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Bioarchaeology: The Lives and Lifestyles of Past People

Clark Spencer Larsen[1]

Skeletons represent the most direct evidence of the biology of past populations, and their study provides insight into health and well-being, dietary history, lifestyle (activity), violence and trauma, ancestry, and demography. These areas help inform our understanding of a range of issues, such as the causes and consequences of adaptive shifts in the past (e.g., foraging to farming, sedentarism), the biological impact of invasion and colonization, differential access to food and other resources (e.g., by gender or status), and conflict and warfare. Central to bioarchaeological inquiry are the interaction between biology and behavior and the role of environment on health and lifestyle. Bioarchaeological analysis has traditionally focused on local settings. However, important perspective on general questions of human adaptation is possible both regionally and globally.

KEY WORDS: diet; health; lifestyle; population history; paleodemography.

INTRODUCTION

A person's skeleton is remarkably informative about their health and well-being, dietary history, lifestyle (activity), ancestry, and key biological attributes (i.e., age and sex) that are used to construct demographic profiles of the population from which they originate. This paper discusses how these areas are documented and interpreted via the study of human remains recovered from archaeological settings. The literature in bioarchaeology is large and growing, and I necessarily limit this discussion to a representative rather than a comprehensive treatment of the topic (see Larsen, 1997; Mays, 1998, for comprehensive treatments).

Bioarchaeology has its origins in human osteology, a field that pertains mostly to the anatomical study of skeletal remains. Osteologists are interested in a range

[1]Department of Anthropology, 244 Lord Hall, 244 West 17th Avenue, Ohio State University, Columbus, Ohio 43210-1364; e-mail: Larsen.53@osu.edu.

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of issues, but from a historical perspective racial typology and classification dominated in the United States and elsewhere, and still has lingering influences in the human biological sciences (see Armelagos *et al.*, 1982; Larsen, 1987, 1997; Wolpoff and Caspari, 2000). In settings where skeletal morphology of human groups differs temporally, morphological differences between earlier and later populations were often interpreted to reflect population diffusion and replacement. For example, in the Nile Valley of Sudanese Nubia later populations with relatively short, round skulls were seen as having replaced earlier populations with long, narrow skulls. Processually oriented studies revealed, however, that these differences in skull shape were likely due to changes in chewing and mechanical loading of the jaws and teeth in the same population over time and not to diffusion and replacement (Carlson and Van Gerven, 1977). Similar trends in cranial form have been documented in many areas globally, which may reflect common adaptations to changing dietary circumstances and subsistence-related technology (reviewed in Larsen, 1995, 1997).

The study of cranial morphology from an adaptive perspective is illustrative of the paradigm change in biological anthropology first articulated by Sherwood Washburn (1947a,b) in his pioneering experimental research on laboratory animals relating food consistency (hard vs. soft) and cranial form and his call for replacing the typological approach to human variation with an adaptive approach (Washburn, 1951). For skeletal biologists dealing with past populations, this approach was not readily adopted, leading Armelagos *et al.* (1982) to push for the wider use of the adaptive approach to the study of past human variation.

In the 20 years since Armelagos *et al.*'s assessment of skeletal biology (Armelagos *et al.*, 1982), there has been considerable progress in the field. In the following discussion I highlight some recent developments in bioarchaeology, including dietary reconstruction from bone chemistry, infectious disease, physiological stress, violence and trauma, dental function and tooth use, lifestyle (activity), population history and biological relatedness, and paleodemography.

DIETARY RECONSTRUCTION FROM BONE CHEMISTRY

Diet (the foods the consumer eats) and nutrition (the nutrients these foods provide) are fundamental elements of a person's health and well-being. Moreover, the kinds of foods produced and eaten play an important role in how a society is structured (e.g., simple vs. complex) and settlement pattern (e.g., sedentary vs. mobile) (see Smith, 1995). The knowledge of what people ate in the past also helps us interpret health in these settings. Poor nutrition is often linked to elevated levels of infectious disease and stress (and see below).

Dietary reconstruction in archaeological contexts is often based on plant and animal remains. Plants and animals, of course, provide valuable perspectives on diet, but they largely document the *presence* of a particular food or group of foods and not the *quantity* of a food or foods. Just because a particular plant has been identified in an archaeological assemblage does not mean that it was an important element of the diet for a population. Therefore, quantification is a necessary requisite for drawing meaningful inferences about nutrition.

Bone chemistry provides a powerful approach for documenting diet and for assessing the importance of particular foods in past populations (see reviews in Katzenberg, 2000; Larsen, 1997; Sandford and Weaver, 2000; Schoeninger, 1995). The most important breakthrough in dietary and nutritional studies is analysis of ratios of specific stable isotopes in skeletal and dental tissues of past populations. The most studied of the stable isotopes are the carbon stable isotopes ^{13}C and ^{12}C. Carbon stable isotope ratio analysis is based on the fact that plants eaten by humans (and other animals) extract and metabolize carbon from atmospheric carbon dioxide differently through the process of photosynthesis. Owing to the manner in which the carbon is utilized in the different types of photosynthesis—C_3 (Calvin-Benson), C_4 (Hatch-Slack), and CAM (crassulacean acid metabolism)—very small differences in the ratio of $^{13}C/^{12}C$ (called $\delta^{13}C$ in ppm or ‰) are expressed in the plant tissue. The isotope ratio differences in the plants also are reflected in bones, teeth, and other tissues of the animal and human consumers (Tieszen, 1991). In some settings of the New World (e.g., most of eastern North America), maize was the only major C_4 plant consumed by humans, whereas most other plants were C_3 plants. For these settings, carbon stable isotope ratio analysis has resulted in a precise picture of the adoption of C_4 plant domesticates as well as their increase (or decrease) in importance (Fig. 1; see Ambrose, 1987; Hutchinson *et al.*, 1998;

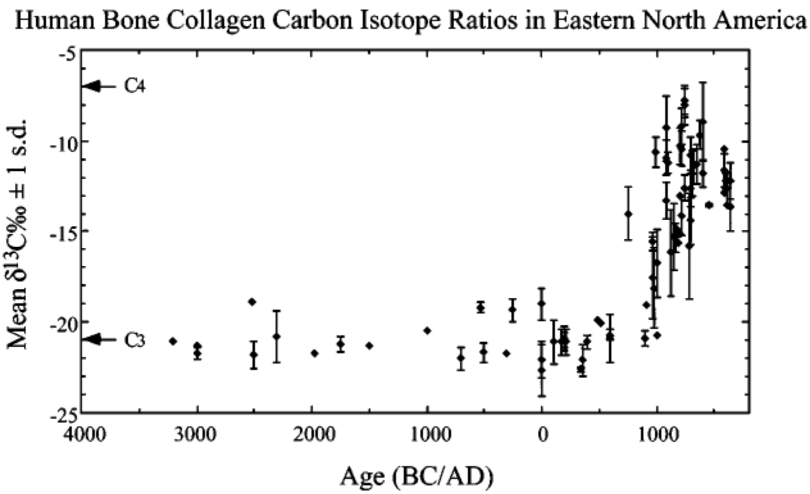

Fig. 1. Plot of $\delta^{13}C$ values from eastern North America. Less negative values indicate shift to C_4 foods (maize) at ca. A.D. 1000 (adapted from Ambrose, 1987; reproduced with permission of author and Center for Archaeological Investigations and Board of Trustees, Southern Illinois University).

Katzenberg *et al.*, 1995; Murray and Schoeninger, 1988; Schoeninger *et al.*, 2000; White and Schwarcz, 1994; and many others).

Collagen, the protein component of bone, requires essential amino acids for its formation. Thus isotope ratio analysis of collagen from archaeological bone, the most common form of isotope analysis, mostly reflects the protein component of diet. Paleodietary studies attempting to develop a reconstruction of the whole diet, including protein, carbohydrates, and fat, analyze the apatite, the mineral component of bone (Ambrose and Norr, 1993; Tieszen and Fagre, 1993).

Stable isotope ratios of several other elements also have resulted in new and profound insight into a range of dietary and other issues in the human past, such as consumption of marine (and freshwater) foods (δ^{15}N; Schoeninger and DeNiro, 1984; Schwarcz *et al.*, 1985), dietary access in relation to status (δ^{15}N; Schutkowski *et al.*, 1998), infant feeding and weaning patterns (δ^{15}N; Fogel *et al.*, 1989, 1997; Herring *et al.*, 1998; Katzenberg *et al.*, 1996; Katzenberg and Pfeiffer, 1995; Schurr, 1997), residence, individual migration, and population movement (δ^{87}Sr; Price *et al.*, 1994a,b; Sealy *et al.*, 1991; Sillen *et al.*, 1998; δ^{18}O; White *et al.*, 1998, 2000), and climate reconstruction (δ^{18}O; Fricke *et al.*, 1995).

Elemental analysis also is important for identifying patterns of diet and behavior, but in a much more restricted sense than was once thought. When elemental analysis first began in the early 1970s, many accepted on face value that the wide range of elements identified in human bone samples from archaeological settings were valuable for reconstructing dietary patterns. However, problems of diagenesis (postdepositional modification) first identified by Lambert *et al.* (1979) have revealed that many of the initial assumptions about diet and specific elements are unfounded (see also Ezzo, 1994; Price *et al.*, 1992; Sandford, 1993; Sandford and Weaver, 2000).

Ezzo (1994, p. 608) has made a convincing case that strontium is "the only firmly established elemental model in bone-chemistry analysis." In this regard, strontium resembles calcium structurally and therefore can substitute for calcium in various physiological roles. Importantly, strontium is distributed trophically in a predictable fashion owing to the fact that mammals, including humans, acquire strontium in quantities that are inverse to their trophic position (Sandford and Weaver, 2000). Herbivores have greater amounts of strontium in their bones than carnivores, and omnivorous humans are somewhere in between the two ends of the spectrum, although with a high degree of variation. Barium is also like calcium structurally, and so it too shows variation according to trophic level and is informative about food consumption and temporal shifts in diet. One important application of barium analysis is the identification of marine and nonmarine diets as well as some aspects of terrestrial diets (Burton and Price, 1990a,b; Ezzo, 1992, 1993, 1994; Ezzo *et al.*, 1995; Fabig *et al.*, 2000).

INFECTIOUS DISEASE AND HEALTH

Humans and humanlike ancestors have been around for well over five million years, and for that entire time populations were exposed to a wide range of infectious agents—bacteria, fungi, and viruses—resulting in various disease states. Molecular evidence suggests that some of the current human viruses may be as old as the first bipedal hominids (Van Blerkom, 2001). Population size and settlement pattern are key factors for interpreting the pattern and incidence of many infectious diseases. Generally speaking, the origin of infectious diseases present in the world today and in the recent human past can be traced to the time populations became large enough to sustain the pathogenic organisms that are responsible for their spread. In addition to the "crowd diseases," there are a host of other infectious diseases, old (e.g., plague) and newly emerging (ebola, mad cow disease), that are only partially crowd-dependent and that originated under special ecological circumstances.

Bioarchaeologists and paleopathologists have studied various types of infections that result from disease. Most of the life-threatening acute infections (e.g., smallpox) are not well known from archaeological skeletons, primarily because the pathogenic agents that result in the disease kill the human host quickly. There are a number of chronic infectious diseases that have been documented in the study of ancient remains from around the world. Some of the best evidence is from dental caries, treponematosis, tuberculosis, and leprosy (Fig. 2; for other diseases see Aufderheide and Rodríguez-Martín, 1998; Ortner and Putschar, 1985; Roberts and Manchester, 1995). As observed in living populations, these diseases must have had a profound impact on the quality of life and ability to move about the landscape. Thus, in addition to just being able to document disease in the past, their study offers a means of gathering a perspective on what living and lifestyle were about for ancient populations. The following is a brief synopsis of what bioarchaeologists and paleopathologists know about these examples of infectious disease.

Dental caries is a disease process involving the demineralization of enamel due to the production of acids that are produced as byproducts of the metabolism of carbohydrates by oral bacteria (e.g., *Streptococcus mutans*). Dental caries is not usually thought of as a life-threatening condition. However, in the preantibiotic world (and still today in many Third World settings), cavities resulting from caries continue to grow in size and are prone to infection that can spread to surrounding bone and soft tissues.

The cause of dental caries is controversial, but an enormous dental literature documents the close association between caries and carbohydrate consumption (see Larsen, 1997, for review). Analysis of carious lesion frequencies from a variety of archaeological settings shows a link between degree of carbohydrate consumption, especially domesticated plants, and elevated caries frequencies (Larsen, 1997; Larsen *et al.*, 1991). The record is dominated by findings from North America

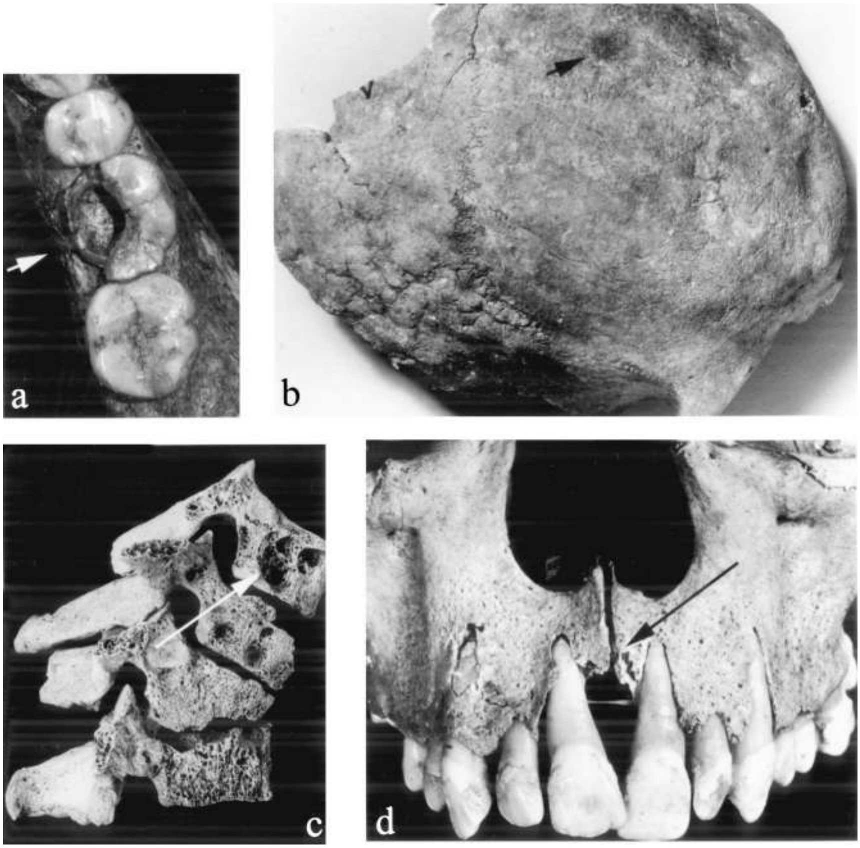

Fig. 2. Pathological indicators of specific infectious diseases: a. dental caries. b. treponematosis. c. tuberculosis. d. leprosy. (b. from Hutchinson, 1993; with permission from author and John Wiley & Sons, Inc. c. from Larsen, 1997; with permission of Cambridge University Press. d. from Møller-Christensen, 1978; with permission of Odense University Press).

where maize was the primary plant carbohydrate. For other areas of the globe—especially Africa and Asia—little is known about the link between degree of commitment to agriculture and caries. In Southeast Asia there is some evidence to suggest that there is a limited relationship between rice agriculture and caries (Oxenham, 2000; Tayles *et al.*, 2000).

Treponematosis, tuberculosis, and leprosy had potentially more profound results for past humans. In the New World, bioarchaeologists have documented elevated prevalence of treponematosis—a group of diseases that include venereal syphilis, nonveneral (or endemic) syphilis, yaws, and pinta (pinta is the only one of the four diseases that do not leave an obvious skeletal response). The skeletal lesions that are characteristic of nonvenereal syphilis have been documented in especially high frequency in the American Southeast and Midwest. The disease appears to have become especially prevalent as prehistoric communities became larger and more sedentary (e.g., Hutchinson, 1993; Powell, 1992, 2000; and others).

Some authorities argue that treponematosis also was present outside of the Americas (e.g., Roberts, 1993), but the vast body of cases that have been identified are from the Americas. Indeed, the origin of venereal syphilis may well have originated from a nonvenereal pathogen brought back to the Old World at the time of Columbus's first voyage. The pathogen may then have quickly evolved once reaching a different cultural setting where climate was cold and people wore more clothing (see overview in Baker and Armelagos, 1988). This scenario makes sense from a genetic perspective in that the DNA of the *Treponema* spirochete that causes venereal syphilis (*T. pallidum pallidum*) and that causes nonvenereal syphilis (*T. pallidum endemicum*) differ by a few base pairs only (Centurion-Lara *et al.*, 1998; Fraser *et al.*, 1998).

Tuberculosis, a chronic acid-fast mycobacterial infection resulting in a distinctive pattern of bone tissue destruction, especially involving the vertebrae, also has been well documented in eastern North America. Like treponematosis, tuberculosis appears to have increased in conjunction with populations living in close, crowded communities where the infectious agent is more readily transmitted from person to person. Tuberculosis is clearly present in many settings of the New World and Old World prior to the beginning of European exploration of the Americas. However, fungal infections such as blastomycosis have similar symptoms as tuberculosis (Frean *et al.*, 1993; Guler *et al.*, 1995). Thus some of the instances of tuberculosis reported by various researchers may be fungal infections.

Leprosy was a devastating disease in the past. Today the disease is found in tropical and subtropical regions of Africa, Asia, and South America, but in the past leprosy was much more widespread, extending to northern latitudes (e.g., Scandinavia). Unlike the other infectious diseases discussed above, leprosy appears to have been entirely Old World in origin. The infectious pathogen, *Mycobacterium leprae*, affects the peripheral nervous system, resulting eventually in the atrophy of the midfacial region, fingers, and toes. The attendant deformities are highly diagnostic and have been especially well documented in conditions involving poor sanitation, poor nutrition, and population crowding in medieval Europe (Møller-Christensen, 1961, 1978). Unlike tuberculosis and treponematosis, the disease has largely (although certainly not completely) disappeared.

The present discussion does not mean to imply that diagnoses for these and other diseases are straightforward. Diagnosis from archaeological human remains is not straightforward. However, the ability to diagnose specific diseases from archaeological human remains has greatly improved in recent years. For example, histological (microscopic) and radiological analysis of bone tissue are important tools for precise diagnosis involving anatomical change in response to disease (e.g., Carli-Thiele, 1996; Schultz *et al.*, 2001). The ability to extract and amplify the DNA of disease-causing organisms from ancient skeletons and other remains is beginning to confirm (or reject) earlier hypotheses about specific disease origins and spread for tuberculosis, treponematosis, and leprosy (e.g., Kolman *et al.*, 1999; Mays *et al.*, 2001; Rafi *et al.*, 1994; Salo *et al.*, 1994; Spigelman and Lemma, 1993; Stone, 2000). Moreover, the sequencing of DNA in living bacteria and viruses is providing new insight into the antiquity of a range of diseases not visible from human remains directly (e.g., Van Blerkom, 2001).

Other nonspecific pathological conditions ranging from slight elevations of bone surfaces to expansion of bone shafts have been observed by paleopathologists from diverse settings worldwide. In most circumstances, it is not possible to link these lesions—called periosteal reactions—to any known specific disease or cause. In general, periosteal reactions are an inflammatory response that may result from bacterial infection, but they also can be caused by a blow to the bone (Eyre-Brook, 1984). Like the specific infectious diseases, the frequency of periosteal reactions increases in areas involving expansion in population size and increased sedentism. An abundant bioarchaeological record for North America shows clear increases in frequency of periosteal reactions in a range of settings (reviewed in Larsen, 1997). This pattern is likely also present in other areas of the world, but the study of these lesions is not as comprehensively documented in the Old World as in the New World. This pattern of increase in frequency associated with population size and sedentism suggests that crowding had important and negative implications for quality of life. That is, as lifestyle changed during the Holocene, the burden of infectious disease increased.

PHYSIOLOGICAL STRESS: DISRUPTION OF GROWTH

Physiological stress is pervasive in humans, and it has potentially devastating results for individuals and the populations of which they are members. Stress, or physiological disruption resulting from impoverished environmental circumstances, is a central issue in the study of health and well-being of past populations. The cells responsible for the development of dental and skeletal tissues are easily disrupted if negative circumstances arise while the tissues are forming. In teeth, growth disruption can be identified both microscopically and macroscopically (Fig. 3). Macroscopically, growth disruption is indicated by various attributes, such as delayed development (Smith, 1991), reduced size (Dempsey *et al.*, 1996), elevated fluctuating asymmetry (Kieser, 1990), and presence of enamel defects, both microscopically and macroscopically (Goodman and Rose, 1991; Simpson, 1999).

The study of enamel defects has been especially productive in revealing the pattern and prevalence of stress in past populations. Microscopic structures known as pathological Retzius lines (or accentuated striae of Retzius or Wilson bands) provide a detailed record of short-term stress (1 to several days) (Rose, 1977;

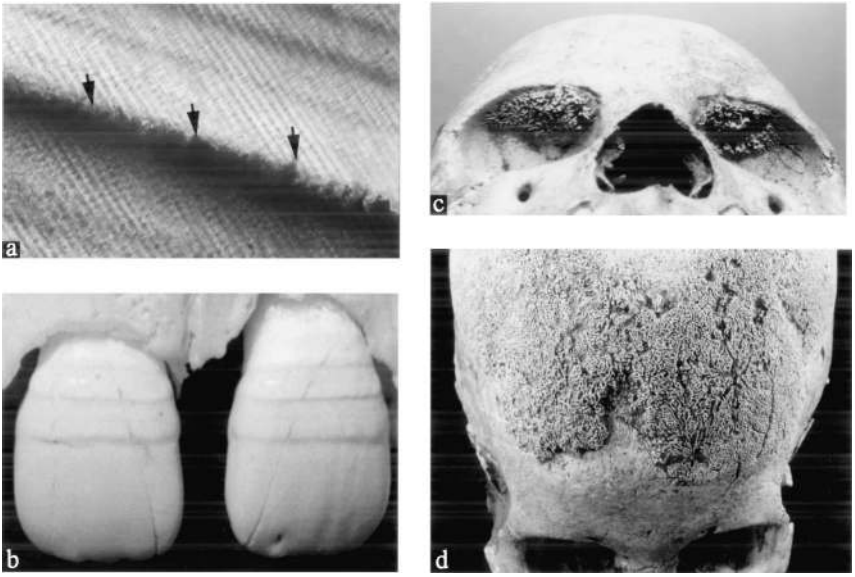

Fig. 3. Pathological indicators of stress and physiological disruption: a. accentuated striae of Retzius. b. hypoplasia. c. cribra orbitalia. d. porotic hyperostosis. (c. from Larsen, 1994; permission from Wiley-Liss, Inc. d. from Schultz *et al.*, 2001; permission from University Press of Florida).

Simpson, 1999, 2001). These are abnormal areas of enamel that mark the position of disruption of cells (ameloblasts) that are responsible for enamel development. One common association is with the birth event, resulting in a "neonatal line" on the teeth that are in the process of forming. Other factors relating to disease or malnutrition—especially infantile diarrhea—also are implicated (Simpson, 1999, 2001). Macroscopically, defects are represented as deficiencies in amount or thickness of enamel. Typically, these deficiencies, called hypoplasia, are grooves or lines marking the point at which enamel development was arrested, either most commonly by disease or malnutrition or some combination thereof (Goodman and Rose, 1990, 1991). Owing to the highly regular periodicity of tooth development, it is possible to track with some precision at what point in life the stress episode occurred during the early life of the individual (e.g., Hutchinson and Larsen, 1988, 1990; but see caution in Reid and Dean, 2000). In general, hypoplasia represents long-term stress lasting from weeks to several months. Commonly, hypoplasia is found at the stage of dental development representing ages 1–4 years. Although this pattern may be related to the stresses of weaning, the discordance between observed age-of-stress and records available in historic-era populations indicates that other factors can be involved (e.g., Blakey *et al.*, 1994; Saunders and Keenleyside, 1999).

Aside from dentition, the skeleton also provides valuable information about stress in the past. The stress indicators in the skeleton, like the information from teeth, largely derives from changes taking place during the juvenile years when the bone tissue is forming. Areas that bioarchaeologists employ for documenting stress include reduced growth rates (Saunders, 2000; Saunders and Hoppa, 1993), adult height (Lambert, 1993), pelvic flattening (Walker, 2001), bowing of weight-bearing long bones from nutritional deficiencies (Roberts and Manchester, 1995), reduced size of the neural canal of vertebrae (Clark *et al.*, 1986), lines of growth disruption at the ends of long bones known as Harris lines (Garn *et al.*, 1968), and elevated frequency of skeletal changes (porotic hyperostosis, cribra orbitalia) often linked with iron deficiency anemia (Stuart-Macadam, 1989). As with dental stress indicators, most of these skeletal indicators of disruption are nonspecific. However, unlike the dental indicators of stress where teeth do not remodel, skeletal tissues remodel throughout the course of a person's lifetime. For example, Harris lines are known to disappear and thus do not represent a precise record of stress in a person who is a mature adult (Garn *et al.*, 1968). Similarly, cribra orbitalia and porotic hyperostosis are largely representative of anemia that occurs during the early juvenile years (Stuart-Macadam, 1985, 1992). Nevertheless, the elevated presence of these indicators in juveniles of a skeletal series are likely representative of elevated stress in the population as a whole.

Growth retardation and stress has been documented in the archaeological record from studies of various indicators of skeletal and dental disruption. It is important to emphasize, however, that the presence of stress indicators does not represent causation; it also is important to consider factors from archaeological evidence and from modern population studies that inform our understanding of why a population has elevated stress. For example, sedentism appears to have resulted in increased stress in a range of settings, mostly owing to population crowding (King and Ulijaszek, 1999; Larsen, 1997). In contemporary settings, the combination of and interaction between poor nutrition and infection is the most common cause of physiological stress and poor health (King and Ulijaszek, 1999).

VIOLENCE AND TRAUMA

All human populations experience some form of physical confrontation at some point in time. Archaeologists document violence (especially warfare) by various lines of evidence, including fortifications, defensible site locations, settlement pattern, weaponry, and iconographic and symbolic representations that depict people, places, and activities relating to conflict (e.g., Redmond, 1994; Steponaitis, 1991; and many others). Unfortunately, these kinds of evidence identify the *threat* of conflict and not its *outcome* for the individuals involved. Bioarchaeologists are well positioned to study the presence and pattern of injuries deriving from violence. Important population-oriented studies that place violence in the larger context of society, environment, and other factors are based on skeletal samples from various settings in North America and Europe (Fiorato *et al.*, 2000; Lambert, 1997; Milner

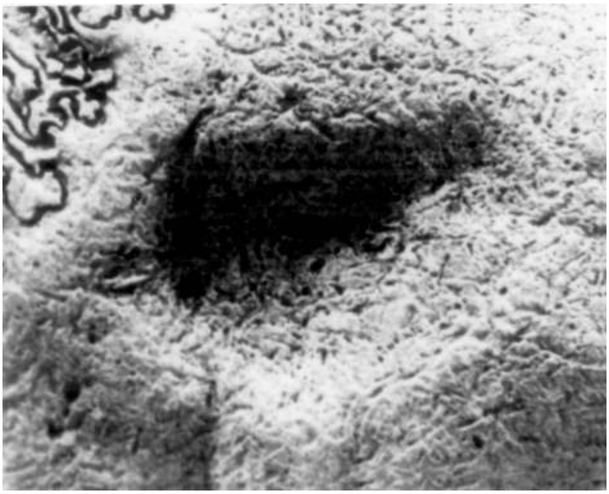

Fig. 4. Cranial depression fracture (from Walker, 1989; with permission from John Wiley & Sons, Inc.).

et al., 1991; Willey, 1990; see also various authors in Eisenberg and Hutchinson, 1996; Martin and Frayer, 1997; see reviews in Lambert, in press; Milner, 1999).

One especially compelling study of human remains from the Pacific coast of southern California shows a likely influence of environmental circumstances on behavior over a span of 7500 years. In this setting, skulls of numerous adults display indentations called depressed fractures (Fig. 4). These fractures are caused by a blow to the head, usually with a club. Prior to A.D. 580, most of the injuries are healed, strongly suggesting that homicide was not the intention of the aggressor. After that date, lethal projectile wounds are more common. The apparent increase in frequency of homicide coincides with a deterioration of climate involving less rainfall, reduced resources, increased stress, and increase in population size and sedentism. This suggests that the context for violence may have been environmental, involving fewer resources and increased competition. That is, tree-ring and other climatological data indicate a period of environmental instability and decreased resource productivity (Lambert, 1997). This resource stress hypothesis is consistent with the finding that various stress indicators (e.g., hypoplasia) increased during the same time that deadly violence intensified.

Another setting where individuals display traumatic injury relating to violence is the American Southwest. From the Four Corners region, various workers have documented the presence of facial trauma where the person had been struck in the mouth, knocking out anterior teeth and fracturing the adjacent bone (e.g., Billman *et al.*, 2000; Turner and Turner, 1999). Clearly, these individuals with facial trauma had been the victims of violence.

In the Southwest, skeletal injuries are associated with a range of other perimortem bone alterations indicating that the bodies had been processed for food (Billman *et al.*, 2000; Turner and Turner, 1999; White, 1992). The exact evidence for food processing varies from location to location in the region generally, but the skeletons commonly display extensive diaphyseal fracture (for marrow extraction), cut marks at tendon and ligament attachment sites (for removal of flesh), and charring and blackening (from cooking over open fires) (Fig. 5). Critics argue that

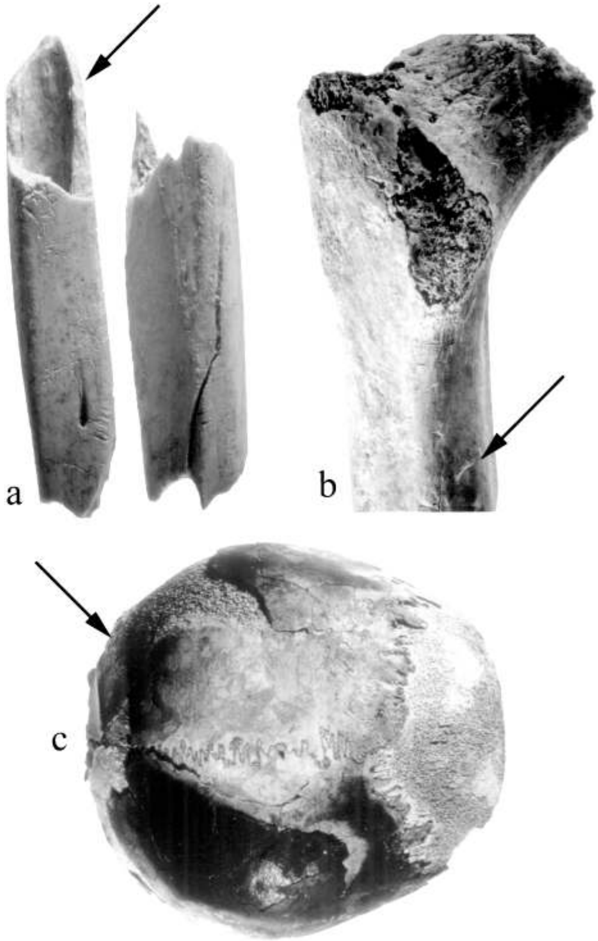

Fig. 5. Bone modifications consistent with cannibalism: a. cut marks and bone breakage. b. cut marks. c. burning (a. from Lambert *et al.*, 2000. b. and c. from Billman *et al.*, 2000; with permission from John Wiley & Sons, Ltd., and *American Antiquity*).

these processing patterns—no matter how similar to processing patterns observed in animal remains—do not by themselves indicate actual ingestion of human flesh (e.g., Dongoske *et al.*, 2000). At the Cowboy Wash site in southwestern Colorado where seven individuals had been processed in a manner consistent with defleshing and cooking for consumption, presence of human myoglobin in a human coprolite deposited at about the time the human remains had been cooked can only mean one thing: feces had been deposited by someone who had consumed human flesh (Billman *et al.*, 2000; Lambert *et al.*, 2000; Marlar *et al.*, 2000).

Various explanations have been offered to explain why cannibalism occurred in this and other archaeological settings. In the American Southwest, cannibalism may have been due to severe resource stress—people ate other people because they needed the food (e.g., Billman *et al.*, 2000). At Cowboy Wash, very few (non-human) food remains were found, suggesting scarcity of dietary resources. Moreove, during the time of the abandonment of the site (mid-12th century A.D.), the region experienced a severe drought or succession of droughts, resulting in a reduction in food. Billman *et al.* (2000) argue that it was during a period of resource stress that the people living at Cowboy Wash had been attacked by (hungry) intruders, then killed, butchered, cooked, and eaten. Interestingly, when the region in general was reoccupied in the 13th century following its initial abandonment, cannibalism did not resume—there is no bioarchaeological evidence of processing of human remains. This behavior appears to have stopped as suddenly as it began.

ACCESSING BEHAVIOR: MASTICATORY FUNCTION AND TOOTH USE

Humans use their jaws and teeth for an incredible range of purposes, mostly for food processing, but also for a range of extramasticatory (tool use) functions (Milner and Larsen, 1991). The resulting patterns of wear and other damage is highly informative about the uses of teeth in day-to-day living. Macroscopically visible wear has long been a key tool for identifying patterns and severity of wear that can be used to draw inferences about diet and tooth use. For example, Smith (1984) showed that foragers from a range of settings worldwide tend to wear their teeth flat, unlike farmers who display distinctive cupped wear on the occlusal surfaces of their molars. Moreover, farmers in general show less severe tooth wear than do foragers, and less intensive farming results in less tooth wear than more intensive farming does (review in Larsen, 1995).

Although wear on teeth is important for identifying tooth use patterns, microscopic damage yields much more detailed information (Fig. 6) (Teaford, 1991). Using scanning electron microscopy, a range of experimental analyses shows that teeth of animals and humans who eat soft or nonabrasive foods have fewer microwear features (scratches and pits) than animals and humans who eat hard or abrasive foods (Teaford, 1991; Teaford and Lytle, 1996). These differences are due

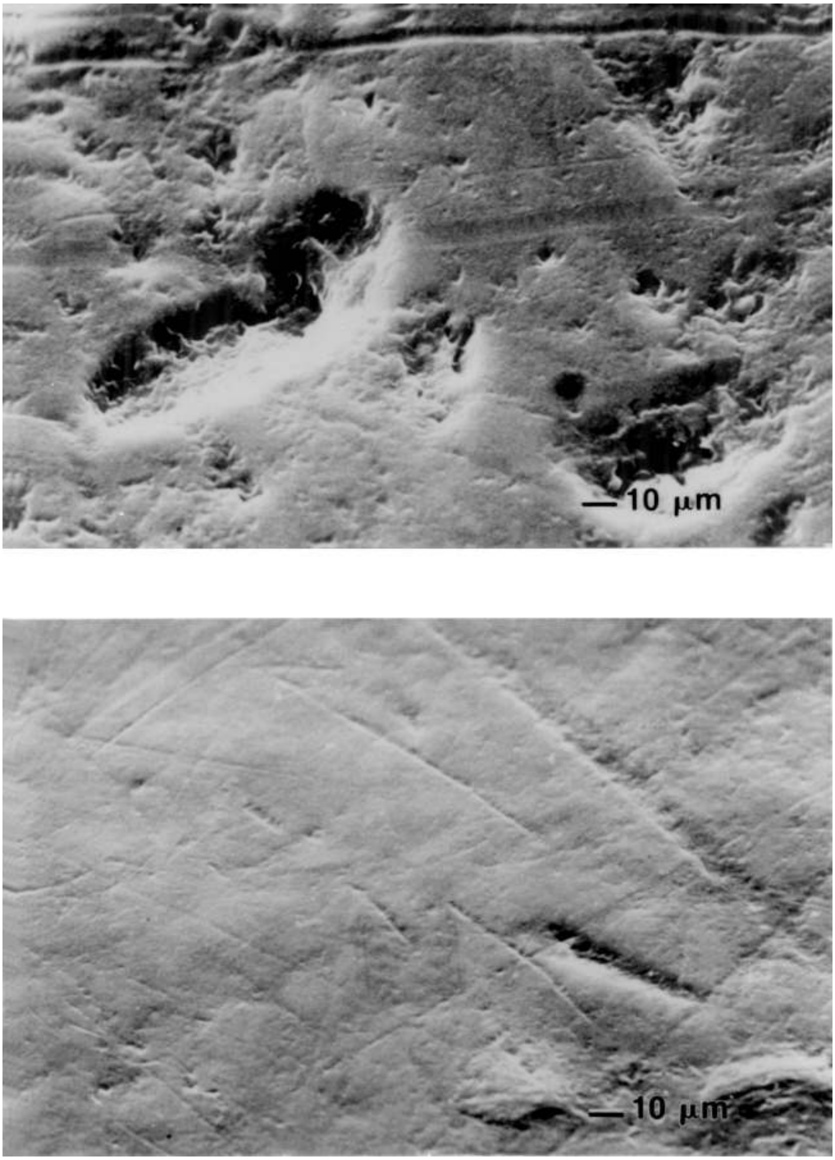

Fig. 6. Microwear showing contrasts between pitted surface (top) and smooth surface (bottom) on maxillary molars reflecting hard-textured (foraging) and soft-textured (maize farming) diets (from Teaford, 1991; with permission from Wiley-Liss, Inc.).

to the properties of the food itself (e.g., silica content) and by extraneous substances introduced by different types of processing (e.g., stone grinding of grains).

One of the important problems that has been addressed by microwear analysis is the shift from foraging to farming over the last 10,000 years. In a series of archaeological sites dating from 12,000 to 7,000 B.P. in northern Syria, the transition from foraging to farming has been documented through study of plant and animal remains (see Molleson *et al.*, 1993; Molleson and Jones, 1991). However, the precise timing of the transition has been debated. In this setting, Molleson and Jones (1991) have documented an increase in microwear features on teeth in the early Neolithic, reflecting a shift from eating less-coarse nondomesticated grains by the preceding Mesolithic groups to eating coarse grains by early Neolithic farmers. In the later Neolithic, however, with the introduction and widespread use of ceramic vessels for cooking, the microwear declines (Molleson *et al.*, 1993). Similar patterns of reduction in microwear have been documented in South Asia (Pastor, 1992) and in eastern North America (e.g., Bullington, 1991; Rose *et al.*, 1991; Teaford, 1991; Teaford *et al.*, 2001). Other settings show changes in different types of microwear, such as comparison of pits and scratches (e.g., Schmidt, 2001; Teaford *et al.*, 2001). Regardless of the change, microwear reveals subtle shifts in diet and tooth use.

ACCESSING BEHAVIOR: LIFESTYLE RECONSTRUCTION AND INTERPRETATION

Lifestyle, or physical activity, is a defining characteristic of human beings. For example, hunter–gatherers are often described as highly mobile and physically active, whereas farmers are described as sedentary and inactive. In his influential archaeology textbook, Braidwood (1967, p. 113) described hunter–gatherers as leading "a savage's existence, and a very tough one . . . following animals just to kill them to eat, or moving from one berry patch to another (and) living just like an animal." Ethnographic evidence indicates tremendous variation in activity levels and patterns in hunter–gatherers and other human groups (Kelly, 1995). The study of archaeological skeletons facilitates in some important ways the reconstruction and interpretation of lifestyle by several important indicators. The indicators include degenerative pathology relating to mechanical loading of articular joints (osteoarthritis), biomechanics and structure of long bones (cross-sectional geometric analysis), and muscle attachment site morphology (enthesiopathies).

Degenerative Pathology of the Articular Joints

The articular surfaces of the joints of the skeleton are well adapted to mechanical loading, such as from walking (a behavior affecting the joints of the

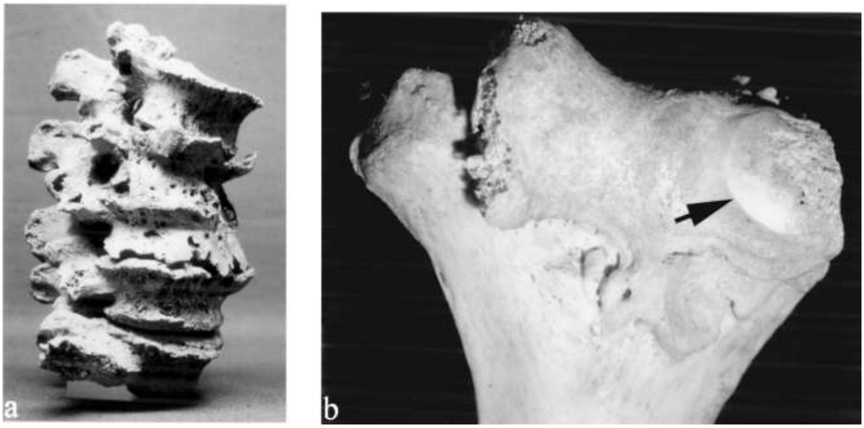

Fig. 7. Osteoarthritis: a. marginal lipping on lumbar vertebrae. b. eburnation (polishing) on distal humerus (b. from Larsen, 1987; with permission from Academic Press, Inc.).

hips, knees, and feet) or lifting (a behavior affecting the joints of the shoulders, elbows, hands, and back). Over the course of a person's lifetime, the cartilage covering the surfaces of the articular joints begins to erode as a result of use of the joints. Depending on the degree of use (or overuse), the joints begin to display skeletal changes, including spicules of bone along the margins of the joints and erosion of the joint surface (Fig. 7). These skeletal changes are symptomatic of osteoarthritis (also called degenerative joint disease). Osteoarthritis has been documented in many hundreds of skeletons worldwide, and specific patterns have been identified that are suggestive of activity (e.g., Bridges, 1992). For example, there is a tendency in some regions for more osteoarthritis in skeletons of hunter–gatherers than in farmers. However, there is a high degree of variation in incidence and severity, suggesting that osteoarthritis is linked to localized circumstances involving a complex interplay between lifestyle, culture, and environment (see Bridges, 1992; Larsen, 1997). Higher prevalence of osteoarthritis in males than in females is nearly universal, suggesting that workload and mobility—at least as it affects the articular joints—is greater in men than in women in past societies.

Structural Adaptation

Bone tissue remodels itself in response to mechanical stimulation (Wolff, 1892). In areas of the skeleton that are subjected to high levels of mechanical loading, bone tissue is added to strengthen the bone. By measuring the external dimensions of long bones, such as the breadth and circumference of bone shafts of the leg (e.g., femur) and arm (e.g., humerus), it is possible to infer levels of physical activity. Simply, larger (more robust) long bones indicate greater strength and physical activity than smaller (less robust) long bones. This is an imprecise way of measuring bone strength (although see Pearson, 2000) and does not allow the analysis of *distribution* of bone, which is the most meaningful attribute of bone strength for inferring lifestyle.

To more precisely document bone strength, physical anthropologists have applied engineering theory to the study of skeletal morphology (see Ruff, 2000). Civil and mechanical engineers routinely measure the strength of materials used in the construction of buildings. They base their assessments of material strength on beam theory, which states the simple notion that when viewed in cross-section, the further the material is placed away from a central axis, the stronger the section and the greater its ability to withstand breakage or collapse when subjected to loading. Long bones can be modeled as hollow tubes, which are best adapted to bending and torsional (twisting) forces. Using a series of cross-sectional geometric properties developed by engineers for measuring strength of a structure, it is possible to measure the strength of a bone and to infer its ability to resist bending and torsion. These properties are represented as values called areas, which measure amount of bone in a cross-section, and second moments of area, which measure the distribution of bone in the same section. For bending strength, values are called I with a subscript referring to the specific axis running through the cross-section (Fig. 8). For example, I_x refers to the x axis and denotes bone strength in the front-to-back bending plane, and I_y refers to the y axis and denotes the side-to-side bending strength in relation to that plane, perpendicular to the x plane. For torsional strength, values are called J and refer to the sum of two I values perpendicular to each other, such as I_x and I_y. I values are calculated as products of very small unit areas in the bone cross-section (such as the midshaft of the femur) and squared distances from the central axis. The images from which the analysis is performed are derived by cutting the bone and photographing the cross-sections or by computed tomographic (CT) scanning. Calculations of section properties are then done via computer software designed by engineers and adapted for archaeological skeletons (Ruff, 2000).

Biomechanical analysis has been applied to a range of human populations, revealing several patterns of lifestyle in the history of our species. Comparisons of second moments of area between earlier and later hominids reveals that bone strength has declined dramatically in the last several million years, continuing to the present (Ruff *et al.*, 1993). In recent populations, Ruff and coworkers (Larsen *et al.*, 1995; Ruff, 1999, 2000; Ruff and Larsen, 2001) have shown that bone strength (J) was generally higher in North American foragers than in farmers, but for males only. This trend is consistent with the notion that with agriculture, humans became increasingly sedentary, resulting in a reduction in loading of the femur (Ruff, 1987). In contrast, bone strength (J) for females show little or no

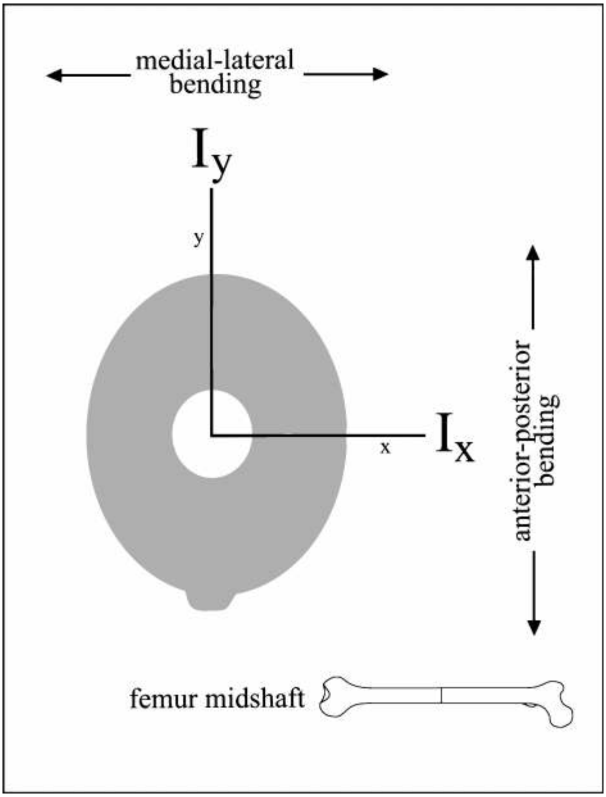

Fig. 8. Schematic illustration showing cross-sectional geometric properties I_x and I_y. I_x is anterior–posterior bending and I_y is medial–lateral bending in the midshaft of the femur. The top of the cross-section is anterior and the bottom of the cross-section is posterior.

relationship to subsistence strategy. Rather, torsional loading corresponds more closely with degree of ruggedness of terrain than subsistence technology. Females from mountainous settings have the highest bone strength, whereas females living in areas of flat terrain have the lowest bone strength.

Although general tendencies in bone strength are clear, local factors also play an important role in determining bone strength. For example, the shift from foraging to farming in the Eastern Woodlands of North America involved highly variable responses in bone strength, including increase (Ruff *et al.*, 1984; Ruff and Larsen, 2001), decrease in bone strength (Bridges, 1989), and no change at all (Barondess, 1998). Thus, while there are some important tendencies of skeletal adaptation that allow us to infer patterns of activity and mobility, it is essential that local circumstances involving adaptive shifts be considered.

Muscle Attachment Scars

A number of key studies have demonstrated the importance of muscle scars called enthesiopathies located at specific muscle attachment sites for inferring activity and behavioral adaptation (see Churchill and Morris, 1998, for review). Enthesiopathies represent the skeletal response to muscle activity—the larger the scar, the more developed (and more highly used) the muscle or group of muscles represented. For example, analysis of size and morphology of enthesiopathies on upper and lower limb bones from prehistoric Khoisan from South Africa by Churchill and Morris (1998) revealed that forest-dwelling males were more active than savanna-dwelling males, suggesting that activities associated with the food quest were more demanding in forest settings. In females, however, they found no differences in enthesiopathy morphology between the two regions, suggesting that the work demand—at least those tasks that are gender-based—was equal across the ecological spectrum for women.

Confirmation of the role of bone and muscle insertion has been recently investigated using experimental behavior in laboratory sheep (Zumwalt *et al.*, 2001). The study revealed that moderate exercise plays little or no role on development of muscle insertion sites. Although speculative, this finding suggests that the extreme forms of insertion site remodeling seen in numerous archaeological skeletons indicate very heavy demands taking place throughout the lifetime of the individual.

POPULATION HISTORY AND BIOLOGICAL RELATEDNESS

Anatomical Indictors of Relatedness

Form and structure of bones and teeth contain key information about the history of a population and its relationship to other populations, especially since this morphology is at least in part genetically determined. Relatedness between human groups has long been an important area of interest in anthropology. Biological distance or "biodistance" is the measurement of relatedness or divergence between populations or subgroups within populations based on the analysis of polygenic skeletal and dental traits (Buikstra *et al.*, 1990). The approach is based on the well-founded assumption that populations sharing attributes are more closely related than populations not sharing the same attributes. Biodistance analysis identifies statistical patterns of variation within and between groups by simultaneous consideration of multiple traits via various multivariate techniques (e.g., discriminant function, principal components; Mayhall, 2000; Scott and Turner, 1997). Two classes of data are used in biodistance analysis: metric and nonmetric. Metric traits are continuous linear measurements or indices, and nonmetric (or discrete) traits are discontinuous or quasi-continuous traits that are either present or absent or present in various grades of expression. For example, shovel-shaped incisors, a trait used to link Native Americans to a common Asian ancestor, is either not present or present in one of seven ordinal grades that range from slight to pronounced (Scott and Turner, 1997; Turner *et al.*, 1991).

Cranial metric traits also provide important information on potential population relationships (see Hillson, 1996; Larsen, 1997; Mayhall, 2000; Pietrusewsky, 2000; Scott and Turner, 1997). One limitation of linear dimensions in identifying ancestral–descendant relationships is the role of skeletal plasticity. An excellent case in point is the aforementioned craniofacial changes in ancient Nubia that were once thought to have been due to diffusion and population replacement, but now appear to have been caused by the shift from eating hard- to soft-textured foods.

Some of the most compelling biodistance research is based on discrete dental traits. As indicated in the study of living populations (e.g., Harris and Bailit, 1980), dental traits are under relatively strong genetic control, and their evolution is highly conservative. Thus dental traits offer an important source of information on biological relatedness. Building on the pioneering work of Albert Dahlberg (1956), Turner and his associates developed a list of more than 30 traits that identify population relationships (Scott and Turner, 1997; Turner *et al.*, 1991). The traits are documented in published form as well as in a series of plaques available from the Dental Anthropology Laboratory at Arizona State University.

The robust nature of dentally based biodistance analysis is illustrated in Jacobi's study of Contact-era Maya Indians from the Tipu mission in Belize (Jacobi, 2000). Multivariate and univariate statistical treatment of dental traits revealed groupings of people buried in the cemetery. For example, Jacobi found a low percentage of labial (lip side of tooth) curvature of maxillary incisors in the individuals buried in the inside front (nave) of the church but not elsewhere. This pattern indicates that people who were buried first in the church shared a common genetic heritage, distinctive from individuals buried later in time. The earlier component may represent traditional Maya, whereas others in the burial sample may have originated from outside the Tipu community (Jacobi, 2000).

Biodistance also has important potential for identifying the possible descendants of skeletons from archaeological settings. Alaska, for example, is a highly fruitful setting for identifying ancestral groups of living populations, in large part because of the presence of a highly visible and vital native population in this region of North America. Scott (1994) has found a strong similarity between pre-Koniag (1500 B.C.–A.D. 1100) and Koniag (A.D. 1100–1763), suggesting the presence of long-term population continuity for these groups (and see below).

The origins and evolution of native populations in the Americas has been a point of discussion by scholars for centuries (see Powell and Neves, 1999; Steele and Powell, 1993). Statistical analysis of cranial measurements of early Holocene remains from North America reveals that the braincase of Paleoindians is shaped differently from recent American Indians (Fig. 9). That is, the cranial vaults of Paleoindians tend to be longer and narrower and their faces tend to be shorter

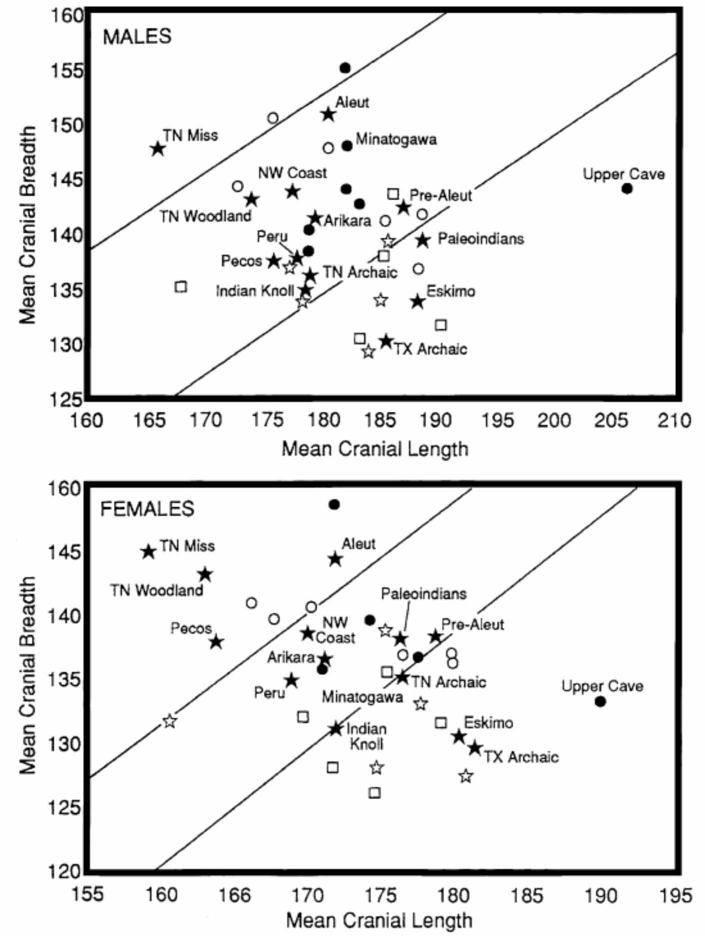

Fig. 9. Bivariate plot of mean cranial breadth versus mean cranial length for adult males and females in modern and prehistoric populations. The lines separate broad crania (brachycranic), mesocranic, and narrow crania (dolichocranic) groupings (from Steele and Powell, 1993; with permission from John Wiley & Sons, Inc.).

and narrower than those of recent Indians (Chatters, 2000; Powell and Neves, 1999). Overall, craniofacial morphology of Paleoindians is similar to generalized Asians, confirming the Paleoindian ties to northern Asia, but the distinctiveness from modern native populations is not fully understood. These cranial differences between the earlier Paleoindians and modern populations indicate that they were either not ancestral to living groups or the differences reflect craniofacial changes that have occurred over the course of the Holocene. This is an important area that requires further study.

Ancient DNA: Tracing Ancestry

The study of DNA from archaeological remains offers a new and potentially powerful means of addressing many of the issues previously under the purview of biodistance analysis of skeletal and dental morphology alone. This new frontier in biodistance analysis has strong potential to address this and other issues in anthropology relating to spatial and temporal associations between and within populations (O'Rourke *et al.*, 1996, 2000a; Pääbo, 1989; Stone, 2000). Beginning with Pääbo's successful extraction of DNA from an Egyptian mummy (Pääbo, 1985) and the development of polymerase chain reaction (PCR) for amplifying DNA fragments, it has become possible to access the human genome in ancient populations for a variety of purposes, including sex identification, relationships of individuals within an ancient population, population migrations and origins, and long-term phylogenetic relationships (see Stone, 2000). Molecular bioarchaeologists are still grappling with some fundamental problems, such as contamination in and authentication of DNA (Handt *et al.*, 1994; Kolman and Tuross, 2000; Stone, 2000). Moreover, most of the DNA that has been extracted and amplified is mitochondrial DNA (mtDNA) deriving from mitochondria, structures located outside the nucleus of the cell, versus DNA from the nucleus. Analysis of mtDNA from ancient Australian skeletal remains suggests that information on relatedness and long-term tracing of evolutionary relationships may present different results than would nuclear DNA (Adcock *et al.*, 2001). The initial excitement about ancient DNA is now somewhat tempered by the realization that many skeletons do not preserve DNA that is useful for analysis (e.g., Kumar *et al.*, 2000).

The study of DNA in living and extinct populations engenders new perspectives on population origins in the Americas that supplements the biodistance analyses of skeletons. Studies of living Native Americans show that specific mutations of mtDNA identify at least four founding lineages, called haplogroups A, B, C, and D (Kaestle *et al.*, 1999; O'Rourke *et al.*, 2000a,b; Schurr *et al.*, 1990; Torroni *et al.*, 1993). More than 90% of all Native Americans are from one of these four haplogroups. The haplogroup frequencies are highly structured in both the living and ancient populations studied, and the ancient samples studied thus far are most similar in their haplogroup frequencies to the modern groups inhabiting various regions in the Americas today (O'Rourke *et al.*, 2000b). These analyses suggest that there has been a remarkable stability for at least 2000 years and possibly much longer. The stability indicated by the genetic studies suggests that the craniofacial differences between Paleoindians and modern groups (see above) may be due to change over time in morphology. Importantly, the geographic distribution of the four lineages suggests few (perhaps only one) migration of a founding population from Asia to the New World (Merriwether *et al.*, 1995).

Within specific settings, some interesting results have emerged that contribute to an understanding of population history. In the American Great Basin of the

Desert West, there has been a long-standing debate about the origins of the native groups that currently inhabit the region. Native populations in the Great Basin today are Numic speakers. On the basis of their analyses of languages in the Great Basin, Steward (1940) and Lamb (1958) suggested that the present populations derived originally from a Numic homeland located in the southwestern Great Basin (California) about 1000 years ago. Analysis of mtDNA in living and ancient populations from the far-western Great Basin (Stillwater) by Kaestle and coworkers (Kaestle, 1995; Kaestle *et al.*, 1999; Kaestle and Smith, 2001) indicates a high frequency of haplogroup D and lack of haplogroup C in the ancient groups. These findings, along with characteristics of serum albumins extracted from the archaeological skeletons and living populations, indicate that the living groups most likely represent an admixture of Numic and pre-Numic populations rather than a replacement of the latter by the former. The similarity in haplogroup frequencies between ancient and modern populations from the other side of the Great Basin in the Great Salt Lake wetlands in Utah points to an ancestral–descendant relationship between the archaeological and living populations (O'Rourke *et al.*, 1999).

PALEODEMOGRAPHY: SEX AND AGE STRUCTURE OF PAST GROUPS

Physical anthropologists have developed an extensive repertoire of methods for estimating age-at-death and identifying sex of skeletons (see Buikstra and Mielke, 1985; Buikstra and Ubelaker, 1994; Jackes, 2000; Meindl and Russell, 1998; White, 2000). Methods for identification of sex of juvenile skeletons are imprecise, but new avenues for identifying the presence of the sex chromosomes, XX and XY, via DNA analysis are beginning to open up the possibility of sex identification (e.g., Faerman *et al.*, 1995; Kaestle, 1995; Stone, 2000). Identification of sex based on morphological attributes of adolescent and adult skeletons has a high degree of accuracy. Age-at-death estimation, however, is much more problematic. Bocquet-Appel and Masset (1982) argued that age estimation of adult skeletons from archaeological contexts was so problematic that it was highly questionable whether or not paleodemographic analysis was even feasible (see also discussions by Jackes, 2000; Meindl and Russell, 1998; Milner *et al.*, 2000). Age estimation methods have improved in recent years, facilitating the reconstruction of demographic profiles in past populations (see Meindl and Russell, 1998). There still exists, however, a great deal of variation in the accuracy of different age estimation methods, and this is one area that is being addressed (see Jackes, 2000).

Even in a perfect world where the age estimates for all individuals within a skeletal series are accurate, the meaning of the demographic profiles is still open to question. Simply, do these mortality samples (almost always) drawn from different times and assembled into one archaeological collection represent the actual mortality experience of a population? Intuitively, archaeological mortality samples—a collection of dead people—do represent mortality profiles. However, evidence derived from the study of age-at-death structure in both archaeological and contemporary samples strongly suggests that mortality samples from ancient cemeteries are representative of fertility and birthrates of a population and not mortality and death rates (Buikstra *et al.*, 1986; Johansson and Horowitz, 1986; McCaa, in press; Milner *et al.*, 1989; Sattenspiel and Harpending, 1983). In other words, a population with a low average age-at-death more likely represents the presence of relatively high fertility and growth rather than low life expectancy. This is because a population that is growing because of high birth rates will display a younger age profile in a skeletal assemblage than a population that is declining because of low birth rates, especially in the absence of immigration. Thus the record suggests that we cannot learn much about mortality from death assemblages, but potentially a lot about fertility from skeletal assemblages.

Wood *et al.* (1992; see also Milner *et al.*, 2000) argue that sampling bias due to various taphonomic, cultural, and methodological factors presents a potential problem for interpretation of health profiles in past populations. They note that simply because a skeletal series displays a high frequency of lesions does not necessarily mean that the population had especially poor health. Indeed, the high frequency of lesions can mean either that the living population was in poor health or the population enjoyed relatively good health because individuals survived the illnesses long enough for the lesions to develop. On the other hand, a skeletal series showing few or no lesions could mean that either the population was quite healthy or the members of the population were dying quickly, not allowing enough time for the appearance of the lesions. Wood *et al.* (1992) remind us that the analysis of a collection of archaeological skeletons is neither easy nor straightforward. Rather, various issues need to be considered when drawing conclusions about health. One solution to the "osteological paradox" is to consider multiple indicators of health in collections of skeletons in order to identify consistent patterns of health (and see Goodman, 1993). When inconsistencies between health indicators are identified in a skeletal series, problems associated with sampling bias may be indicated.

THE BIG PICTURE: DEVELOPING A HISTORY OF THE HUMAN CONDITION

All archaeologists are well aware of the complexity of the processes—social, cultural, economic, and political—that gave rise to societies and cultures in the past and present day worlds. Indeed, no other discipline provides the essential understanding of the past in interpreting the present. I would argue that health, well-being, and the human condition in general also should be included in this set of factors for interpreting how humans got to where they are today. How, then, has human health and well-being changed over time? What are the causes of these changes, especially in relation to key environmental factors such as diet, climate, topography, socioeconomic conditions, and so forth? The diversity of health and well-being has likely been enormous over the history of our species. Given the major changes in diet (from foraging to farming), settlement (increasing sedentism in both foragers and farmers), and increasing social complexity, industrialization, and globalization over this time period, it should be expected that health and well-being changed in discernible ways.

A large body of bioarchaeological data has been generated over the last 20 or so years that suggests that health did change over this time frame, beginning with the shift from a lifeway based exclusively on hunting and gathering to one that incorporated plant and animal domesticates (Cohen, 1989; Cohen and Armelagos, 1984; see Larsen, 1995, for review). In general, populations that made this transition show an increase in pathological conditions that reflect deteriorating health (e.g., cribra orbitalia, periosteal reactions, enamel defects, reduced adult height). It is important to point out, however, that these changes are not universal, reflecting the diversity of subsistence practices and environmental circumstances. Indeed, as Milner *et al.* (2000) point out, it is simplistic (and often incorrect) to think of foragers and farmers in typological terms. The pigeonholing of collections of skeletons in one or the other category masks the variation in the human experience—biological, cultural, or social.

Large-scale comparative analyses of spatial and temporal variation using skeletal evidence began with the compendium of studies presented in a volume edited by Mark Cohen and George Armelagos (1984), *Paleopathology at the Origins of Agriculture*. Contributors to the book assembled skeletal evidence from a range of settings in the world comparing pre- and postagricultural populations. The transition has long been considered a major advance for human societies, forming the foundation of complex social organization, art, literature, and all things "civilized." The collection of studies challenged this perspective, finding that health appears to have declined with the transition from foraging to farming. The interpretation that health declined over the last 10,000 years has not gone unchallenged. One obvious criticism is that the contributors did not use a uniform coding scheme thereby leading to incomparability of results.

Steckel and Rose (in press) addressed the issue of comparability in a large study of the history of health in the Western Hemisphere. The study involved the collaboration of a group of bioarchaeologists, economic historians, and others that coded skeletal health indicators (e.g., cribra orbitalia, porotic hyperostosis, trauma, periosteal reactions) and combined the individual data set into a large sample numbering some 12,500 skeletons. The skeletons date from about 4000 B.C. to the early 20th century and include Native Americans, African Americans, and Euroamericans. Given the ancestral diversity of the data set, the range of questions addressed exceeds the more limited issue of the transition from foraging to farming.

In addition to examining frequency patterns of specific indicators of health, Steckel and Rose (in press) developed a multiattribute, severity-graded, age-adjusted health index for assessing geographic and temporal variation. The health index was then used to rank populations according to health status.

As with any skeletal assemblage, there are limitations to the Western Hemisphere project, such as representativeness of samples and variation in age estimation techniques used by different researchers. Nevertheless, the study revealed some important trends and patterns of variation. Index values suggest, for example, a reduction in health that coincided with the adoption of agriculture and increased sedentism, which lends support for the earlier pattern articulated by researchers. Analysis of the index revealed a downward turn of health continued in some regions of the Americas but not in others following the arrival of Europeans in the late 15th century. For some groups, health appears to have actually improved during the contact era (at least relative to the prehistoric period). Notably, equestrian nomads from the Great Plains show a very high health index in the Contact period, which may reflect improvements in their ability to acquire dietary resources following the adoption of the horse. African Americans show an interesting pattern of health variation along socioeconomic lines. For example, "free" individuals had relatively high childhood health, but "enslaved" individuals had low childhood health. As also shown in historical sources, the contrast between the two groups of African Americans reflects the differences in living circumstances (Steckel and Rose, in press).

CONCLUSIONS: WHERE WE'VE BEEN AND SOME FUTURE DIRECTIONS

Much of the record of the human past is reconstructed and interpreted from archaeological and historical records. Skeletal remains provide an important resource for understanding the interaction between humans and their environment and the history of our species. For the period prior to writing, skeletal remains are the only source of information for documenting these types of interactions. Walker (2000) makes the important point that archaeological and historical sources of information about the past—like skeletal data—are susceptible to interpretive error. Historical sources, for example, often reveal much more about the value systems of the historian rather than the reality of the subject being investigated. The skeletal record of the past has a different set of issues that cloud interpretation. By using a diversity of resources for addressing the past, we are better equipped to eliminate explanations about past events. Use of diverse sources of information also applies to the study of the skeletons themselves and other lines of biological information. For example, based on his interpretation of mtDNA evidence, Cavalli-Sforza (2000) argued that populations living in the Tarim Basin of western China (Xinjiang Province) had a European origin. He noted that the mummies found there lacked the so-called "Mongoloid" cranial features that distinguish them from surrounding Asian groups. Hemphill's biodistance analysis of cranial metrics, however, provides compelling evidence that the ancestry of the Tarim Basin groups was non-European (Hemphill, 2000). Rather, his analysis reveals a biological affinity with the Indus Valley population of northern India for the earlier groups, whereas the later groups show affinity to populations of the Oxus River valley in south-central Asia.

Skeletons—the physical remains of the people themselves—are the most direct evidence of the biology of past populations. The direct nature of skeletal remains makes possible a range of investigations that are not accessible from other lines of evidence. For example, it is often assumed by anthropologists and nonanthropologists alike that although theoretically interesting, gender attribution and social inequality are largely inaccessible in archaeological contexts. These subjects have received significant attention by archaeologists beginning with the publication of Conkey and Spector's study (Conkey and Spector, 1984). Human remains offer an important window into gender, largely owing to the fact that sex (a biological attribute) of an individual is nearly always revealing about their gender (a social attribute). Indeed, the jump from sex identification to social identity and behavioral inference is not a big one. Human remains encapsulate a picture of health and well-being, lifestyle, and behavior, as well as a means of linking gender and the various components, all that make us a biological organism (see various authors in Grauer and Stuart-Macadam, 1998).

When coupled with historical information, skeletons provide a fund of data for addressing other events in the past. In this regard, skeletons dating to the post-Columbian period of North America offer important perspective on issues such as the impact of European contact and missionization on native populations (e.g., Larsen, 1990, 2001; various authors in Baker and Kealhofer, 1996; Larsen and Milner, 1994; Verano and Ubelaker, 1992) and the interaction between environment and health in various settings for Euroamericans and African Americans (e.g., various authors in Blakely and Harrington, 1997; Grauer, 1995; Pfeiffer and Williamson, 1991; and Blakey *et al.*, 1994; Larsen, 2000; Rankin-Hill, 1997; Rathbun, 1987).

Bioarchaeology is currently experiencing growth in a number of regions of the globe, but nowhere is the growth as explosive as in North America. Bioarchaeological data sets dealing with general or specific topics (e.g., disease) have been generated and studied elsewhere, for example, in western Europe (e.g., Arcini, 1999; Bennike, 1985; Carli-Thiele, 1996; Lynnerup, 1998; Palfí *et al.*, 1999), eastern Europe (Jankauskas, 1994; Jankauskas and Kozlovskaya, 1999), South Africa (e.g., Morris, 1992; Sealy, 1986), North Africa (e.g., Armelagos *et al.*, 1984; Calcagno, 1989), the Middle East (e.g., Smith *et al.*, 1984), South Asia (e.g., Kennedy, 1984; Lukacs and Hemphill, 1991; Walimbe and Gambhir, 1994), East Asia (e.g., Hanihara, 1994; Kaifu, 2000), Southeast Asia (e.g., Oxenham, 2000; Pietrusewsky, 1988; Tayles *et al.*, 2000), Australia (e.g., Webb, 1995), and the Pacific (e.g., Owsley *et al.*, 1994; Pietrusewsky and Douglas, 1994; various papers in Hanson and Pietrusewsky, 1997) but huge gaps remain. I would like to see continued development of bioarchaeological study in areas of the world that are poorly represented to build a more comprehensive picture of the history of human health and lifestyle in a broad diversity of environmental and cultural settings.

This paper has discussed how the various areas of bioarchaeological research build our growing understanding of the human past. Problem areas have been identified, such as sampling bias and gaps in coverage for many regions of the globe. One remarkable advance in the last few years has been in the study of ancient DNA, allowing more precise diagnosis of disease and better understanding of individual and population history. This area of research is still in its infancy, but there is great potential for growth. The progress being made in this and other fronts indicates a bright future for bioarchaeology.

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