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Assessing the effects of fluvial abrasion on bone surface modifications using high-resolution 3-D scanning

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ABSTRACT

Stone tool cut marks and carnivore tooth marks on fossil bones are invaluable traces of the feeding behavior and ecology of our ancestors. Recent research has focused on quantifying the micromorphology of experimentally created cut and tooth marks using high-resolution 3-D scanning technology with the goal of improving the reliability and accuracy of interpretations that are based on these feeding traces. However, to apply these experimental data in the identification and interpretation of bone surface modifications on fossil bones, the effect of post-depositional processes on the micromorphology of feeding traces must be known. Previous research has shown that fluvial abrasion has a substantial impact on the qualitative criteria that are used to identify cut marks, but the specific effect of hydraulic transport and abrasion on quantifiable attributes of bone surface modifications is completely unknown.

The objective of this research is to understand the effects of fluvial abrasion on the micromorphology of cut marks and mammalian carnivore tooth marks using high-resolution 3-D data. An experimental study was undertaken by tumbling cattle and deer bones in a rock tumbler filled with sand and water to simulate the effects of fluvial abrasion on the bone surface modifications. Variables were measured using qualitative (visual observation of rounding and polishing of the bone surfaces, and the effect of these processes on the potential identifiability of cut and tooth marks) and quantitative (surface area, volume, maximum depth, mean depth, maximum length, maximum width, roughness, angle, and radius of the marks) criteria. The 3-D data from cut and tooth marks was collected using a white-light confocal profilometer and analyzed with specialized surface metrology software. Analyses of both qualitative and quantitative data indicate that fluvial abrasion has a greater effect on cut marks than tooth marks, suggesting that the frequency of cut marks could be underestimated relative to carnivore tooth marks in archaeological assemblages preserved in fluvial environments. This could affect interpretations of hominin feeding behavior based on the abundance of bone surface modifications when relying on qualitative methods alone. However, 98.6% of marks were identified correctly after tumbling when using multivariate quantitative methods of analysis bolstering the need for applying these methods in the interpretation of bone surface modifications on fossil specimens.

1. Introduction

Bone surface modifications, such as stone tool cut marks and carnivore tooth marks, can provide vital information about the taphonomic history of fossil bone assemblages, particularly those recovered from Early Stone Age archaeological sites where few other behavioral traces are left behind (Binford, 1981; Bunn, 1981; Potts and Shipman, 1981; Olsen and Shipman, 1988; Fisher, 1995; Njau and Blumenschine, 2012). They offer important clues about ecological interactions between hominins and carnivores and have been used to infer the technological and behavioral capabilities of our ancestors as they began to encroach upon the larger carnivore guild around 2.5 million years ago (Blumenschine, 1988, 1995; Capaldo, 1995; Dominguez-Rodrigo, 1997; Ferraro et al., 2013; Pante et al., 2012; Pante and de la Torre, in press; Pante et al., in press; Pobiner et al., 2008). However, hominin behavioral interpretations that are based on bone surface modifications remain among the most debated in paleoanthropology, due to the lack of standardized methods and the subjectivity of identifications that rely on qualitative criteria (Blumenschine et al., 2007; Domínguez-Rodrigo and Barba, 2006; Domínguez-Rodrigo et al., 2012; McPherron et al., 2010; Pante et al., 2015, 2017). In response to these challenges researchers have focused their efforts on developing quantitative and replicable

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methods for the identification and interpretation of bone surface modifications (Bello and Soligo, 2008; Maté-González et al., 2015, 2017; Aramendi et al., 2017; Arriaza et al., 2017; Harris et al., 2017; Pante et al., 2017; Yravedra et al., 2017; Otárola-Castillo et al., 2018). Most recently, Pante et al., 2017 introduced the first method for distinguishing between stone tool cut marks and carnivore tooth marks using only quantitative measurements collected from 3-D scans. However, these comparisons were based on feeding traces created in experimental settings where bones had not undergone post-depositional modification by processes such as hydraulic transport and abrasion.

Despite a body of research that has addressed hydraulic transport of bones in fluvial environments (Dodson, 1973; Wolff, 1973; Boaz and Behrensmeyer, 1976; Coard and Dennell, 1995; Coard, 1999), there is very little knowledge of the specific effects of fluvial processes on cut mark micromorphology, and the effect on carnivore tooth marks remains completely unknown. Research concerning the impact of hydraulic abrasion on bone surface modification morphology is limited to only a few studies, none of which use quantitative criteria. These studies have shown that fluvial process can alter the morphology of cut marks by erasing their diagnostic features (Shipman and Rose, 1983, 1988) and hinder their identification on bone surfaces (Shipman and Rose, 1983, 1988; Gaudzinski-Windheuser et al., 2010) suggesting that fluvial abrasion has the potential to impact interpretations of the behavior and ecology of hominin feeding that are based on these marks. However, these observations are based only on qualitative criteria such as cross-sectional morphology of the marks or internal topography (i.e. striations and crushing) and the effects of fluvial abrasion have yet to be measured quantitatively. Shipman and Rose (1983, 1988) carried out the most systematic observations of the effects of fluvial abrasion on cut mark morphology using a scanning electron microscope (SEM) and found that cut marks lose all of their qualitative diagnostic features such as fine striations and V-shaped cross sections and were reduced to rounded indentations after only a few hours of abrasion in a rock tumbler. They argued that “hydraulically transported bones cannot be expected to show cut marks that can be identified on the basis of SEM inspection” (Shipman and Rose, 1988: 320). A later study conducted by Gaudzinski-Windheuser et al. (2010) investigated the effects of sediment abrasion on bone and cut marks that were exposed to unidirectional and multidirectional water movement. They observed that most cut marks on cattle bones were altered or completely vanished after 3 to 6 h of unidirectional and multidirectional water movement. They also noted that, after 16 h of multidirectional tumbling, the cut marks on sheep bones were altered while most cut marks on cattle bones were obliterated (Gaudzinski-Windheuser et al., 2010). This research shows that qualitative observation of cut marks on bones recovered from fluvial environments is likely to be unreliable.

In this study, we present a systematic and comprehensive assessment of the effects of fluvial abrasion on stone tool cut marks and carnivore tooth marks using both qualitative (rounding and identifiability of the marks) and quantitative (surface area, volume, maximum depth, mean depth, maximum length, maximum width, roughness, opening angle, and floor radius) criteria. Following Shipman and Rose (1983, 1988), we employ a rock tumbler to simulate the effects of fluvial processes on bone surfaces. However, we are the first to employ a confocal profilometer to quantify the effects of fluvial abrasion on bone surface modifications following the methods prescribed by Pante et al. (2017) and to assess the differential impact of fluvial processes on cut and tooth mark morphology. Ultimately, this research provides important context for the application of both qualitative and quantitative methods in the identification of fossilized feeding traces.

2. Materials and methodology

2.1. Sample

Our sample consists of limb bone fragments from six adult cattle and five sub-adult deer, determined by the lack of epiphyseal fusion. The cattle bones came from a local market, and the deer bones were received from the Zooarchaeology and Paleoanthropology Laboratory at Colorado State University, Fort Collins, Colorado (Table 1). The bones (three tibiae and three femora) in the cattle sample were previously frozen with a small amount of flesh and grease remaining, while the bones from the deer sample (two tibiae and three femora) were devoid of grease due to subaerial weathering.

Table 1
List of specimens and the distribution of the cut marks (CM) and the tooth marks (TM).

Specimen	Animal	Weathering stage	Skeletal element	CM number	TM number
B1	Cattle	0	Tibia	1	4
B2	Cattle	0	Tibia	2	10
B3	Cattle	0	Tibia	9	0
B4	Cattle	0	Femur	3	4
B5	Cattle	0	Femur	2	5
B6	Cattle	0	Femur	5	0
B7	Deer	1	Femur	3	0
B8	Deer	1	Tibia	7	0
B9	Deer	0	Femur	7	0
B10	Deer	0	Femur	2	0
B11	Deer	1	Tibia	8	0
Total				49	23

2.2. Experimental procedure

The condition of bones was observed and recorded prior to any experiments. Among the criteria recorded were the weathering stages of the bones as defined by Behrensmeyer (1978) and if the bones preserved soft tissue. The cattle bones from the local market were all determined to be weathering Stage 0 or fresh. However, the deer bones were in variable states of weathering with three in weathering Stage 1 and two unweathered.

Once the condition of bones was recorded, cut and tooth marks were inflicted on bone surfaces. Cut marks were created by slicing defleshed bones with chert and/or obsidian flakes in a direction perpendicular to the long axis of the bone, while attempting to keep force and angle relative to the bone surface as consistent as possible. Unretouched flakes made from chert and obsidian were selected to create marks similar to those found in Stone Age archaeological sites, as cut marks produced by stone tools have been shown to have different morphological features from those created by metal blades (Bello and Soligo, 2008; Boschin and Crezzini, 2012). All cut marks were produced on boiled and degreased bone surfaces with the periosteum removed. Tooth marks were created by a 10-year-old dog (husky breed) on 4 cattle bones (B1, B2, B4, B5) bearing small amounts of flesh. The dog accessed each bone separately and the gnawing process lasted almost 3 h in total, all within a single day. The gnawed bones were boiled with a small amount of degreasing detergent for nearly 4 h. After the boiling process, the remaining periosteum was removed from bone surfaces without the aid of any tool. Eight of the cut marks were created on these gnawed cattle bones subsequent to the boiling and degreasing process.

A total of 53 cut marks and 26 tooth marks were created. However, three cut marks and three tooth marks were not scanned after tumbling due to issues with sand particles getting stuck in the marks during the tumbling procedure. These marks were excluded from both qualitative and quantitative analyses. Also, one cut mark was excluded from quantitative analysis since it was completely eroded after tumbling. Consequently, 49 cut marks and 23 tooth marks were used for both qualitative and quantitative analyses (Table 1). All marks were labeled on bone surfaces, and they were photographed and scanned following the below procedure prior to any additional modification.