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The use of tooth pits to identify carnivore taxa in tooth-marked archaeofaunas and their relevance to reconstruct hominid carcass processing behaviours

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Abstract

Tooth marks on bones have been used as a proof of carnivore involvement in carcass modification in archaeological assemblages. Recognition of the array of potential carnivores that may intervene in the consumption of carcass elements accumulated at archaeological sites may condition the way archaeologists reconstruct hominid–carnivore interaction and resource availability for both types of taphonomic agents. The development of techniques aimed at discerning carnivore taxa according to tooth mark location and size has proven problematic so far. The present work introduces new information, based on the use of tooth pit size, to determine the types of carnivores that have modified bone surfaces. It is concluded that tooth marks alone cannot be used to differentiate among specific taxa, unless the analysis of tooth pits is carried out taking into account their distribution and ranges of variation in large samples, together with other variables, such as the location of tooth marks according to bone section and element, and the anatomical distribution of furrowing. Even so, the attribution of specific bone damage to determined carnivores can only be confidently made when comparing small-sized versus large-sized carnivores.

Keywords: Tooth pits; Carnivores; Hominids; Furrowing; Epiphysis; Diaphysis

1. Introduction

The identification of tooth marks on archaeofaunas has allowed zooarchaeologists to document the presence of carnivores in the formation and modification of bone assemblages. The distribution and percentages of tooth marks have also been used to evaluate the degree and order of intervention of carnivores in faunal assemblages [4,10,23]. However, researchers are still unable to discern the types of carnivores involved in the modification of bone assemblages.

Tooth mark sizes and shapes have been mostly overlooked by taphonomists. Few of them have paid attention to the diagnostic criteria identifying tooth mark morphology [1,5–7,19,18], or tooth mark diversity (pits, scores, punctures, furrowing) and anatomical location [2,19,23]. Carnivore taxonomic identification from tooth marking processes has been attempted by some researchers [3,17,23]. Haynes [17] used the distinctive types of damage inflicted by carnivores when gnawing bones to differentiate among diverse taxa. He observed the degree of bone destruction (especially the medium to heavy stages) to claim distinctions among bone-gnawing animals. However, several of his observations are subjected to equifinality: canids have been documented to be sometimes as destructive as hyenids and large-sized felids overlap with the former in moderate destructive processes [3,14].

One of the best analytical approaches to tooth marks was provided by Selvaggio's [23] study. She avoided furrowing (which Haynes focused on) and compared tooth pits from a wide sample of carnivores. She also observed that tooth mark sizes are related not only to carnivore size, but also to bone density. For this reason,

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she stratified her sample in three levels: cancellous bone, thin-cortical bone, and dense cortical bone. Selvaggio analyzed the length (major axis) and breadth (minor axis) of tooth pits and quantified their circularity and areas. She included hyenas, leopards, lions, jackals and cheetahs, as well as impressed specimens from fossil carnivore teeth, including *Dinofelis*, *Homotherium*, *Megantereon* and *Percrocuta* in her sample. Her length to breadth ratio documented a strong overlapping among the different carnivores. However, the use of both variables (length and breadth) separately has a great potential, which inspired the present work. Our study suggests that conspicuous tooth marks can be used to distinguish three groups of carnivores: small, medium and large. In the current state of research, we are skeptical that specific carnivore taxa can be identified from tooth mark analysis alone. Nevertheless, data stemming from tooth mark sizes combined with other criteria, such as the degree of furrowing and conspicuous tooth marking and its anatomical distribution [14,17], together with bone attrition could tentatively be used to support specific carnivore species in the modification of a given bone assemblage.

2. Method and sample

The present study focused on tooth pits (Table 1). Scores were also measured for comparative purposes (Table 2). Following Selvaggio's [23] definition, scores are considered here as tooth marks whose length is about three times longer than their width. The sample was stratified according to bone density: cancellous bone (from epiphyseal sections) and dense cortical bone (from mid-diaphyseal sections). Marks were obtained from bones fed upon (in fleshed state) by lions, jackals, and bears and (in defleshed state) by hyenids, dogs, and baboons. The sample of tooth marked bones from lions was obtained in the northern Maasai Mara National Reserve (Kenya). Bones tooth marked by jackals were obtained in two feeding experiments carried out in Tsavo East. Tooth marked bones from hyenas were obtained in experiments documenting carnivore ravaging in Galana and Kulalu [15], as well as from a carcass consumed by humans and ravaged by hyenas [13]. Bones tooth marked by bears were obtained at feeding experiments carried out in the natural reserve of Cabarcenos in Spain. Bones modified by baboons were obtained from a study conducted in the Barcelona zoo (Spain) [16] and at Tsavo East [15]. Bones gnawed by dogs were obtained in feeding experiments with German shepherds (*Canis familiaris*) [21]. All the carcasses used for these experiments are medium sized, belonging to either bovids or equids. Only the bones fed upon by jackals were from a small-sized carcass.

Conspicuous marks were measured in length and breadth. Measurements were taken using binocular lenses and an electronic calliper on molds from marks obtained with Ventura Top light and catalyst gel (similar to Xantopren). Sample size for each carnivore species is shown in Tables 1 and 2.

3. Results

A clear correlation between length and breadth was documented in the pits generated by all the carnivore taxa (Table 1). However, this correlation is not regular in scores, as would be expected, since scores are made by dragging tooth cusps and are not directly related to tooth size alone (Table 2). Tooth size is, therefore, the main factor which accounts for the correlation of both dimensional variables in tooth pits. Initially, pits would, thus, be more reliable for the identification of carnivore taxa than scores. The correlation of both axes in pits is maintained irrespective of the type of bone tissue. Both cancellous and dense bone surfaces show that length and breadth vary together in the same proportion.

The size of both pits and scores is bigger on cancellous bone tissue than on dense cortical surfaces. For the sake of comparison and to increase the sample of carnivore taxa, the data of our analysis are compared to those of Selvaggio's [23] on similar carnivores, adding her data on leopards and cheetahs to our sample (Fig. 1). Pit length on cancellous bone (epiphyseal sections) can be used to reliably establish three tooth-marking groups:

1. Marks under 4 mm, represented by moderately conspicuous marks, and observed in all carnivores but lions. When considering the size of tooth marks, samples with most marks smaller than these measurements are from small canids (jackals) and middle sized felids—leopards and cheetahs [23]. Larger-sized canids seem to leave bigger tooth marks than middle-sized felids, because the former tend to gnaw bones whereas the latter try to avoid it.
2. Marks between 4–6 mm are mostly made by middle-sized and large-sized carnivores except felids other than lions. The mean percentage of tooth marks this size belongs to baboons, dogs and bears.
3. Marks above 6 mm are made by large carnivores, mostly attributable by mean percentage to lions and hyenas.

These results are similar when considering pit breadth. In this case, a sector of tooth marks smaller than 2 mm correspond to medium-sized felids. An intermediate sector of tooth marks between 2–4 mm is the size range where most carnivores overlap. Finally, a sector corresponding to tooth marks above 4 mm corresponds to marks made by hyenas, bears, lions and dogs.

Table 1
Sample size and distribution of the pit marks analyzed. Standard deviation (s.d.), Pearson's coefficient, a probability of each sample are shown. A 95% confidence (two-tailed) interval (C.I.) is also included

		Pits			Pits		
		Epiphyses			Diaphyses		
		Length		Breadth	Length		Breadth
Hyenas							
	No. of marks		50			38	
	Mean	7.37		5.32	3.27		2.24
	s.d.	3.76		2.13	2.13		1.34
	95% C.I.	(2.80–20.80)		(2.00–11.00)	(0.90–11.30)		(0.50–5.80)
	r		0.784			0.877	
	P		0.000			0.000	
Baboons							
	No. of marks		34			34	
	Mean	4.6		3.55	2.55		1.54
	s.d.	5.55		0.56	1.03		0.63
	95% C.I.	(0.23–9.90)		(1.55–5.55)	(1.09–6.08)		(0.46–3.39)
	r		0.76			0.733	
	P		0.000			0.000	
Jackals							
	No. of marks		40			40	
	Mean	3.5		3.55	1.45		0.85
	s.d.	0.7		0.56	0.75		0.46
	95% C.I.	(2.80–4.20)		(1.55–5.55)	(0.51–3.67)		(0.26–2.40)
	r		0.78			0.84	
	P		0.000			0.000	
Bears							
	No. of marks		44			14	
	Mean	5.24		3.73	2.9		1.88
	s.d.	2.84		2.1	0.88		0.58
	95% C.I.	(1.43–13.99)		(0.50–9.97)	(1.60–4.93)		(1.00–2.93)
	r		0.93			0.67	
	P		0.000			0.009	
Dogs							
	No. of marks		23			16	
	Mean	4.93		3.34	3.87		2.38
	s.d.	2.02		1.71	1.47		0.84
	95% C.I.	(1.84–9.88)		(1.37–7.93)	(1.96–6.32)		(1.01–4.28)
	r		0.84			0.72	
	P		0.000			0.001	
Lions							
	No. of marks		13			10	
	Mean	6.5		4.32	3.45		2.2
	s.d.	1.08		0.86	0.48		0.31
	95% C.I.	(4.50–8.00)		(3.00–5.60)	(2.50–4.00)		(1.50–2.50)
	r		0.97			0.97	
	P		0.000			0.000	

When diaphyses are considered (thick cortical bone), tooth marks can be broadly divided into two groups: one of them, identified by marks under 2 mm long and 1.5 mm broad, belonging to small carnivores, such as jackals, and to middle-sized felids. Marks above those measurements can be attributed to the remaining of carnivores. Differences can only be clearly established when the size is superior to 4 mm in length and 2 mm in breadth. In such cases, either hyenas, dogs or lions could be responsible for them. A general phenomenon of convergence makes it almost impossible to isolate a determined carnivore species based solely on tooth pit dimensions on cortical bone surfaces.

4. Discussion

Tooth marks alone cannot confidently be used to identify specific carnivore taxa in bone assemblages

Table 2
Sample size and distribution of the score marks analyzed. Standard deviation (s.d.), Pearson's coefficient, and the probability of each sample are shown. A 95% confidence (two-tailed) interval (C.I.) is also included

		Scores			Scores		
		Epiphyses			Diaphyses		
		Length		Breadth	Length		Breadth
Hyenas							
	No. of marks		13			59	
	Mean	13.4		4.59	7.34		1.29
	s.d.	6.59		2.62	4.67		1.22
	95% C.I.	(7.10–25.20)		(1.40–9.00)	(2.00–31.60)		(0.20–8.10)
	r		0.77			0.55	
	P		0.002			0.678	
Baboons							
	No. of marks		19			19	
	Mean	4.5		3.5	8.08		1.09
	s.d.	1		0.5	3.18		0.84
	95% C.I.	(3.50–5.50)		(3.00–4.00)	(2.46–17.85)		(0.28–3.53)
	r		−0.41			−0.51	
	P		0.773			0.836	
Jackals							
	No. of marks		—			40	
	Mean	—		—	3.35		0.41
	s.d.	—		—	1.09		0.15
	95% C.I.	—		—	(1.88–5.67)		(0.19–0.73)
	r		—			0.127	
	P		—			0.651	
Bears							
	No. of marks		4			14	
	Mean	10.64		2.19	10.92		1.65
	s.d.	5.87		1.28	5.02		1.31
	95% C.I.	(5.30–17.55)		(1.06–3.67)	(5.32–19.57)		(0.30–5.32)
	r		−0.71			0.452	
	P		0.929			0.105	
Dogs							
	No. of marks		12			23	
	Mean	12.8		1.77	12.8		1.5
	s.d.	4.65		1.19	6.12		0.76
	95% C.I.	(6.26–21.48)		(0.58–4.58)	(4.95–26.55)		(0.45–3.49)
	r		0.2			0.188	
	P		0.520			0.390	
Lions							
	No. of marks		7			5	
	Mean	23.7		4.95	8.4		2.2
	s.d.	4.22		0.61	1.14		0.27
	95% C.I.	(18.20–29.00)		(4.00–6.00)	(7.00–10.00)		(2.00–2.50)
	r		0.11			0.8	
	P		0.814			0.898	

(contra [24]). Different tooth mark sizes, both considering length and breadth, can be used, accordingly, to distinguish between groups of carnivores including several taxa in each group. Small-sized carnivores, together with middle-sized felids can clearly be differentiated from other (larger) carnivores in tooth mark sizes both in cancellous (epiphyseal) and cortical (diaphyseal) bone surfaces. A preliminary tooth-marking region can be used as a frame of reference to further differentiate among diverse carnivore taxa. This region would be defined by the mean and one S.D. of tooth pit sizes in each sample attributed to specific carnivore species. Given the ambiguity of some overlapping tooth mark size ranges, mixing tooth mark sizes and bone furrowing processes can yield a better basis for speculation regarding the identification of the carnivore species involved in the modification of any given bone assemblage [17]. For instance, intense bone furrowing of epiphyseal

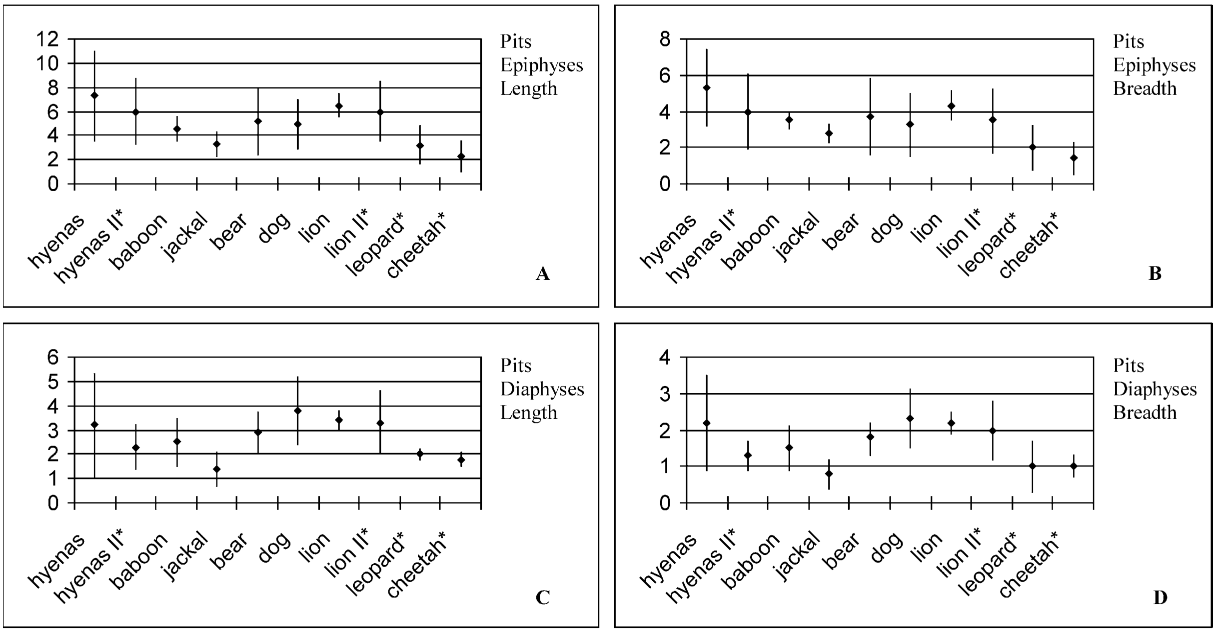

Fig. 1. Mean percentages and one S.D. of tooth pit sizes stratified by bone type: cancellous (A, B) and dense cortical (C, D), and length (A, C) and breadth (B, D). Samples with (*) have been taken from Selvaggio [23] for comparative purposes.

fragments from most limb elements is more likely to be the action of hyenids and canids than of lions [15]. Lions focus mostly on the proximal and distal sections of upper limb bones (humerus and femur) for furrowing. Furrowing by lions in other elements is much more marginal and only appears in smaller carcasses [14].

The only procedure that could produce a better basis to use tooth mark sizes to identify carnivore taxa is the consideration of the global sample of tooth marks and their ranges of variation, as shown in this work. Isolated marks are of little use. Recently, Selvaggio and Wilder [24] have reported data on tooth mark sizes for a wide variety of carnivores. They have also made interpretations of carnivore involvement at the FLK Zinj site. They observed that the "mean area of tooth pits on cancellous bone in the FLK Zinj sample is similar to those inflicted by hyenas and lions" [24], p. 467. They have also claimed that (p. 467) "for cortical bone, the Zinj sample is most similar in area to pits inflicted by cheetahs, leopards, and spotted hyenas". According to these data, carnivore involvement at the FLK Zinj could be the effect of hyenas post-ravaging bones abandoned by hominids or the action of medium-sized felids defleshing carcasses, hominids demarrowing them and then, hyenas ravaging the assemblage. To support the latter claim, Selvaggio and Wilder observe that "tooth pits in the Zinjanthropus sample exhibit more variation in the ratio of the major to minor axes than those made by any single modern or extinct carnivore species". However, this assertion assumes, rather than demonstrates, that a greater variation in the length/breadth ratio at the FLK is the result of several carnivore taxa involved in bone tooth marking. In order for this claim to be supported, the length/breadth ratio of all the carnivores together should yield a wide standard variation. Regarding this issue, in our study, we have observed that:

Table 3
Mean breadth:length ratio of all carnivore pits plus one standard deviation

	Mean	S.D.
Hyenas	1.45	0.49
Baboons	1.51	0.5
Jackals	1.83	0.57
Bears	1.51	0.38
Dogs	1.61	0.45
Lions	1.53	0.57
All	1.55	0.47

1. The length/breadth ratios for individual carnivore taxa are similar but not the same as those reported by Selvaggio and Wilder [24] for the same species. This documents a wider variation than isolated experiments have reported thus far.
2. When lumping all the carnivore pits together, as a single sample, the length/breadth ratio and its corresponding standard variation is similar to those shown by most carnivore pit samples analyzed individually by taxa (Table 3). The range of variation is equally reduced. The broad standard variation reported for the FLK Zinj should be the result of other processes or reasons unaccounted for in

Selvaggio and Wilder's [24] work and does not seem to be the result of multiple taxa involved in tooth marking the same elements.

A closer look at the FLK data shows that pits and scores have been mixed. The upper standard variation includes marks that are three times longer than wider. Furthermore, if applying the global distribution of pit sizes by sample, the sizes (in mm) obtained in the FLK Zinj for pits on cancellous sections (X=6.3 ± 3.5 long and X=3.6 ± 2.5 broad) and cortical sections (X=2.1 ± 1.0 long, X=0.9 ± 0.5 broad) are mostly similar to those obtained for spotted hyenas: cancellous bone (X=6 ± 2.7 long; X=4.8 ± 2.1 broad) and cortical bone (X=2.3 ± 0.9 long; X=1.3 ± 0.5 broad) [23]. Rejecting the multiple carnivore hypothesis also avoids the conflict in assuming that medium-sized felids would be responsible for defleshing the carcasses represented at the FLK Zinj, being most of them middle-sized (size 3; [9]), and, therefore, outside the predatory range of carnivores the size of leopards or cheetahs. Although leopards have been reported to sporadically prey upon larger carcasses [12,20], most of the animals they hunt are smaller than 150 kg [8,11,22,20,25]. Tooth pit size, therefore, cannot be used to support the three-stage model (carnivore–hominid–carnivore) defended by Selvaggio and Wilder [24] to explain hominid–carnivore interaction at the FLK Zinj site of Olduvai.

Tooth pit size, considered together with other bone destruction processes, can yield significant information regarding the type of carnivores involved in the modification of carcasses. However, given the differential resolution of mark sizes on epiphyseal and on cortical bone sections, experimentation has not yet been able to rule out equifinality in several of these processes. Further research should increase the differentiation threshold initiated by Selvaggio and Wilder [24] and the present work.

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