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Identification of fragmentary bone from the Pacific

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ABSTRACT

We explore bone microstructure for taxonomic identification of archaeological bones too fragmentary to permit secure identification on morphological grounds. Backscattered electron (BSE) imaging is used to observe bone tissue types and the arrangement of vascular canals, and to facilitate quantification of osteonal canal dimensions. Examination of known examples of relevant taxa (humans [$n = 8$], pigs [$n = 4$] and dogs [$n = 4$]) shows significant differences among them. When the results of this examination are applied to a blind test of modern and archaeological specimens (humans [$n = 8$], pigs [$n = 2$]), 100% of specimens are identified correctly. The approach is applied to 13 morphologically unidentifiable fragments from Hawai'i and Fiji to evaluate its potential for identifying bone tools and to increase the number of samples available for dietary analysis. Potential applications of the approach for other contexts are discussed.

1. Introduction

There are times when bones are too fragmentary or too modified to permit secure taxonomic identification using gross morphological characteristics. Further, when otherwise identifiable assemblages have significant fragmentary (or burned) fractions, the unidentified pieces cannot be assumed to be random samples of the identified components. Being able to identify morphologically unidentifiable bone at relatively low cost would provide valuable data for a broad range of archaeological and other applications.

Forensic scientists have developed a suite of techniques (including diaphyseal radiography, immunological reactions, DNA analysis and bone microstructure examination) to aid in distinguishing morphologically unidentifiable sources of bone (Harsányi, 1993). Except for relatively recent advances in the analysis of ancient DNA (e.g., Newman et al., 2002; Nicholls et al., 2003; Yang et al., 2005), these techniques are rarely applied in archaeological contexts. Indeed, although there are numerous published works (e.g., Cuijpers, 2006; Cuijpers and Lauwerier, 2008; Hillier and Bell, 2007; Martiniaková et al., 2007; Mulhern and Ubelaker, 2001; Singh et al., 1974) that explore the utility of bone histology for distinguishing the bones of various mammalian taxa, we are not aware of any published archaeological studies which use bone microstructure as an aid in taxonomic identification. Bone microstructure has been used, however, in an attempt to identify the taxonomic source of bone used in bone-tempered ceramics (Walter et al., 2004). Here, we explore using bone microstructure for taxonomic identification of archaeological bones that are too fragmentary to permit secure morphological identification.

1.1. Analytic value of bone microstructure

Use of bone tissue microstructure to address questions about the evolutionary and life history of vertebrates has been of long-standing scientific interest, providing a background for this research. Scholars have sought to resolve several kinds of issues using bone microstructure, including identifying unknown bone specimens (Botha and Chinsamy, 2000; Chin et al., 1998; Goodrich, 1913; Owsley et al., 1985; Quekett, 1849b), demonstrating phylogenetic affiliations (Chinsamy and Dodson, 1995; Nopcsa and Heidsieck, 1933), and establishing variables such as degree of thermoregulation (Enlow and Brown, 1958; Peabody, 1961; Ricqlès, 1976), ecological adaptation (Peabody, 1961; Schaffler and Burr, 1984), organism age (Ahlquist and Damsten, 1969; Castanet, 1985, 1986–1987; Castanet and Naulleau, 1985; Kerley, 1965; Kerley and Ubelaker, 1978; Peabody, 1961), health status (Boyde et al., 1986; Schultz, 1993, 2001), wild vs. domestic forms (Alioniene, 2004; Drew et al., 1971; Pollard and Drew, 1975), and biological racial affinity (Goodman, 2002). These efforts have met with only mixed success to date, but they show promise in at least some analytic contexts.

Several comparative studies (Amprino and Godina, 1947; Enlow and Brown, 1956, 1957, 1958; Foote, 1916; Quekett, 1849a,b) have identified distinctive patterns in bone microstructure that allow discrimination between different vertebrate classes. It is important to note, though, that the same basic kinds of structural units (see

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Enlow, 1963, 1966, 1969; Francillon-Vieillot et al., 1990; Ricqlès et al., 1991 for excellent descriptions of variation in bone tissue types) are present in the bone of all groups—it is the relative proportion and organization of those units that varies (Foote, 1916). Bone microstructure does not increase in complexity or refinement through vertebrate evolutionary sequences; instead, it is patterned according to the biological circumstances of the animal (Francillon-Vieillot et al., 1990). Thus, it is primarily because of adaptational differences that the bones of vertebrate classes can be distinguished, to the extent they can, on the basis of their microstructure.

Broad comparative studies have isolated variables such as organism size, metabolism, growth rate and longevity, local anatomical demands and ecology as being more important in determining bone microstructure than phylogeny (Ricqlès, 1993). Such factors sometimes combine in ways that, for some taxa, result in peculiar diagnostic structures (e.g., acellular bone in teleosts, non-vascular bone in squamates). More often than not, though, since the patterns of bone microstructure are overwhelmingly functional rather than historical in origin, tissues of animals from unrelated lineages will appear similar simply because the animals faced analogous physiological circumstances (e.g., plexiform bone dominates the long bone cortex of both artiodactyl mammals and sauropod dinosaurs). Consequently, researchers may encounter difficulties when they attempt to use bone microstructure to identify particular genera or species (Chin et al., 1998). It is often easier to determine with certainty which species a specimen is not, rather than which one it is (Enlow, 1966).

2. Microstructural features useful in taxonomic identification

Long bone specimens that are too fragmentary or too distorted morphologically to identify may be distinguished taxonomically using two qualitative characteristics: the kind of bone tissue and the arrangement of particular histological features called osteons (e.g., Cattaneo et al., 1999; Harsányi, 1993; Martiniaková et al., 2007; Schultz, 1997a; Ubelaker, 1989). In addition, researchers have noted taxonomic differences in the quantitative dimensions of features like osteons (Albu et al., 1990; Cattaneo et al., 1999; Horni and Paine, 2002; Jowsey, 1966; Martiniaková et al., 2007).

2.1. Bone tissue type

Bone tissue classifications reflect differences in the nature and organization of vascular canals and the orientation of collagen fibrils (Enlow, 1966; Francillon-Vieillot et al., 1990; Ricqlès, 1976; Ricqlès et al., 1991). Several bone tissue types, and gradations among them, have been recognized, but only two are of relevance to the problem at hand: lamellar bone and plexiform bone.

Lamellar bone (Fig. 1a) is the dominant tissue type in long bone cortices of humans and many other mammals. Laid down during times of relatively slow growth, lamellar bone is recognized by its regularly-oriented and evenly-spaced lamellae (Enlow, 1966; Francillon-Vieillot et al., 1990; Schultz, 1997b) that produce a structure reminiscent of plywood. Lamellae may be found circumferentially (along the external and internal surfaces of shafts), surrounding vascular canals (forming osteons), and/or interstitially (in the spaces between osteons). Vascular channels within lamellar bone are generally, but not exclusively, oriented parallel to the axis of the shaft.

Plexiform bone (Fig. 1b) has a "maze-like" appearance that is a consequence of a more-or-less regularly-arranged three-dimensional network of vascular channels (Enlow, 1966). Formed during periods of relatively rapid growth, plexiform bone dominates in the long bones of many large animals, particularly artiodactyls. It is rare in human bone, occurring only in young people (Mulhern and Ubelaker, 2001). The presence of plexiform tissue in thick cortical bone, then, is consistent with a non-human source.

2.2. Osteons

Blood vessels run through the bone in both primary vascular canals and osteonal canals. Primary vascular canals (Fig. 1c) are the result of blood vessels being incorporated simply into the bone as it is being formed. An osteon (Fig. 1d) is composed of lamellar bone that encircles a vascular canal, through which run one or more blood vessels and nerves. Osteons are often identified as either primary or secondary, a distinction that reflects their relative origin (Castanet and Ricqlès, 1986–1987; Enlow, 1969). Primary osteons are formed when lamellae are deposited concentrically within spaces remaining from initial bone formation. Secondary osteons (also known as Haversian systems) are formed as part of bone turnover when resorption produces cavities in previously-deposited bone and lamellar bone is subsequently deposited concentrically within those resorption spaces. Primary and secondary osteons are distinguished by the absence or presence, respectively, of an encircling cement line (also known as a resorption or reversal line) that indicates bone deposition on a previously resorbed surface (Fig. 1d).

The presence and/or frequency of secondary osteons can be a clue as to the source of a bone fragment. Many taxa, including most reptiles, amphibians, small mammals and small birds tend to lack secondary osteons (Chinsamy and Dodson, 1995; Enlow and Brown, 1956, 1957, 1958; Jowsey, 1968; Ricqlès, 1976; Stout and Ross, 1991). Large birds and mammals typically have secondary osteons (Chinsamy and Dodson, 1995; Enlow and Brown, 1957, 1958; Ricqlès, 1976).

A common criterion for distinguishing human from some taxa of non-human bone is the linear arrangement of osteons often found in bones of the latter, but not the former (Cattaneo et al., 1999; Ubelaker, 1989). In human bone, osteons are generally scattered randomly within the bone (Fig. 1e) and they typically do not form distinct rows (banding); when banding is present in human samples, the rows are short and isolated. In bone of many non-human taxa, osteons may be organized into long bands (Fig. 1f) and there are often multiple, parallel rows. Mulhern and Ubelaker (2001) compared the organization of osteons statistically among human, sheep and miniature pig bones, paying particular attention to the prevalence of linear bands composed of five or more osteons. They found a significant difference between human and non-human bone in the degree of linear osteonal organization.

2.3. Size of histological features

There is some indication that the dimensions of histological features can be used to aid in taxonomic identifications. Measurements like mean osteon diameter, mean Haversian canal diameter and/or mean Haversian canal area do increase generally with body size (Georgia and Albu, 1988; Jowsey, 1968; Martiniaková et al., 2007), but there is considerable overlap among taxa. Maximal and minimal mean diameters, perimeters and/or areas show greater promise for statistically discriminating taxa than do mean values (Cattaneo et al., 1999; Martiniaková et al., 2007). Fig. 2 plots mean Haversian canal area for several taxa compiled from several published sources. As with other measures, the human data overlap with those of non-human taxa, but maximum canal area remains potentially a useful variable for distinguishing taxa.

When comparing osteon dimensions among different taxa, human samples always show the greatest range of values. In part, this could be due to the significantly greater number of human specimens analyzed; it could also be due to variation in how different researchers define and measure osteons (cf. Pfeiffer, 2000). Much of the variation within humans, though, may be due