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Analysis of fracture patterns from experimentally marrow-cracked frozen and thawed cattle bones

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A B S T R A C T

Pre-breakage treatment of bones affects fracture mechanics and bone-breakage patterns. Understanding the results of various treatments leads to a more objective interpretation of archaeological faunal assemblages. Little is known about the specifics of fracture pattern differences between frozen and thawed bone, which is important in the context of studying potential frozen meat caches. This study reports the results of experiments performing hammerstone bone-breakage on frozen and thawed cattle femora and humeri with the periosteum and a thin layer of muscle meat left intact. Results indicate that the frozen or thawed state of the bone influenced the extent and type of fracture and resulting fragments. These differences potentially allow for the macroscopic identification of frozen and thawed marrow-cracked bones from an archaeological assemblage or scavenging site.

1. Introduction

Understanding bone fracture mechanics is essential to recognizing the history of a zooarchaeological assemblage. Without knowledge of differences in microstructural changes in fresh, dry, frozen, and heated bone, marrow-cracked bone in an archaeological assemblage can be misinterpreted (Johnson, 1985:158). The difference between fresh, dry, and frozen marrow-cracked bone may mean the difference between a fresh kill and a scavenged or cached carcass. Pre-depositional treatment and handling of faunal remains is as important to site interpretation as understanding the difference between human-modified and nonhuman-modified bone.

Previous studies in archaeology, biology, and forensics (e.g., Cáceres et al., 2002; Johnson, 1985; Karr, 2015; Karr and Outram, 2012; Morlan, 1984; Outram, 2002; Pickering and Egeland, 2006; Tersigni, 2007) show that bone in different states such as fresh, frozen, heated, and dry exhibit varying fracture patterns. These differences "result in water loss and adversely affect the bone's ability to absorb and withstand stress" (Johnson, 1985:178–179; see also Gottsauner-Wolf et al., 1995), as well as contribute to an altered microstructure (Tersigni, 2007).

The work of Morlan (1984) and Johnson (1985) brought to attention questions of bone preparation, bone fracture mechanics, and taphonomic history. Since then, experimental research has expanded knowledge of bone fracture studies beyond fresh versus dry (e.g., Boehm, 2011; Cáceres et al., 2002; Coelho and Cardoso, 2013; Galán et al., 2009; Karr and Outram, 2012; Outram, 2002; Pickering and Egeland, 2006). Despite knowledge of how freezing, thawing, and heating effects bone microstructure, little is known about how these differences affect specific fracture patterns, and what such bones would look like in an archaeological context. This information is essential when analyzing a faunal assemblage for potential use as a frozen meat cache or scavenging in cold climates, and therefore examining specifically frozen and thawed bone is warranted.

Knowing the exact pre-breakage treatment of bones, such as duration of freezing or thawing, is imperative to understanding the reasons why bones fracture a certain way. The process of freezing is more complicated than the loss of moisture. Upon freezing, and especially during freeze-thaw cycles, ice crystals form, grow, and converge within and around muscle tissue, bone, and marrow (Gottsauner-Wolf et al., 1995; Tersigni, 2007). In bone, this cyclical process damages microstructures, such as Haversian canals, though inconsistently (Ballin and Lametsch, 2008; Tersigni, 2007). Deterioration over long-term freezing is exhibited by increasingly dry fracture patterns (Karr and Outram, 2012; see also Karr, 2015; Karr and Outram, 2015) and in the archaeological paleo-bison assemblage at the Harder site (Morlan 1994). The effects of long-term freezing of the Harder bones reduced the moisture content enough that the bones became dry and the impact fracture front crossed the articular surface, a phenomenon not known in fresh bone (Johnson, 1985:222). A similar outcome can be seen in six bones experimentally frozen for 20 weeks and subsequently thawed (Outram, 2002:56), which exhibited a slightly less fresh quality than bones frozen for shorter periods.

As a first step in answering questions regarding the effects of freezing and thawing on bone fracture patterns, I examine macroscopic,

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qualitative differences between frozen and thawed cattle (*Bos taurus*) femora and humeri and their resulting fragments after having been struck with a hammerstone while the periosteum and a thin layer of muscle tissue remained intact. The purpose of my experiments are:

1. to determine if macroscopic differences between frozen and thawed bone fracture patterns exist, as they do between fresh and dry bone;
2. to determine the governing factors in any differences between frozen and thawed bone fracture patterns; and
3. to provide data for future comparison to archaeological faunal assemblages, particularly ones with potential frozen meat caches.

The experiments detailed in this paper, performed by myself and others, are designed to complement and expand upon Outram's (1998) experiments, which are performed on many different types of longbones fully cleaned of adhering soft tissues (see also Karr and Outram, 2012; Outram, 2002). The experiments are intended to demonstrate differences and similarities between frozen and thawed bone fracture patterns, and add to our understanding of bone fracture mechanics and morphology.

2. Methods

Previous publications (Johnson, 1985; Lyman, 1994; Outram, 2002; Villa and Mahieu, 1991) employ a set of terms in reference to bone anatomy, breakage, and fracture patterns. The term fracture pattern refers to the entire suite of characteristics observed on the broken bone (Johnson, 1985; Outram, 2002). For example, a bone may exhibit a fresh fracture pattern, meaning the bone exhibits fracture outlines, edges, and angles that generally occur on fresh bones. All else being equal, these aspects of fragmentation are dependent on the state of the bone and its moisture content (Johnson, 1985; Outram, 2002).

Fracture outline refers to the shape a fracture forms on a bone (Fig. 1). The terms regular and irregular refer to the smoothness of the outline. An irregular fracture does not follow one fracture front, but rather forms an outline that changes direction several times. An irregular spiral outline has the appearance of multiple helical or oblique fractures or a mix thereof, but its overall shape is helical.

Fracture surface refers to the area of the fracture that cuts through the cortical bone, with textures either smooth, rough, or a variant thereof (Fig. 2). Fracture surfaces on fresh bones are generally smooth, while on dry bones surfaces can be rough or granular (Johnson, 1985; Morlan, 1984:165; Outram, 2002:54).

Fracture angle is the percentage of right angles formed on the fracture surface in respect to the medullary cavity (Johnson, 1985; Outram, 2002:Fig. 6.5). Fresh bones generally exhibit acute or obtuse angles, whereas dry bones exhibit more right angles. Percentage of angles is taken from the fracture surfaces of the main bone itself, its proximal and distal halves, as well as from any large fragments forming a substantial portion of the diaphysis. Smaller fragments are not included in this percentage, as such fragments did not always occur during experimentation and are not always found in the archaeological record. Angle percentages are rounded to the nearest five.

2.1. Preparation

Hammerstone impact experiments were performed on cattle femora and humeri that had been filleted by a butcher. All bones retained muscle tissue on the shafts (not exceeding 0.5 cm) as well as the periosteum and some connective tissues. Both before and after acquiring from the butcher, bones were frozen for varying lengths of time (Table 1). Slaughter dates and duration stored were recorded by the facility, and these storage times were included in the total days frozen variable.

Prior to bone-breakage, the periosteum is generally removed from the area of the diaphysis at the preferred striking location on the bone (Binford, 1978:153, Binford, 1984:157). The periosteum is extremely elastic and is therefore able to withstand stress and hold the bone together upon fracture (Crowder and Stout, 2012; Eyre-Brook, 1984; Kitaoka et al., 1998; Yiannakopoulos et al., 2008). Bone-breakage studies experimenting with the periosteum intact are therefore rare. Three studies (Boehm, 2011; Galán et al., 2009; Pickering and Egeland, 2006) performed hammerstone bone-breakage experiments without removing the periosteum; however, these studies used fresh bones, and only Pickering and Egeland (2006) reported fracture patterns. My current study fills this gap, providing results from experimentally broken frozen and thawed bones retaining the periosteum and a thin layer of muscle tissue.

2.2. Parameters and process

Specimens were obtained already frozen from butchers as bones became available. Each animal or set of animals was slaughtered on a

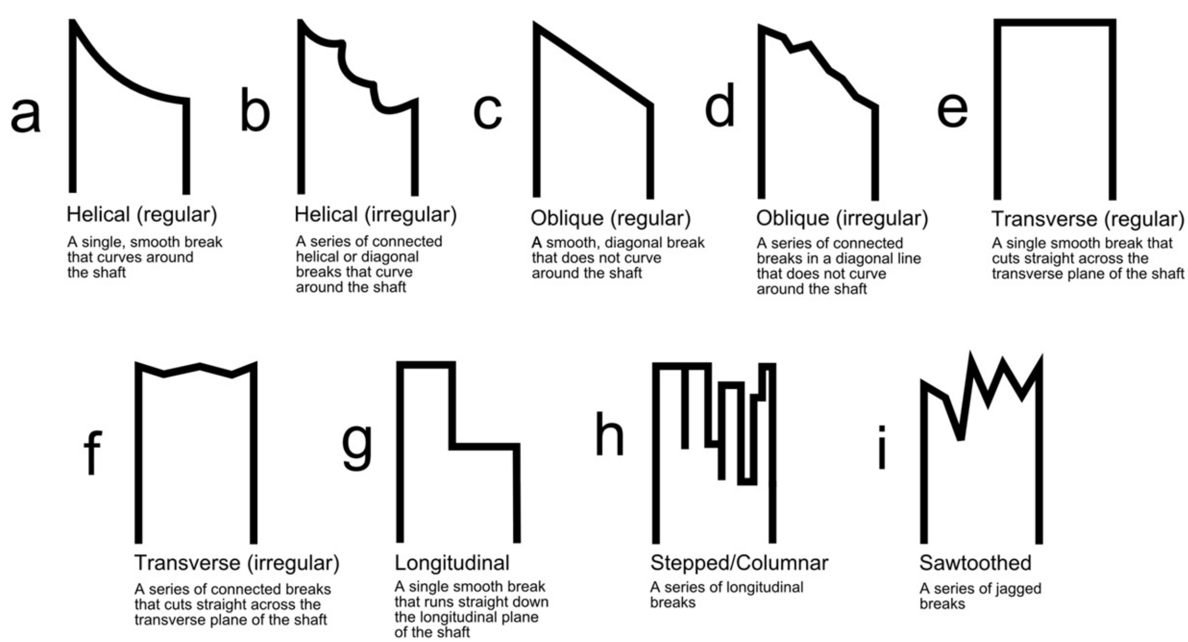

Fig. 1. Fracture outlines often seen on bone.