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The trajectory of bone surface modification studies in paleoanthropology and a new Bayesian solution to the identification controversy

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ABSTRACT

A critical issue in human evolution is how to determine when hominins began incorporating significant amounts of meat into their diets. This fueled evolution of a larger brain and other adaptations widely considered unique to modern humans. Determination of the spatiotemporal context of this shift rests on accurate identification of fossil bone surface modifications (BSM), such as stone tool butchery marks. Multidecade-long debates over the agents responsible for individual BSM are indicative of systemic flaws in current approaches to identification. Here we review the current state of BSM studies and introduce a novel probabilistic approach to identifying agents of BSM. We use control assemblages of bones modified by modern agents to train a multivariate Bayesian probability model. The model then identifies BSM agents with associated uncertainties, serving as the basis for a predictive probabilistic algorithm. The multivariate Bayesian approach offers a novel, probabilistic, and analytical method for BSM research that overcomes much of the bias that has typified previous, more qualitative approaches.

1. Introduction

A primary goal of taphonomy is to identify the processes responsible for the differences in taxonomic composition and completeness between a fossil assemblage and the ecological community from which it is derived. These processes often leave physical traces on the surfaces of bones in the form of fractures and marks (Bonnichsen, 1989; Gifford-Gonzalez, 1991; Lyman, 1994; Fisher, 1995). Anthropogenic traces left on the surfaces of bones provide crucial sources of inference into hominin behavior within paleoanthropology, where material remains are largely in the form of stone artifacts or fossil bone. Because bone surface modifications (BSM) are the direct result of past dynamics, they are foundational components of the taphonomic inferential system.

A number of taphonomic agents have been implicated as imparting BSM to fossils, including mammalian carnivore feeding (Selvaggio, 1994; Capaldo, 1995; Pobiner, 2007), crocodile feeding (Njau, 2006; Baquedano et al., 2012), raptor feeding (Andrews, 1990), Trampling damage (Behrensmeyer et al., 1986; Olsen and Shipman, 1988; Fiorillo, 1989), biochemical etching, and weathering (Behrensmeyer, 1978; Andrews and Cook, 1985; Fisher, 1995; Domínguez-Rodrigo et al., 2009). Anthropogenic BSM are especially important to human origins studies and offer a unique source of inference into how hominins interacted with their environment. Because anthropogenic BSM typically include cut and percussion marks inflicted during butchery, they have great potential to offer information about hominin subsistence behavior.

However, the inferential potential of BSM is limited by the ability to correctly identify the agent(s) responsible for modification. That is, all interpretations derived from BSM rely on accurately identifying both the actor responsible for generating the force required to produce the BSM as well as the effector – the material directly contacting the surface of the bone, thus modifying its surface (Gifford-Gonzalez, 1991). We argue that before any higher-level inference can be made using BSM—such as inferring level of carcass access (e.g., Bunn and Kroll, 1986; Blumenschine, 1995) or identifying spatiotemporal trends in taphonomic actors (e.g., Egeland and Domínguez-Rodrigo, 2008)—the validity of individual BSM identification must be demonstrated.

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Current methods of identification, however, are often largely subjective, relying on categorical diagnosis by a single expert, which lacks analytical standardization and limits inter-analyst comparisons. The goals of this study are first to review the current state of knowledge of BSM research, specifically focusing on the historic trajectory of BSM studies. Second, we examine long-term debates in BSM studies, highlighting the need for analytical improvement. And finally, we describe a new analytical approach to analyzing BSM data. Historically, approaches to identifying BSM have relied on qualitative identification methods, and we greatly improve upon this via a novel probabilistic approach to identifying agents responsible for producing individual BSM.

2. A critical history of BSM studies

In its nascence, BSM studies were limited to qualitative descriptions of marks and the distributions of marks as they occurred on skeletal elements, rather than the morphology of the marks themselves (Brain, 1967, 1969; Binford, 1978, 1981). The agency responsible for bone modification was identified largely through coarse-grained, side-by-side comparisons of modern analogs, such as ethnographic observation, and was limited to uncontrolled scenarios of carnivore feeding and modern hunter-gatherer butchery practices (Brain, 1967; Binford, 1978). Further, early descriptions of individual marks focused primarily on hominin butchery and were broadly qualitative, relying on simple traits associated with a mark, such as the cross-sectional shape of the mark (Walker and Long, 1977; Bunn, 1981, 1983; Shipman and Rose, 1983), presence and trajectory of microstriations (Andrews and Cook, 1985), and the presence of small barbs or hooks supposedly occurring at the initiation or terminal end of a mark (Shipman and Rose, 1983). Although limited in their inferential potential, these qualitative assessments resulted in greater attention to specific features of BSM and cued researchers as to the morphological inter-agent variation associated with marks.

As it became increasingly clear that certain agents of modification were prone to equifinality, where different processes lead to ambiguous or indistinguishable results, more emphasis was placed on revealing unique morphological features associated with agents of modification in an attempt to improve differential diagnostic methods (Blumenschine and Selvaggio, 1988; Blumenschine, 1988, 1995; Blumenschine et al., 1996; Domínguez-Rodrigo, 1997). The presence of "cut mark mimics" underscored the danger of misidentifying marks as anthropogenic when in fact they may be the result of non-human post-depositional forces (Behrensmeyer et al., 1986; Fig. 1). This issue catalyzed experimental and actualistic research and has contributed greatly to our understanding of the agency responsible for BSM and, very importantly, has elucidated both inter- and intra-agent morphological variation (Blumenschine and Selvaggio, 1988; Njau and Blumenschine, 2006; Domínguez-Rodrigo et al., 2009). Current researchers are beginning to engage more with linking the physical properties of effectors to the properties of resultant marks (Braun et al., 2016; Maté-González et al., 2016); along with this increase in experimental and actualistic studies, analysts recognize the need for standardized analytical protocols and statistical validation of their inferences (Domínguez-Rodrigo et al., 2009; James and Thompson, 2015; Pante et al., 2017). Although BSM studies have seen numerous advances in BSM attribute data collection methods (Maté-González et al., 2016; Pante et al., 2017), the issue of equifinality, especially among agents known to produce marks with a high degree of morphological overlap, has still not been adequately addressed using an explicitly probabilistic approach.

2.1. Hunting/scavenging debate

The shift to a diet with significant amounts of meat was a revolutionary step in hominin evolution (Foley, 2001). There is consensus that by the appearance of Neanderthals and early modern humans, large mammal hunting with the consequent regular inclusion of meat in the diet was a consistent aspect of behavior. There is debate, however, over when and how that incorporation of meat into the diet was accomplished. Varying types and combinations of scavenging and hunting have been

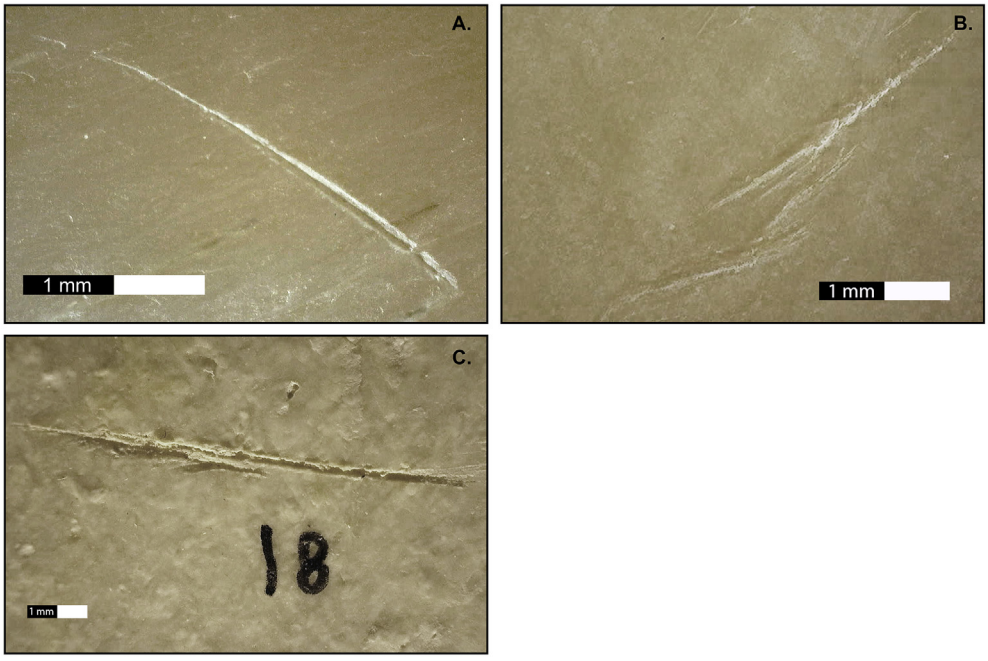

Figure 1. Experimentally generated BSM: A (butchery mark), B (large ungulate trampling), and C (Nile crocodile feeding), possess several overlapping morphological characteristics.