount of damage caused to a bone is dependent on the relation between the strength of the bone and the tooth morphology and jaw mechanics of the scavenging animal (12). Recent studies have determined that the size of tooth marks in bone can assist in determining the general size of the scavenger but the particular carnivore taxon cannot be accurately identified through tooth mark measurements (13). Bones can even be entirely consumed, leaving little to analyse, depending on the size of the scavenging animal (12).

The ability to identify the animal species by its bite marks in bone can be of great worth. In South Africa, there is still a level of proximity and interaction between humans and wild animals despite the rapid increase in global urbanisation and conservation efforts to isolate animals within national parks and government protected areas (14, 15). Animal attacks are common in South Africa and these often involve people who climb over the fences of game reserves, tourists who leave the safety of camping grounds or vehicles, and poachers. As a result, there are often cases where human skeletal remains are recovered in such locations. In these cases, it will be the role of the forensic anthropologist to analyse the bone trauma and differentiate between perimortem trauma inflicted by a human perpetrator and bite marks caused by animals. For example, there was a case where human skeletal remains were recovered from a lion enclosure at a South African game park. The victim was thrown into the enclosure by perpetrators (16). In this instance the forensic anthropologist had to distinguish between bone fractures that resulted from trauma and bite marks from the lions. Not all animal bite marks look the same. Animal bite marks can be mistaken for blunt, sharp, or ballistic trauma by the unexperienced. The more we can understand the different bite marks caused by different animals, the easier it will be to differentiate them from tool marks and other traumas.

The vast majority of research published on scavenging trauma is of a paleoanthropological nature (11, 17-26) and those in the forensic context are on North American and European environments and species (1). Furthermore, the majority of forensic research on scavenging has been based on wolves, coyotes, rodents, and vultures (1). Much of the published forensic literature describing skeletal trauma caused by scavenging animals is anecdotal and based on actual forensic case studies with the described trauma being inferred upon an assumed animal with no knowledge of the taphonomic processes and previous trauma the bones may have been exposed to (5). This study therefore aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest. The results will provide information that is missing from current forensic literature; a description of African animal bite marks on bone. These descriptions will help provide context to future forensic anthropological analyses of bones in Africa, including discerning or excluding the animal. These results will also assist forensic anthropologists in differentiating between perimortem trauma and animal bite marks.

Methods

The scavenging animals selected for this study included wild dog (Lycaon pictus), spotted hyena (Crocuta crocuta), lion (Panthera leo), leopard (Panthera pardus), black-backed jackal (Canis mesomelas), caracal (Caracal caracal), and porcupine (Hystrix africaeaustralis). These animals were selected as they are known to forensic anthropologists as scavengers of forensic cases in South Africa. Some of the animals are common scavengers (wild dog, jackal, caracal, and porcupine) and some are less common scavengers (lion, leopard, and hyena) however all are of forensic interest in South Africa.

Sparsely fleshed and articulated bovine thoracic limbs (consisting of nine bones: humerus, radius, ulna, and carpals), pelvic limbs (consisting of seven bones: femur, tibia, and tarsals), and racks of fleshed ribs (consisting of six ribs per rack and rib shafts only as the heads and sternal ends were cut off by the butcher) were purchased from a licenced butchery. Bovine limbs and ribs were selected as this is the usual meat source fed to the animals at the NZG. Pelvic limbs were placed in the leopard, lion, caracal, and hyena enclosures and thoracic limbs were placed in the wild dog, porcupine, and jackal enclosures. A humerus was also placed in the caracal enclosure in addition to the pelvic limb to prevent fighting between the two resident caracals. The use of thoracic limbs and pelvic limbs was based on availability and which animals were fed which type of limb was random. A rack of ribs was placed in each animal enclosure. The fleshed limbs and ribs were left in the animal enclosures for two days before collection of the remains. The study of bone trauma on bovine limbs (or other animal analogues) experimentally fed to captive animals in a zoological park is consistent with previously published literature (5, 11). The surviving bones (i.e. bones which were not consumed or removed by other scavenging animals and were visible in the enclosures) were collected and macerated (removal of any remaining soft tissues).

An external light source in the form of a flashlight with controllable light intensity was used to locate and observe the trauma. A table was drafted for each animal that described the tooth and claw marks observed on each bone. The descriptions included: number of bones recovered, type of trauma (pits, furrows, punctures, or scores), location of the trauma on the bone, and a description of the trauma. The descriptions included the number of tooth or claw marks, the depth (deep or shallow), breadth (wide or narrow), length (long or short), and the shape (e.g. fan-like, conical, irregular, etc.). The intensity of scavenging was also recorded as a semiquantative scale (+/++/+++) with 'none' indicating no trauma, (+) indicating minor or insignificant trauma with little-to-no alteration to the morphology or integrity of the bone, (++) indicating moderate trauma with noticeable alterations to the morphology of the bone, and (+++) indicating destruction to the morphology of the bone or the total consumption of the bone. The descriptions of trauma were compared between the species and unique species-identifying features were highlighted.

Photographs of the trauma were taken with a Canon (SLR) 80D (EOS) camera with an EFS, 15-85mm, I.S. (image stabiliser), U.S. (ultrasonic) lens. Measurements of the tooth marks were not taken. It is suggested that the size of tooth marks in bone can assist in determining the general size of the scavenger but the particular carnivore taxon cannot be accurately identified through tooth mark measurements (13).

Results

The jackals caused the least trauma of all the animals and all bones survived. Observable bite marks were isolated to a few superficial pits and scores on the ribs, humerus, and radius (Table 1 and Figure 1). Nothing was noted on the ulna and carpus bones. Trauma caused by the jackals was very difficult to see on the bones as they were generally short and superficial. A very good light source was employed to see the trauma clearly.

The wild dogs consumed most of the ribs however a single rib survived along with the humerus, radius, ulna, and carpus bones. Multiple pits and scores of varying depth, size, and shape were present on the ribs, humerus, and ulna (Table 1 and Figure 2). Shallow furrows were present in the trabecular bone of a gnawed region in the margin of the greater trochanter of the humerus (Figure 2C). Claw marks (thin scores) were also present in the cartilage of humeral head and trochlea (Figure 2D).

The hyena caused the most damage with very few remaining skeletal elements (Table 1). Only a fragment of the distal tibia and three tarsus bones remained. The femur and ribs were all consumed entirely. The distal end of the tibia survived with a jagged, uneven fracture margin indicative of a spiral fracture on the shaft (Figure 3A). A tarsus bone exhibited a clear separation of the cortical and trabecular bone with additional gnawing and a shallow furrow (Figure 3B).

The porcupine caused distinct and unique trauma to the recovered humerus, radius, and ulna (Table 1). A common, distinctive, fan-like pattern of clustered scores were observed in six different regions (Table 1 and Figure 4A and B). There was extensive trauma to the greater trochanter as it had been completely gnawed away with an uneven, jagged margin (Figure 4C). Another common pattern was observed in the medial and lateral surfaces of the olecranon tuber and the head of the humerus, where each exhibited a large, oval depression with an eroded, polished appearance (Figure 4D).

The leopard left pits and scores on the ribs, femur, tibia, and the calcaneus (Table 1 and Figure 5). A distinctive gnawing pattern was observed on the greater trochanter of the femur. It had been gnawed with multiple distinctive parallel, deep, wide furrows (Figure 5B).

The lions also caused a distinctive gnawing pattern on the greater trochanter of the femur (Table 1 and Figure 6). The greater trochanter contained two wide, deep, parallel furrows (Figure 6A). Large pits and punctures were often located adjacent to regions of gnawing and farrowing. It is presumed that these were created as anchor points to stabilise the bone during the scraping motion of gnawing and furrowing. The tibia presented with large, deep punctures on the superior, medial margin of the medial tibial plateau (Figure 6D) and conical punctures in the tibial tuberosity (Figure 6E).

The caracals exhibited the greatest variety of trauma (Table 1 and Figure 7). The proximal end of the humerus had been extensively gnawed with the head and greater trochanter missing. A distinctive gnawing patterns was observed on proximal epiphysis of the humerus as was caused by the leopard and lions. The gnawed proximal end of the humerus presented with multiple long, deep, parallel furrows (Figure 7B). The margin of the gnawed proximal end of the humerus showed signs of crushing with curved flaked bone fragments still adhering (Figure 7C), and a single deep puncture.

Generally, the animals focus on and caused the most severe trauma to the proximal ends of long bones with scoring on the shafts. Scores tended to always be horizontal across the shafts of on long bones. Furrowing always occurred as multiple, parallel furrows - in gnawed regions where trabecular bone had been exposed. Large and deep pits and punctures in the long bones often occurred opposite or adjacent to gnawed regions. It is presumed that these were created by mandibular canine and carnassial teeth as an anchor point for gnawing and furrowing actions of the maxillary teeth. Trauma to the ribs only ever exhibited as scores and pits. Each of the animals in this study caused a number of different types of trauma (pit, score, puncture, and furrow) in different combinations. One type of trauma on its own was not distinct but rather the pattern and location of the trauma was distinct. This was apparent in the porcupine and the cats (lion, leopard, and caracal). The fan-like clusters of scores caused by porcupines are very distinct and unique. All cats in the study (lion, leopard, and caracal) caused distinctive furrows in gnawed proximal ends of long bones.

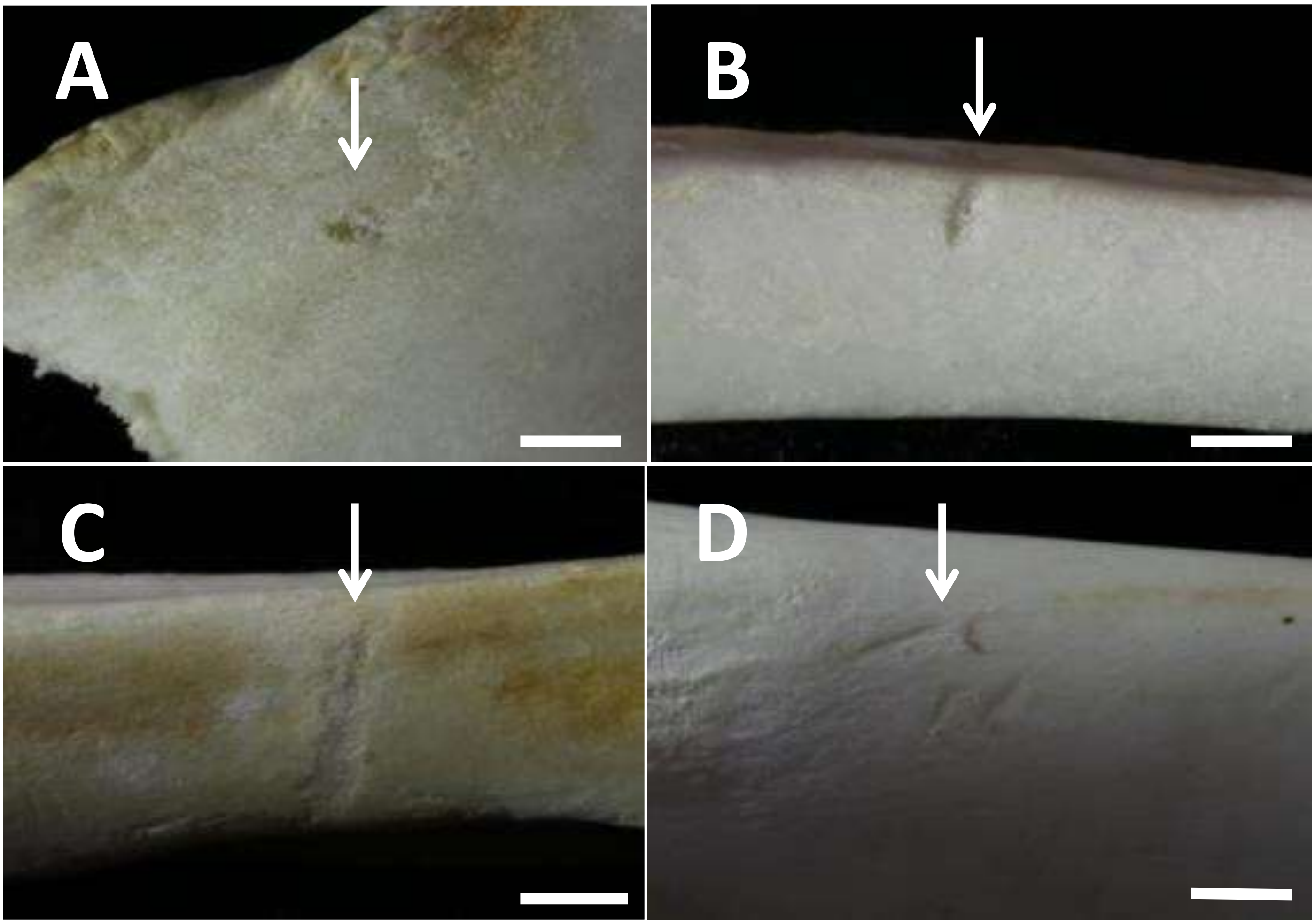

Fig. 1 Jackal trauma (arrows) on bone shafts including: (A) a pit on a rib, (B & C) scores on ribs and (D) the radius (scale line = 5mm)

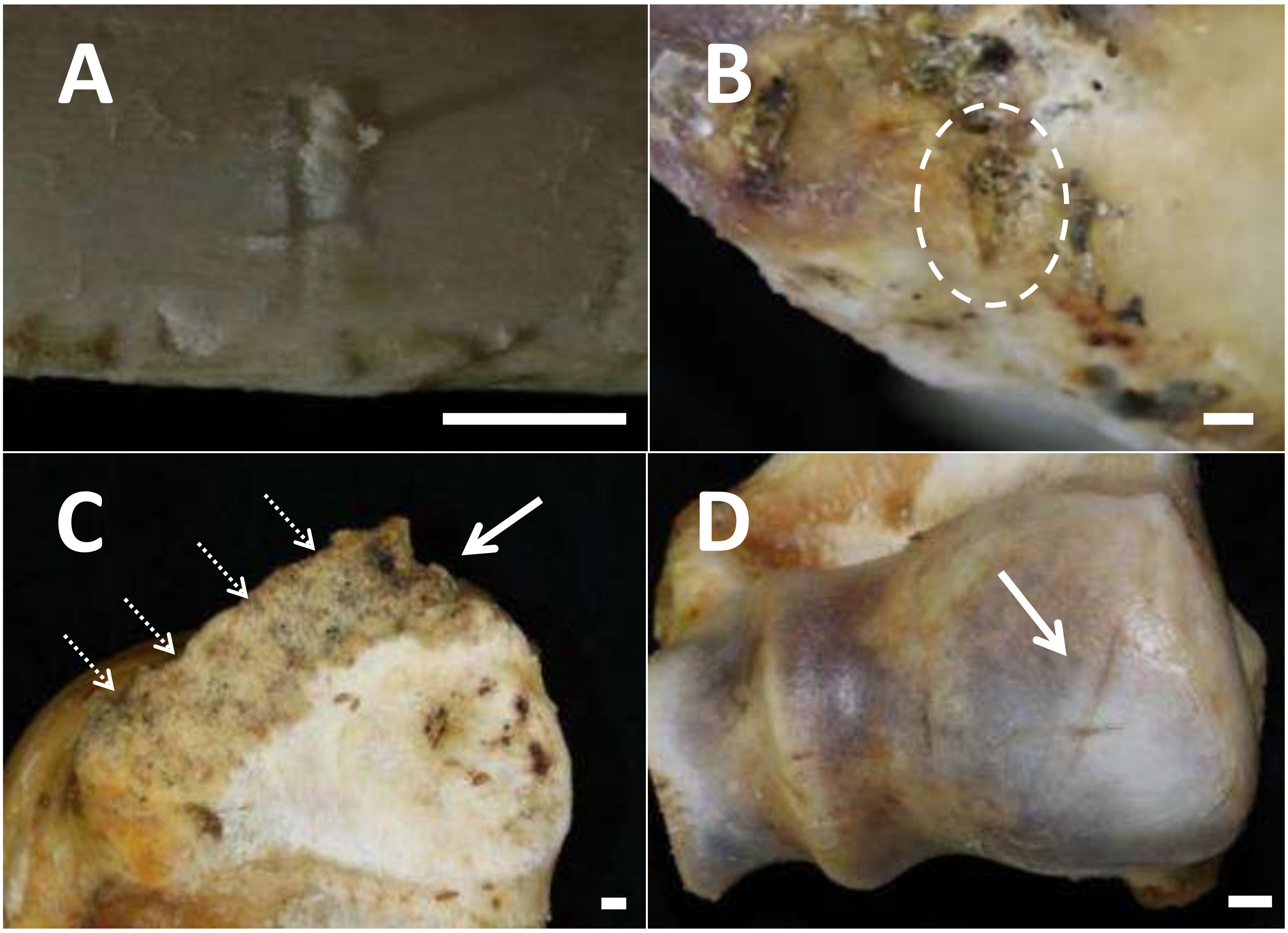

Fig. 2 Wild dog trauma on bone including: (A) a score with frayed edge on a rib shaft, (B) pit on the a head of humerus (dotted circle), (C) gnawing (solid arrow) and shallow furrowing (solid arrow) on a humeral greater trochanter, and (D) claw scores in the cartilage of the humeral trochlea (solid arrow) (scale bar = 10mm)

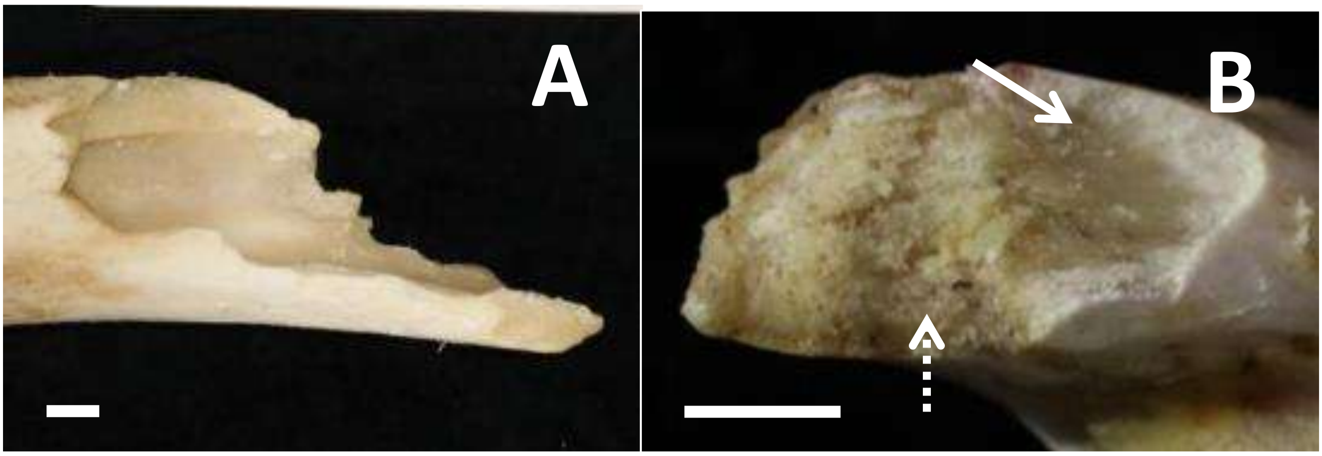

Fig. 3 Hyena trauma on bone including: (A) the jagged margin of the tibia shaft fracture and (B) the separation of cortical and trabecular bone (solid arrow) in addition to gnawing and a shallow furrow (dotted arrow) in a tarsus bone (scale line = 10mm)

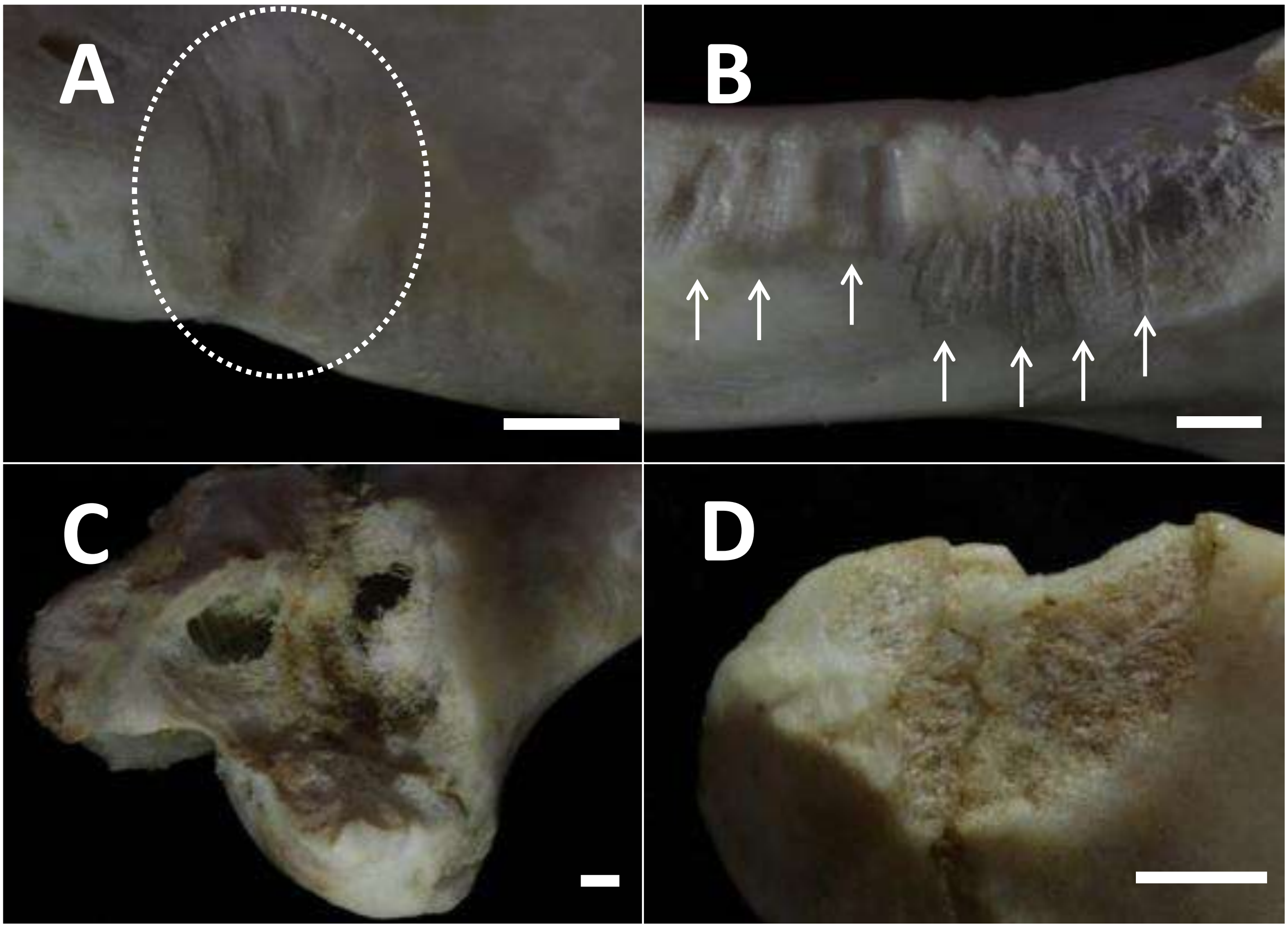

Fig. 4 Porcupine trauma on bone including: (A) fan-like scoring clusters (dotted circle) on the shaft of the humerus and (B) radius (arrows), (C) complete loss of the greater trochanter due to gnawing, and (D) a large, oval depression with an eroded, polished appearance on the olecranon tuber (scale line = 10mm)

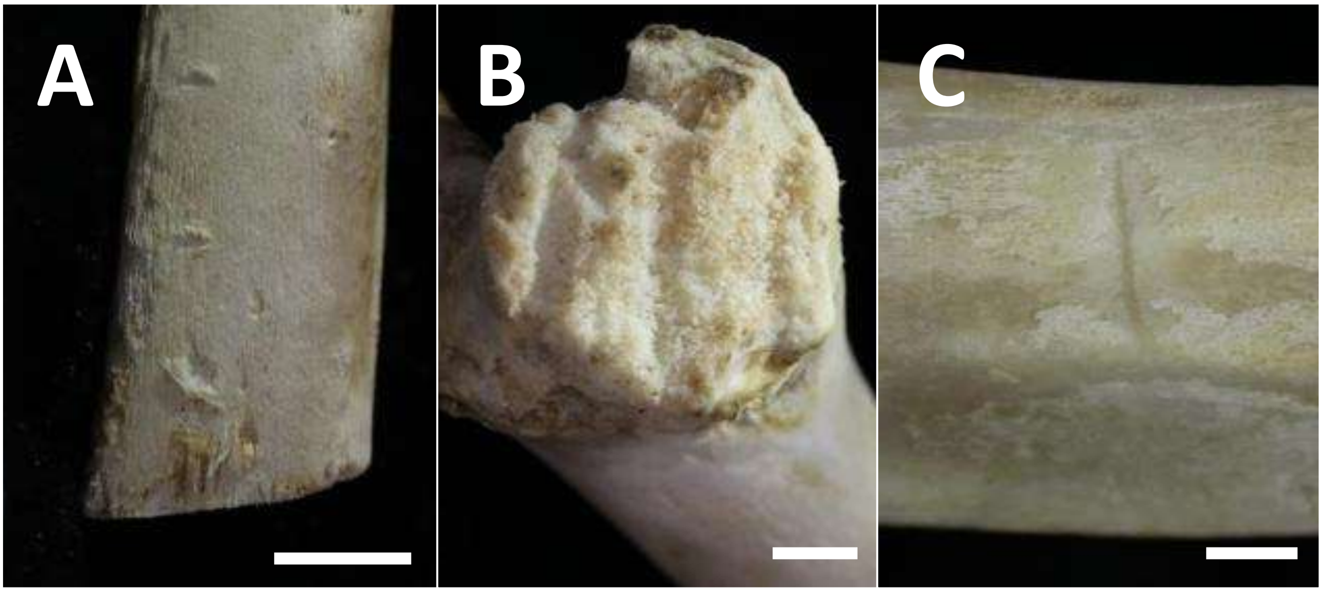

Fig. 5 Leopard trauma on bone including: (A) shallow pits with frayed margins on rib, (B) gnawing with distinct furrows on the femoral greater trochanter, (C) and a wide superficial score on the shaft of a tibia (scale line = 10mm)

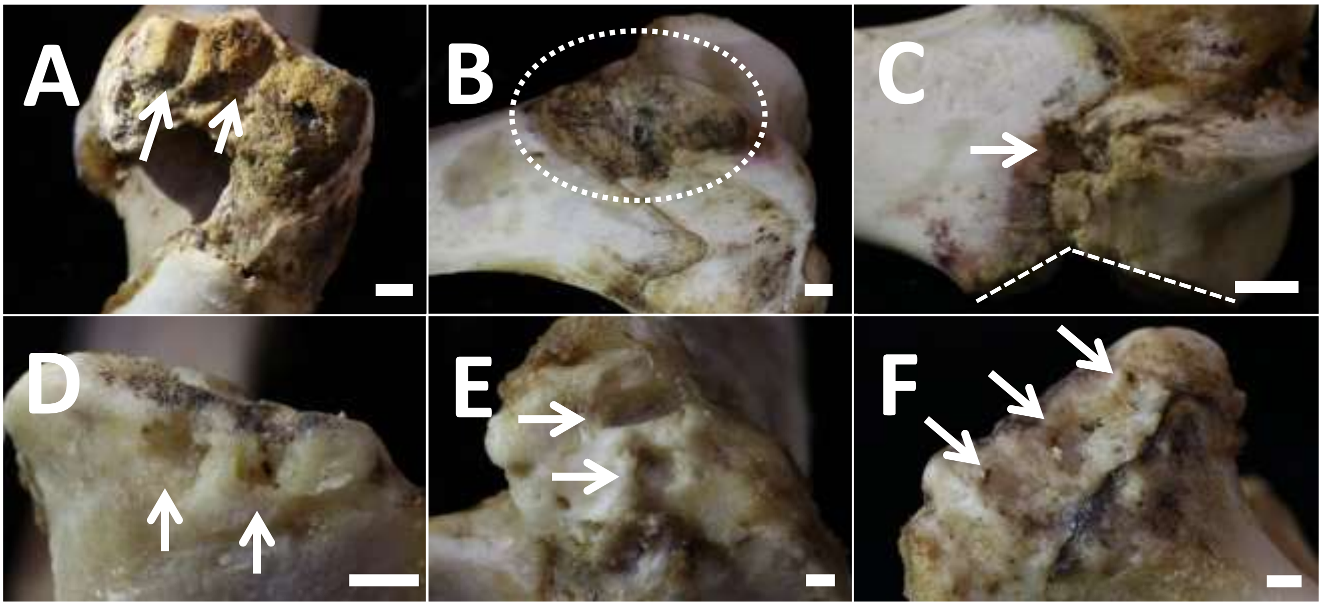

Fig. 6 Lion trauma on bone including: (A) furrows in the greater trochanter (arrows), (B) gnawing of patellar surface (dotted circle), (C) a large conical puncture (arrow) opposite to the gnawed region of the patellar surface (dotted line), (D) punctures in the margin of the medial condyle of the tibia, (E) punctures in the tibial tuberosity, and (F) pits in the margin of the tibial condyle (arrows) (scale line = 10mm)

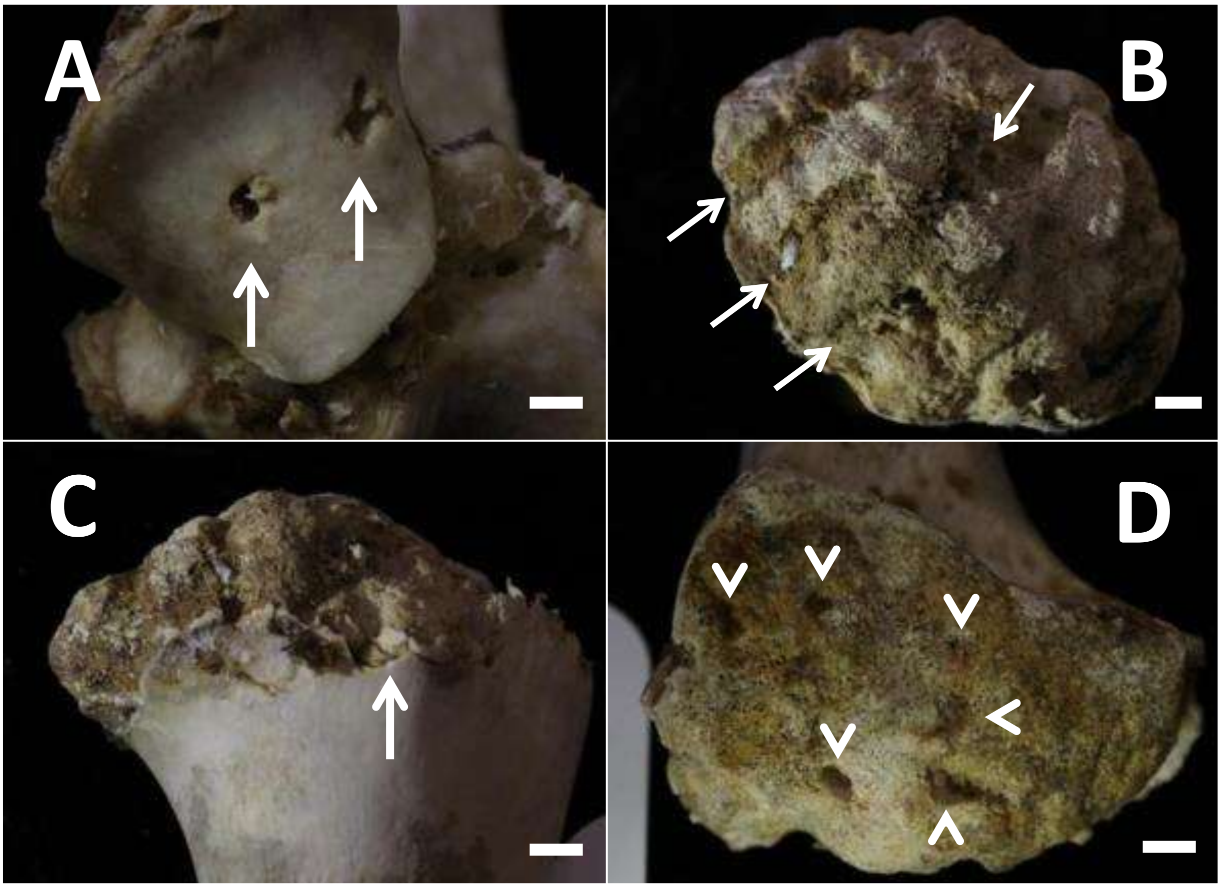

Fig. 7 Caracal trauma on bone including: (A) large irregular punctures (arrows) were present in the condyles of the tibia, (B) furrows (arrows) in the proximal end of the humerus, (C) signs of crushing with curved flaked bone fragments adhering a the gnawed proximal humeral epiphysis (arrow), and (D) multiple large, deep pits (arrows) in the distal end of the humerus (scale line = 10mm)

Table 1: Summary of animal trauma to bovine ribs and limb bones

Animal	Bone	Number of bones placed in enclosure	Number of bones recovered	Intensity of scavenging (+/++/+++)	Type of trauma	Location	Description	Figure
Jackal	Ribs	6	6	+	Pit	Shaft	Single, shallow pit found on one rib	1A
				+	Score	Shaft	Single score found on two ribs each; one shallow & one deep	1B
	Humerus	1	1	+	Score	Mid-shaft	Single, short, shallow, wide score	1C
	Radius	1	1	+	Scores	Shaft	Short, shallow scores clustered in groups of two and three	1D
	Ulna	1	1	None	/	/	No trauma noted	
	Carpus bones	6	6	None	/	/	No trauma noted	
Wild dog	Ribs	6	1	+	Scores	Shaft	The rib exhibited numerous shallow scores; one had frayed boarders of bone peeling out.	2A
				+	Pits	Shaft	Numerous shallow pits of varying depth, size, and shape	
	Humerus	1	1	+	Pit	Margin of the humeral head	Large	2B
				+	Gnawing and furrows	Margin of the greater trochanter	Shallow furrows in trabecular bone of gnawed region	2C
				+	Scores	Cartilage of humeral head	Three scores or varying length	
				+	/	Cartilage of trochlear	Numerous claw marks	2D
	Ulna	1	1	+	Scores	Neck of ulna	Numerous claw marks clustered in a V-shape	
	Radius	1	1	None	/	/	No trauma noted	
	Carpus bones	6	6	None	/	/	No trauma noted	
Hyena	Ribs	6	0	+++	/	/	Consumed entirely	
	Tibia	1	1	+++	Fracture	Shaft	Distal end of shaft remaining with a jagged, uneven fracture margin, indicative of a spiral fracture of the shaft.	3A
	Femur	1	0	+++	/	/	Consumed entirely	
	Tarsus bones	4	3	++	Gnawing	Calcaneus	Gnawing with a shallow furrow. A clear separation of cortical and trabecular bone.	3B

Porcupine	Ribs	6	0	/	/	/	No ribs recovered (suspected mongoose theft)	
	Humerus	1	1	++	Gnawing	Greater trochanter	Completely gnawed away with an uneven, jagged margin	4C
				+	Scores	Neck of humerus beneath gnawed away greater trochanter	Thin fan-like pattern of clustered scores	
				+		Shaft	Wide fan-like pattern of clustered scores	4A
				+		Shaft	Wide parallel and overlapping scores	
				++	Gnawing	Head of humerus	Large, circular region with an eroded, polished appearance	
	Radius	1	1	+	Scores	Mid-shaft	Wide parallel and overlapping scores	4B
				+		Superior and distal ends of shaft	Wide fan-like pattern of clustered scores	4B
	Ulna	1	1	++	Gnawing	Medial and lateral olecranon tuber	Large, oval depressions with eroded, polished appearance	4D
	Carpus bones	6	0	/	/	/	No carpals recovered (suspected mongoose theft)	
Leopard	Ribs	6	2	+	Pits	Shaft of ribs	Numerous shallow pits with frayed peeling bone on some pit margins	5A
				+	Score	Shaft	One short, wide score on one rib. One thin, long score on other rib.	
	Femur	1	1	++	Gnawing and furrows	Greater trochanter	Gnawed away cortical bone with three parallel deep, wide, furrows	5B
				+	Scores	Shaft	Two thin claw marks in V-shape vertically along shaft axis	
	Tibia	1	1	+	Gnawing	Medial condyle	Margin gnawed	
				+	Scores	Shaft	Five wide scores of varying lengths, horizontal to the shaft axis	5C
	Tarsus bones	4	4	++	Pits	Calcaneus	Small, deep pits and small shallow pits	
Lion	Ribs	6	0	/	/	/	No ribs recovered (suspected mongoose theft)	
	Femur	1	1	++	Gnawing and furrows	Greater trochanter	Two wide, deep, parallel furrows	6A
				++	Gnawing	Patellar surface	A large, deep defect caused by gnawing	6B
				+	Puncture	Patellar surface	Large deep conical puncture opposite the gnawing region (both on the patellar surface)	6C
				+	Scores	Shaft	Numerous large, parallel scores near region of strongest muscle attachment	

				+	Pits	Greater trochanter, head, condyles, & distal femur	Many pits of varying sized	
	Tibia	1	1	+	Punctures	Superior, medial margin of the medial tibial plateau	Two conical punctures	6D
				+		Tibial tuberosity	Three deep, large punctures, two of which are joined	6E
				+	Scores	Superior shaft	Numerous large, wide, superficial, parallel scores horizontal to the shaft axis	
				+		Condyle cartilage	Numerous clustered claw mark scores	
				+	Pits	Tibial condyles	Multiple deep pits of varying sizes along the lateral boarder	6F
	Tarsus bones	4	3	++	Scores	Calcaneus	Numerous wide, overlapping scores in V-shapes	
				++	Pits	Calcaneus	Numerous pits in the distal end	
Caracal	Ribs	6	5	+	Score	Costal end	One rib exhibits numerous wide, parallel scores along the costal end of the shaft.	
				+		Shaft	One rib exhibits two scores with frayed boarders of cortical bone and one superficial score; all on the shaft. All scores are horizontal to the shaft axis.	
				+	Pit	Costal end	Numerous pits on three of the ribs; all on costal ends or ribs	
	Femur	1	1	+	Scores	Shaft	Seven thin claw mark scores	
	Tibia	1	1	++	Puncture	Condyles	Two large irregular shaped punctures	7A
				+	Scores	Condyles	Numerous clustered scores	
				+	Furrows	Margin of condyle	Six short parallel furrows.	
	Tarsus bones	4	3	None	/	/	No trauma noted	
	Humerus	1	1	+	Scores	Shaft	Numerous long, wide, shallow scores horizontal to shaft axis	
				+++	Gnawing	Proximal epiphysis	Epiphysis gnawed exposing trabecular bone, with a crushed, flaked margin	7C
				++	Furrows	Proximal epiphysis	Numerous long, wide, deep, parallel furrows in the gnawed trabecular bone	7B
				+	Puncture	Proximal epiphysis	Single deep puncture at the gnawing margin	
				++	Pits	Sawn-off trochlea	Six, large, deep pits in trabecular bone in sawn-off trochlea	7D
				++	Gnawing and furrows	Epicondyles	Two short, shallow furrows	

Discussion

This study aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest and to determine if the patterns of trauma could be used to identify the animal. The general tooth mark patterns observed on the long bones included scores being isolated to the shafts and the heavier gnawing, and deep pits and punctures being confined to the epiphyses. As is seen in this study and previous research, it is common for heavier bone damage to be produced at the epiphyses (11) by scavengers as they try to gain access to the marrow (18). Scavengers will still gnaw on the epiphyses even after flesh and marrow has been removed because the grease in these regions is enough to attract the attention of animals (18). Gnawing of the epiphyseal margin with the appearance of grooves or furrows is typically caused by the grinding or shearing motions of carnassial or molar teeth where the cusps are pressed into the cancellous bone (11). This was exemplary in the present study in the long bones retrieved from the wild dogs and caracals. The current study observed thin scores caused by animal claws - as seen in the bones recovered from the caracals, lions and wild dogs – which cannot be mistaken for tooth marks as they are too narrow to be caused by tooth cusps (12) but they can easily be mistakenly attributed to other sharp force trauma (such as scalpel marks made during maceration). These marks can all indicate scavenging activity; however they are not indicative of the specific animal. On the ribs retrieved from the animal enclosures, only shallow pits and scores were observed along the shafts of the ribs. This is likely due to the flesh on the ribs being relatively lighter than on long bones and easily removed by the feeding animals. The pits and scores are likely caused by light tooth cusp pressure as the rib is maneuvered (11). The consequential deformation of the cortical bone is superficial as it does not puncture through to the underlying trabecular bone.

The jackals and wild dogs in this study only caused light bone damage which was isolated to shallow pits and scores with no unique pattern that can be used to isolate them as the perpetrating animal. These were very difficult to observe without a good light source. The wild dog did leave shallow furrows in the gnawed margin of the greater trochanter of the humerus but this alone was not distinctive enough to be diagnostic. Previous literature on jackal and wild dog scavenging has not explicitly described the tooth mark patterns of jackals and wild dogs. This is likely because there is no specific pattern. However, the literature has focused largely on testing if the size of pits caused by jackals can be used to differentiate them from pits caused by other animals (5, 18, 27) with most concluding that tooth dimensions can only be used to determine if a carnivore was large or small (27).

Previous literature has described that heavy gnawing damage to the proximal epiphyseal ends of long bones by large cats, canids, hyenas, and bears is distinctive enough to identify the general type of animal but not the exact taxa or species (11). The deletion of portions of the proximal epiphyses of long bones combined with deep, parallel furrows in the trabecular bone was distinctive in the three felids in this study (leopard, lion, and caracal). This trauma, particularly the removal of the greater trochanter of the humerus leaving relatively deep, parallel furrows has also been observed in tigers and jaguars (11). The furrows in particular are caused by individual tooth cusps (11) as the animal tries to gain access to the marrow (28). This pattern suggests that, although the specific taxon cannot be determined from this trauma, the general identification of felid involvement can be concluded.

The taphonomic alteration of bone by large felids (such as lions, leopards, panthers, and tigers) has been previously studied, however medium-sized felids - such as the caracal - remain underappreciated. The caracals in this study exhibited the greatest variety of trauma. Caracals were the only animal in this study to cause all animal bite mark types: pits, furrows, scores, and punctures in addition to massive gnawing trauma and claw marks. This could potentially be a discriminatory characteristic for identifying caracals from their trauma; however this needs to be studied in more depth to be stated definitively.

The trauma present on the surviving tibia retrieved from the hyena in this study is also distinct. Total consumption of the proximal end of the tibia, leaving one third of the shaft remaining with jagged fracture edges of the shaft, is a classic sign of hyena scavenging (11). The jagged fracture edges are typically not rounded (11) however in this study the fracture edges were slightly rounded. It has been suggested that the possible cause could be due to repeated licking or rubbing against ground surfaces (11). As the hyena used in this study was captive, the environmental context was different to those in the wild. The removal of competition with other animals for food allows for altered feeding behaviours and as a result different bone modification patterns can be expected (29).

Porcupine scavenging is well documented and has been described as a means of honing the incisor teeth or in cases of osteophagia when the individual animal lacks calcium and/or phosphorus (30). Porcupines will scavenge on fleshed and dry bone without discrimination between the two (31). Porcupine bone damage is well documented in previous literature and is distinguishable from other rodent bone damage (25, 30-33). Porcupine trauma has been described (in this study and other studies previously mentioned) as fan-like parallel scores with undefined contours and regions of heavy gnawing, and the scraping of the epiphyses and adjacent areas resulting in the total destruction of the bony region. The large, oval depression with an eroded, polished appearance observed in this study has not been described explicitly in previous literature. The exact cause is unknown but due to the projecting nature of the olecranon tuber as an easily grasped section of bone, the cause could perhaps be attributed to the repetitive grinding of the mandibular and maxillary incisors on the surface of the olecranon tuber. These characteristic traumas in conjunction with the absence of pits are indicative of porcupine intervention.

In summary, the characteristics of heavy scavenging trauma can be reliable indicators of the perpetrating animal. However, attributing a carnivore to bone modifications should not be based off a single pattern but rather a combination of bone modifications (27). For example the unique fan-like pattern of scores in combination to the absence of pits could suggest a porcupine as the causative taphonomic agent. Very light gnawing damage by all taxa of carnivores could be identical and are not very useful for differentiation between scavengers (11). For example, the jackals caused very minimal and light trauma isolated to a few single scores and pits.

Limitations

The animals used in this study are of southern African origin, however the most promising bite patterns described by this study are applicable in other regions of the world. Porcupines are not only native to Africa but also in Europe and Asia. A study in Israel described similar porcupine destruction of bones (31). The bite patterns of the large cats in this study have also been described in other large cats such as tigers and jaguars (11). These patterns will therefore be observed in other non-African regions of the world with wild large cats, particularly Asia, North America and South America.

There is a difference in the extent of trauma caused by animals in captivity compared to animals in the wild. Gidna et al. (29, 34) determined that there is a higher number of tooth-marked elements and the number of tooth marks per element caused by lions in captivity and the wild (29), and similarly for leopards (34). Due to the altered animal behaviour caused by captivity, the extent of the bone modifications described are potentially more pronounced than those seen in a natural setting (29, 34). Nevertheless the described patterns of bone modification are still valid. It is suggested that this study be replicated in a natural setting to compare the extent of bone modification differences between the captive and free-roaming animals used in this study. Additionally, the descriptions of bone modifications to ribs are limited as the costal and sternal ends of ribs were sawn off prior to placing them in the animal enclosures. As such it is suggested that a study of scavenging rib trauma be repeated with whole specimens in the future. Additionally, the number of bones can be increased in future studies to ensure that the patterns described are common to each animal. Another issue that can be reviewed is the time animals have to scavenging on bones.

This was a descriptive study of bite marks observed on bone caused by different animals. As such a statistical comparison is very difficult. Most published articles of a similar nature typically only describe the trauma as these descriptions are of value (10, 11, 29, 35, 36). In studies where the sample size of the bones is large enough, the frequency of a particular bite mark pattern is provided (2) and this is something that can be repeated in a subsequent study for the same animals used in the present study. The value of qualitative research should not be underappreciated especially in taphonomic research.

Conclusion

The trauma caused to bone by scavenging animals can be used to isolate the perpetrating animals. Felids (such as lion, leopard, and caracal) gnaw away the greater trochanter of the humerus leaving deep, parallel furrows. Hyenas cause massive trauma to bone with little remaining fragments, however surviving long bones typically remain as one third of the shaft with jagged fracture edges. Porcupines leave distinctive fan-like parallel scores, and large, oval depression with an eroded, polished appearance. Light scavenging trauma can indicate the involvement of scavenging animal behaviour; however the exact taxa or species cannot be determined. These criteria will be helpful in the African forensic anthropological setting to discern scavenging trauma on bone and potentially isolate the animal which caused the trauma, and to distinguish between taphonomic scavenging trauma and perimortem trauma.

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