Journal of Archaeological Science xxx (2017) 1–12

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Differentiating between cutting actions on bone using 3D geometric morphometrics and Bayesian analyses with implications to human evolution

Erik Otárola-Castillo [a, *], Melissa G. Torquato [a], Hannah C. Hawkins [a], Emma James [b], Jacob A. Harris [c], Curtis W. Marean [c, d], Shannon P. McPherron [e], Jessica C. Thompson [f]

[a] Department of Anthropology, Purdue University, West Lafayette, IN, USA
[b] School of Social Science, The University of Queensland, Brisbane, Australia
[c] Institute of Human Origins and School of Human Evolution and Social Change, Arizona State University, Tempe, AZ, USA
[d] African Centre for Coastal Palaeoscience, Nelson Mandela University, Port Elizabeth, Eastern Cape 6031, South Africa
[e] Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany
[f] Department of Anthropology, Emory University, Atlanta, GA, USA

ARTICLE INFO

Article history:
Received 29 June 2017
Received in revised form
13 October 2017
Accepted 16 October 2017
Available online xxx

Keywords:
Cut marks
Multivariate methods
Butchery
Shape
Taphonomy

ABSTRACT

Studies of bone surface modifications (BSMs) such as cut marks are crucial to our understanding of human and earlier hominin subsistence behavior. Over the last several decades, however, BSM identification has remained contentious, particularly in terms of identifying the earliest instances of hominin butchery; there has been a lack of consensus over how to identify or differentiate marks made by human and non-human actors and varying effectors. Most investigations have relied on morphology to identify butchery marks and their patterning. This includes cut marks, one of the most significant human marks. Attempts to discriminate cut marks from other types of marks have employed a variety of techniques, ranging from subjectively characterizing cut mark morphology using the naked eye, to using high-powered microscopy such as scanning electron microscopy (SEM) or micro-photogrammetry. More recent approaches use 3D datasets to obtain even more detailed information about mark attributes, and apply those to the fossil record. Although 3D datasets open promising new avenues for investigation, analyses of these datasets have not yet taken advantage of the full 3D surface morphology of BSM. Rather, selected cross-sectional slices of 3D scans have been used as proxies for overall shape. Here we demonstrate that 3D geometric morphometrics (GM), under the "Procrustes paradigm" and coupled with a Bayesian approach, probabilistically discriminates between marks caused by different butchery behaviors. At the same time, this approach provides a complete set of 3D morphological measurements and descriptions. Our results strengthen statistical confidence in cut mark identification and offer a novel approach that can be used to discriminate subtle differences between cut mark types in the fossil record. Furthermore, this study provides an incipient digital library with which to make future quantitative comparisons to archaeological examples, including contentious specimens that are key to understanding the earliest hominin butchery.

1. Introduction

Butchery marks on fossil or sub-fossil bones comprise one of the most important classes of material traces with which to infer past human subsistence behavior. Cut mark analyses in particular have enjoyed an extensive history of investigation in archaeology, dating back in the English-speaking literature to the pioneering work of Lartet (1860) and Lartet and Christy (1875). Archaeologists later identified other types of butchery marks such as hammerstone percussion marks (Blumenschine and Selvaggio, 1988), which have played a salient role in the interpretation of early hominin sites such as at Olduvai Gorge, Tanzania (Blumenschine, 1995; Mora and De la Torre, 2005; Pante et al., 2012). Butchery marks are essential for interpreting the timing of hominin access to carcasses (Pante

* Corresponding author.
E-mail address: eoc@purdue.edu (E. Otárola-Castillo).

https://doi.org/10.1016/j.jas.2017.10.004

et al., 2015), what kinds of nutrients (e.g. within-bone or outside-bone) remained at the time of access (Pobiner, 2015), and tool-use strategies (Merritt, 2016). There has been much disagreement over the understanding of early hominin ecology due to inconsistencies in how taphonomists have identified butchery marks (Domínguez-Rodrigo and Alcalá, 2016; Blumenschine et al., 2007; Sahle et al., 2017). Consequently, it is imperative to develop new quantitative and more objective strategies for distinguishing between the agents that have produced the marks (Braun et al., 2016).

Cut marks are some of the most variable butchery traces (Domínguez-Rodrigo and Yravedra, 2009). At the same time, cut marks are the butchery traces predominantly used to make inferences about prehistoric butchery behavior – including, but not limited to, that of early hominins. Therefore, it is crucial to develop a reliable framework with which to discriminate cut mark morphologies from the morphologies of other bone surface modifications (BSMs). Such a framework can achieve two things. First, it can serve to distinguish between cases where the potential for equifinality is a problem, for example where anthropogenic and natural processes – such as stone tool butchery, trampling, and carnivore gnawing – may have created similar mark morphology (Behrensmeyer et al., 1986; Domínguez-Rodrigo et al., 2009; Olsen and Shipman, 1988; Sahle et al., 2017). Second, this framework can be a useful tool for reconstructing details of past behavior, for example, discriminating between activities such as slicing or scraping. Modifications have traditionally been identified by drawing on "expert knowledge", based on extensive experience working with both fossil and experimental collections (e.g. Blumenschine et al., 1996). It has become increasingly apparent, however, that such an approach is problematic in cases where mark morphologies have ambiguous characteristics or are from contentious contexts where the mis-diagnosis of even a few marks could have major implications for the interpretation of ancient hominin behavior (e.g., Domínguez-Rodrigo et al., 2010; McPherron et al., 2010). This problem has been recently reviewed by Harris et al. (2017), who emphasize the need for forms of data collection that rely less on expert knowledge and which produce probabilistic estimates of mark agency.

The solution to this problem is 1) to link morphologies to behavioral functions specific to prehistoric actions, effectors, and actors within a probabilistic framework (e.g., Harris et al., 2017) and 2) to achieve an acceptable level of statistical confidence in discerning between such morphologies. To this end, we develop a novel complete 3D morphometric and statistical approach that is capable of differentiating between BSMs, and demonstrate its utility by discriminating between cut marks produced experimentally through different butchery activities. This approach not only provides replicable results less influenced by analyst subjectivity, but also enables researchers to assign probabilities to the goodness of fit between a given mark and its inferred underlying causality.

2. Background

Over the past two decades, actualistic or experimental studies have dominated research on butchery marks, as archaeologists have sought to determine the conditions under which marks are made and assign those conditions to distinctive morphologies (James and Thompson, 2015). Interpretations of early hominin subsistence strategies in Africa have commonly formed the backdrop of these debates (Blumenschine et al., 2007; Domínguez-Rodrigo and Barba, 2006; Domínguez-Rodrigo et al., 2010; McPherron et al., 2010). Adding another layer of complexity have been controversies over which strategies should be used to record, analyze, and interpret assemblages of marks (Abe et al., 2002; Domínguez-Rodrigo, 2003; Domínguez-Rodrigo et al., 2009; Lupo and O'Connell, 2002; Lyman, 1987; O'Connell et al., 2003; O'Connell and Lupo, 2003; Otárola-Castillo, 2010). Fundamentally, however, all types of butchery mark analysis depend on the accuracy with which marks can be assigned to the actor, effector, and action that caused them (terminology following Gifford-Gonzalez (1991)).

Scientific fields that deal with complex naturalistic datasets, such as conservation biology and ecology, frequently incorporate expert knowledge and practical decision-making into data analysis (e.g., Kuhnert et al., 2010; Martin et al., 2012; Southwell et al., 2017). In zooarchaeology, expert knowledge from analysts who are well trained in the use of relevant reference collections is applied to both the basic identification of faunal remains and the taphonomic modifications that they bear. In the case of butchery mark identification, for example, Blumenschine et al. (1996) demonstrated the success of this approach in blind tests of inter-analyst correspondence and accuracy. The results showed that students with fewer than three hours of training were able to correctly differentiate between experimentally-generated cut marks (from a stone tool), percussion impact marks (from a hammerstone), and tooth marks (from a carnivore) at levels exceeding 86%. There has been less success with other types of zooarchaeological identification, for example when multiple analysts failed to achieve a high level of consistency in identifying fish remains (Gobalet, 2001) and cut mark characteristics (Domínguez-Rodrigo et al., 2017).

The use of expert knowledge in butchery mark studies has sought to achieve the confident identification of marks spanning an enormous range of time periods and geographic areas. This approach has been criticized or dismissed in cases where (a) the presence of butchery marks is unexpected due to the lack of associated artifacts (McPherron et al., 2010; Waters et al., 2011; Fariña, 2015; Dowd and Carden, 2016); (b) there are disputes over the association between faunal and cultural remains (Fillios et al., 2010); or (c) the dates fall outside the accepted range of human presence in the region (Morlan, 2003; Hockett and Jenkins, 2013; Bourgeon et al., 2017). In such cases, some researchers question the reliance on expert knowledge and the use of blind tests to identify the agents generating the bone marks. Instead, they consider mark morphology to be only one component of identification and place heavier emphasis on the context of the finds (Domínguez-Rodrigo et al., 2010; Njau, 2012).

The debate surrounding the discovery of two bones from the site of Dikika DIK-55 in the Afar Region of Ethiopia (McPherron et al., 2010) illustrates the tension between these approaches. These fossils bear damage that was assigned to hominin butchery based on the identifications of three experts in taphonomy and bone surface modification analysis working blind to each other. Two were unaware of the context of the finds. The specimens were recovered from strata associated with *Australopithecus* and dating to 3.39 million years ago (Mya). At the time of their discovery, the oldest evidence of stone tools and hominin butchery (from sites at Gona, Ethiopia) had been dated to approximately 2.6–2.5 Mya (Domínguez-Rodrigo et al., 2005; Semaw et al., 2003). Although stone artifacts have now been reported that date to 3.3 Ma, there is little direct evidence that they were used for butchery (Harmand et al., 2015). Therefore, if the Dikika marks were created through stone tool butchery, this would push back evidence of this behavior by 800,000 years – a shift that would significantly impact our understanding of the evolution of human behavior (e.g., Braun, 2010). Critics have argued that several attributes of the marks, including their morphologies, more closely resemble those produced incidentally through natural trampling within a coarse substrate (Domínguez-Rodrigo et al., 2010). However, those who support the stone tool interpretation have suggested that there is