The Past of Sex, Gender, and Health: Bioarchaeology of the Aging Skeleton

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ABSTRACT Empirical studies of bone maintenance in archaeological populations show that patterns of bone loss do not constitute predictable consequences of aging, either on age or sex. Our understanding of aging and gender identity in the past usually is structured by determining the category of biological sex, which is almost always the first step of bioarchaeological analysis. But this categorization can obscure our analyses and limit the questions that we investigate. The patterns of bone loss observed in archaeological populations illuminate the process of forming the body during the lifetime and the biocultural nature of human tissue. The results provide bioarchaeologists with a model for how to see variation in the morphology of the bone and how to reconstruct age and gender identity in the past. [*bioarchaeology, gender, bone loss, aging, osteoporosis*]

ABSTRACTO Estudios empíricos del mantenimiento de hueso en poblaciones arqueológicos demuestran que patrones de la perdida de hueso no constituyan consecuencias predichas del envejecimiento, ya sean en relación del edad o del sexo. Nuestro entendimiento del envejecimiento y la identidad de género en el pasado por lo general es estructurado por la determinación de categorías del sexo biológico, casi siempre el primer paso de análisis bioarqueológico. Pero esta categorización puede oscurar nuestra análisis, y limitar las preguntas que investigamos. Las patrones de perdida de hueso observados en poblaciones arqueológicos iluminan el proceso de formación del cuerpo durante el curso de la vida, y la naturaleza biocultural de tejidos humanos. Los resultados proveen un modelo para como los bioarqueólogos podemos observar variación en la morfología del hueso, y como reconstruimos la edad y identidad de genero en el pasado.

ABSTRAITE Les études empiriques sur l'entretien des os dans les populations archéologiques montrent que les tendances de la perte osseuse ne constituent pas des conséquences prévisibles du vieillissement, que ce soit sur l'âge ou le sexe. Notre compréhension du vieillissement et de l'identité de genre dans le passé est habituellement structurés en déterminant la catégorie de sexe biologique, presque toujours la première étape de l'analyse bios archéologiques. Mais cette catégorisation peut obscurcir notre analyse, et limiter les questions que nous étudions. Les motifs de la perte osseuse observée dans les populations archéologiques éclairer le processus de formation du corps pendant la durée de vie et de la nature bioculturelle de tissus humains. Les résultats fournissent un modèle pour bio-archéologues la façon dont nous pouvons voir la variation dans la morphologie de l'os, et comment reconstruire l'âge et l'identité de genre dans le passé.

In this article, I explore the fluidity of sex and gender in the past, in intersection with aging, through a bioarchaeological case study of bone loss and fragility. I show that dividing bioarchaeological samples into sex categories as a first step in analysis can obscure significant sources of variation in biological experience, while merging within a single sex category biological experiences that are actually distinct. Bone loss, the focus of my case study, is an ideal example.

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Bone loss and fragility (also referred to as osteoporosis) in past populations has been widely studied as an indicator of health, particularly to interpret female aging. Osteoporosis is widely regarded biomedically and in popular knowledge as occurring primarily in women with the onset of menopause or with senescence of the body that accelerates menopausal bone loss in females. Yet the makeup and integrity of skeletal tissue and the whole skeleton are actually influenced by multiple biocultural influences over the lifecourse. Borrowing from lifecourse approaches used in the study of chronic diseases, Anne Fausto-Sterling (2005) elegantly presents the cumulative nature of influences on bone health and highlights how prior events during life can alter the trajectory of bone development in later points of the lifecycle.

If gender is dynamic over the lifecourse, the reading of gendered patterns of bone loss in past populations will inevitably be obscured by a static mapping of gender to biological sex in skeletal analysis. In this article, I pose the following questions: What are the patterns of bone loss in the past in a series of actual skeletal populations that are historically related? How does the initial imposition of the biological category of sex affect our bioarchaeological expectations and interpretations of bone aging and health in the past? Is there really a distinction between sex-related and gender-related traces of aging? My case study demonstrates variability in bone loss in the past, with a medieval rural population showing bone loss in young age, and equal loss of bone in both sexes in old age, while a medieval urban sample showed the kind of age-related variation in bone between males and females that is typical in modern populations.

BIOARCHAEOLOGICAL APPROACHES TO SEX AND GENDER

The focus of bioarchaeology is the interaction of bone biology and behavior and the role of environmental influences on health and lifestyle (Larsen 2002). The duality of skeletal remains as both a biological and cultural entity has formed the basis of bioarchaeological theoretical inquiry (Armelagos 2003; Buikstra and Beck 2006). Many contemporary bioarchaeologists are keenly interested in engagement with social theory. This is most evident in recent studies of social identity in the past, such as identities based on sex, age, or health (Knudson and Stojanowski 2008; Sofaer 2006b).

A significant number of bioarchaeological studies have examined gender roles in the past (Hollimon 2011). Early bioarchaeological studies particularly discussed gender-based divisions of labor and disease prevalence, examining pathologies such as degenerative joint disease (Bridges 1989), conducting biomechanical studies of robusticity (Ruff 1987), and considering patterns of dental caries rates between the sexes at the transition to agriculture (Larsen 1998; Lukacs 1996). More recently, a number of skeletal studies have more directly addressed the intersection of categories such as sex, status, and occupation. For example, Christine White's (2005) study of food behavior among the Maya explores the complex nature of gendered status and power in Mesoamerica. She demonstrates that differences in elite and nonelite diets were a complex product of power, status, and gendered identity, as well as that status among the Maya cannot be fully understood through interpretations of binary gender categories alone. Similarly, another critical study of social status by John Robb and colleagues (2001) in a historical skeletal sample from Pontecagnano, Italy, emphasizes the lack of expected correspondence between funerary treatment or status and skeletal health. They demonstrate how patterns of skeletal health in the seventh- to third-century sample are the result of complex interactions among gender, status, and labor. Finally, in a recent study in the pre-Columbian Atacama, Christina Torres-Rouff (2002) demonstrates how cranial vault modification was an interaction of both gender and ethnic identity used to reinforce complex group differences during a time of cultural influence from the Tiwanaku state. These few examples, from differing geographic and temporal settings, highlight the fluidity of gender identity and form an important basis for a discussion of the limitations that normative categories such as status, occupation, or ethnicity have on the analysis of skeletal remains.

The bioarchaeological consideration of gender in all of these classic and subsequent studies, however, begins with and is tied to the assignment of biological sex as the first fundamental step in their analyses. Although theoretical work has sought to critically address the dualities of biological sex and gender, there have been very few studies that have explicitly explored this theoretical ground in conjunction with the analyses of actual skeletal remains. Many of the studies that have best considered the social construction of gender have utilized mortuary analysis (e.g., Joyce 1999, 2000, 2001; McCafferty and McCafferty 1994; Sofaer Derevenski 2002). However, in recent years there has been theoretically groundbreaking work in bioarchaeology dealing with the issue of sex and gender in the past. Researchers have critically examined the assumed relationship between sex and gender in bioarchaeology (Stone and Walrath 2006; Walker and Cook 1998), and even more recently they have focused on the limitation of the binary nature of biological sex and the traditional use of heteronormative interpretations of gender roles from skeletal remains (Geller 2005, 2009; Hollimon 2011; Sofaer 2006a). This critical evaluation has allowed the identification of nonbinary genders, or third genders, in the bioarchaeological record through skeletal indicators such as degenerative joint disease (Hollimon 1997) or musculoskeletal stress markers (MSMs; see Perry 2004), as well as recognition of gender bending through archaeological contextualization (Geller 2005).

Joanna Sofaer (2006a) and Rebecca Gowland (2006) emphasize the developmental process of gender over the lifecourse, linking the study of gender with aging. Sofaer (2006b) suggests viewing the skeleton as a form of material culture crafted through lived experience that blurs the division of the biological and social body. In broader archaeology, scholars have emphasized the importance of a lifecourse perspective in providing contextualization for the physical lifecycle (Gilchrist 2000; Knudson and Stojanowski 2008). Although lifecourse approaches have been used in the analysis of mortuary data (Joyce 2000; Meskell 2000; Sofaer Derevenski 2000b; Stoodley 2000), they have not been widely applied in the examination of skeletal data. The use of lifecourse perspectives in bioarchaeology allows us to imagine gender identity in the past as a malleable and dynamic construction that is not locked in with biology. This has vital implications for how we interpret gendered indicators on the skeleton in our reconstructions of diet, activity, and disease.

IDENTIFYING SEX IN BIOARCHAEOLOGICAL ANALYSIS

In bioarchaeology, sex is generally considered to be related to biological differences that begin at conception and continue to develop with physiological influences, while gender is considered a cultural construct in which individuals are classified as male or female or other categories as assigned in a given culture (Armelagos 1998). Biological differences on the skeleton are recognized as sexually dimorphic differences in morphology. Sex and gender are often collapsed, as the exploration of gender is tied to anatomical and physiologically derived skeletal traits (Geller 2005; Sofaer 2006a). Fundamental analysis of skeletal remains thus begins with the recording of elements and traits as either present or absent (or a small scale of degrees between presence or absence) or with recording of quantitative measurements that, when compared to known skeletal samples, can be used to determine sex, age, or other aspects of morphological variation with a given degree of confidence.

The determination of biological sex from archaeological remains using traits related to skeletal morphology and robusticity is presented in most osteological textbooks as the first analysis to be made after the skeletal element inventory. The determination of sex has been cited to be anywhere from 96 percent accurate, particularly for the traditional analysis of the pubic bone of the pelvis (Phenice 1969), to up to 98 percent accurate with newer methods of discriminant analysis of pelvic morphology (Bytheway and Ross 2010) or both pelvic and long bone measurements used together (Albanese 2003). In reality, the fragmentary nature of archaeological remains and the range of variation in sexual dimorphism in human populations (Sofaer 2006a) render many skeletons in an archaeological sample unable to be classified with reasonable certainty as either female or male. In practice, bioarchaeologists score and weigh multiple traits and assign skeletons along a range between male and female. This usually includes individuals scored as male questionable, uncertain or ambiguous, and female questionable (White and Folkens 2005).

In the majority of bioarchaeological studies, particularly those interested in complex questions related to health and disease patterns, unknown or fragmentary individuals that cannot be sexed are excluded from detailed analyses, and only individuals with "certain" or "known" sex are utilized. Thus, the need to be able to divide skeletal samples into biologically known and distinct sex groups forms the basis for how most bioarchaeologists have considered gender differences in the past (Sofaer 2006a). As Pamela Geller (2005) points out, although bioarchaeologists have engaged with the concept of gender as a cultural construction, gender identification is contingent on skeletal anatomical traits and only rarely considered as distinct from biological sex.

Additionally, while the process of aging has been shown to alter dimorphic morphology and affect sex-determination methods (Walker 1995), bioarchaeologists have not taken age and aging into consideration in analyses of gender. By dividing skeletal remains into sex categories first, phenomena that do not vary by sex but, rather, by age will be obscured. Although it is routine to acknowledge that younger individuals cannot be sorted into sex categories, older individuals may also tend to be indiscriminable.

Bioarchaeological analyses of social, political, or economic population-level change are almost always grounded in the initial sex assessments of skeletons. The conventional procedure of dividing bioarchaeological samples into male and female groups at the beginning of analysis is based on a usually unacknowledged assumption: that the most significant social difference is that of sex and, thus, that we should expect to see most variability between males and females.

Other dimensions of social identity, such as age, race, or class, may actually account for more of the variation in a specific human population than does biological sex. By first assigning samples to sex categories, we make it more difficult to see these crosscutting variables, which in contemporary feminist archaeology are discussed as "intersectionality" (Wilkie and Hayes 2006). Grouping individuals on the basis of sex has the effect of creating an a priori social group, a gender, based on selected biological features. A focus on the identity of a biologically determined group, such as "woman," can erase significant variability within that category that comes from intersecting variables.

The signature of biological sex marked and recognized on skeletal remains is both fixed and static. Beginning by dividing a population into two groups by sex assumes that there is a single natural sexual dichotomy on which all cultures, to some extent, base a definition of two opposed and complementary genders. However, we know that there are many ethnographically and historically described examples of third or fourth genders (Hollimon 1997, 2011) and, further, that gender is dynamic across the lifecourse. The methodological first step locks bioarchaeologists into taking a modern two-sex, two-gender, heteronormative ideology as the norm.

In this article, I question how that tether of biological sex affects and can limit our analyses and interpretations of bioarchaeological data. This is particularly well illustrated by the study of gender in health and aging. Analyses of bone loss in aging in medieval British populations demonstrate that, far from presenting biological processes that have easily predictable outcomes at all points in human history, patterns of bone loss—and, by implication, other biocultural experience—are highly diverse. Starting analyses by dividing populations into categories by sex may well obscure patterns of biocultural significance that cut across populations in different ways.

AGE AND SEX-RELATED BONE LOSS AND FRAGILITY: A BIOARCHAEOLOGICAL CASE STUDY FROM MEDIEVAL BRITAIN

Although bone loss is clearly related to menopause and age, additional factors such as genetics, ethnicity, nutrition, physical activity, parity, and lactation all play an important role in bone maintenance (Stevenson et al. 1989; Ward et al. 1995). A large number of early paleopathological studies particularly examined the relationship between bone mass and nutrition. For example, dietary calcium has been traditionally discussed in the literature as an important influence on the evolution and maintenance of the human skeleton, and there has been particular focus on skeletal health with the transition from hunting-and-gathering lifestyles to the full-scale domestication of plants and animals (Larsen 2003). There have been many studies that have considered nutritional hypotheses for the observation of low bone mass from a variety of prehistoric and historic archaeological samples (Ericksen 1980; Gonzalez-Reimers et al. 2002; Martin and Armelagos 1985). More recent bioarchaeological studies have focused on the role of physical activity in bone maintenance, especially in light of the increasing sedentary lifestyle accompanying the Neolithic revolution (Larsen 2003; Ruff et al. 2006).

Although researchers interested in bone loss in archaeological populations recognize the multifactorial etiology of bone maintenance, environmental and cultural influences on bone loss are often viewed as only potential modifiers that are still tightly constrained by biology. Bone loss or osteoporosis in the past is generally treated as reflecting the irreversible course of menopause and aging (Macho et al. 2005; Mays 1996; Mays et al. 1998). For example, although lifestyle factors such as reproductive behavior (parity and breastfeeding; see Mays et al. 2006; Poulsen et al. 2001; Turner-Walker et al. 2001) or diet (Martin and Armelagos 1985) are considered to influence bone maintenance in the past, they are referred to as agents that exacerbate expected biological (hormonal or genetic) changes to bone loss. Bioarchaeologists tend to consider the influence of environmental factors on bone morphology over a short period of time during the life of an individual(s) or during a distinct phase of the lifecycle (typically, the adult and postmenopause phase). The focus on bone maintenance and loss is at the end of the lifecycle, particularly in females, and it is assumed that women will lose bone and have more fragile skeletons as they age. Results from empirical research on bone loss in two British medieval skeletal samples using a lifecourse perspective, together with historical and skeletal data from other historical populations, provide a much more complex story that points to the importance of combined life histories of activity, nutrition, and reproductive patterns.

TABLE 1. *Distribution of Skeletal Sample by Estimated Biological Sex and Age Group*

Rural medieval (Wharram Percy)	Total	Female	Male
Young (18–29 yrs)	17	8	9
Middle (30–49 yrs)	21	9	12
Old (50+)	16	7	9
Total Number	54	24	30
Urban medieval (Royal Mint, St.Nicholas Shambles)			
Young (18–29 yrs)	16	9	7
Middle (30–49 yrs)	42	24	18
Old (50+)	15	8	7
Total Number	73	41	32

Skeletal Sample and Methods

To explore the role of life experience in sex- and age-related bone loss and aging, a comparison was made of patterns of bone loss and fragility in two archaeological samples excavated from a medieval rural village, Wharram Percy, and from urban settings in London. A total of 54 adult individuals (males = 24, females = 30) were examined from the site of Wharram Percy, a deserted rural medieval (11–16th centuries C.E.) village in North Yorkshire, England (Mays 2007; see Table 1). Individuals buried at Wharram Percy are thought to be ordinary peasants who lived at this predominantly agricultural settlement or elsewhere in the parish (Mays 2007).The second sample was comprised of a total of 73 adult individuals (males = 32, females = 41) from two combined urban archaeological samples excavated from the city of London, England (see Table 1). The two sites were St. Nicholas Shambles, an early medieval parish cemetery excavated by the Museum of London in 1975–77 and dated archaeologically to the 11th and 12th centuries (White 1988), and the East Smithfield Black Death cemetery from the Royal Mint site in London, one of the first Black Death cemeteries, excavated in 1986–88 and dated to 1349 C.E. (Hawkins 1990; Kausmally 2007).

Biological sex of skeletons was determined using the standard osteological indicators related to bone morphology and robusticity (White and Folkens 2005) and scored on the five-point scale discussed earlier, with only those individuals with biological sex that could be determined as 1 or 5 (with good certainty as female = 1 or male = 5) included in the analysis. Traditional methods of age determination were used that rely on morphological changes at joints in the body where there is little or no movement (specifically age-related changes at the pubic symphyses and auricular surfaces) and using tooth wear (for futher detail, see Agarwal et al. 2003, 2004). With the difficulty in accurately assigning precise age to skeletons, only conservative age ranges were used. Individuals were divided into three broad age categories: young age (18–29 yrs.), middle age (30–49 yrs.), and older age (50+ yrs.).

Bioarchaeological studies of gendered differences in morphology, including bone loss and fragility, typically begin with the division and analysis of individuals by biological sex. With the assumption that females should show the most significant and relevant association with age-related bone loss, previous studies have only examined age-related bone loss in the biologically female segment of archaeological samples, in isolation from male samples (e.g., Mays 2000, 2006). To better elucidate the gendered patterns of bone loss in this study, patterns of age-related bone loss were only considered in each sex separately if biological sex was found to be a statistically significant factor in the parameter of bone loss examined.

Bone maintenance and loss in the archaeological samples was assessed through the examination of age and sex-related patterns of change in trabecular bone microstructure (see Figure 1) in the fourth lumbar vertebral bone of the lower spine. The analysis of trabecular bone architecture is an ideal measure of bone quantity and quality that does not rely on the mineral content of the sample (such as measures of bone mineral density) that can be altered by diagenetic change in archaeological bone. For the Wharram Percy sample, a five-millimeter section was removed from the mid-body of the lumbar vertebrae and x-rayed. The quantity and quality of the trabecular bone was accessed using a Quantimet 570 (Leica) image-processing and analysis system. In the case of the urban archaeological samples, St. Nicholas Shambles and the Royal Mint, newer noninvasive technology allowed a virtual section of the vertebrae body to be examined using peripheral quantitative tomography (pQCT; Research SA+ Scanner Stratec), with the same image-processing and analysis system to examine the trabecular bone microstructure. Several parameters were collected related to the bone microstructure (such as the trabecular volume [BV/TV], number of trabeculae [Tb.N], and thickness [Tb.Th] and separation [Tb.Sp] of trabeculae) and the connectivity of the bone microstructure using the image-analysis software (Agarwal et al. 2003, 2004). All statistical analyses were conducted using SPSS statistical software (v. 11.0). In both the rural and urban samples, a two-way ANOVA was used to determine if age-related changes in the bone parameters were statistically different for each sex, allowing for the consideration of age, sex, and their interaction as separate factors. A comparison of means with a one-way analysis of variance (one-way ANOVA) was then used to determine significant differences in the parameters across the three age groups. Tukey's test (a post hoc test that accounts for multiple comparisons) was used to determine which pairs of groups differed when the overall ANOVA P-value for a parameter was less than 0.05.

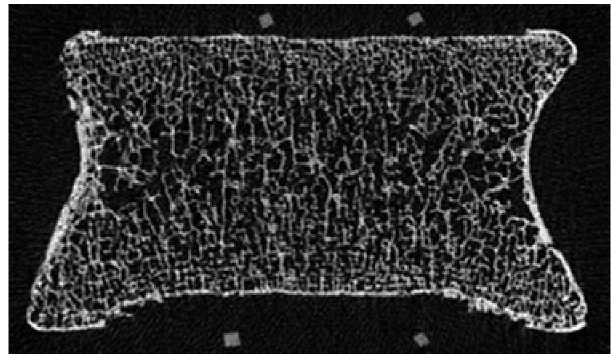

FIGURE 1. *Peripheral quantitative tomography (pQCT) image of a coronal section taken from the middle of the fourth lumbar vertebral body of an adult individual from the urban medieval sample. The anisotropic trabecular architecture was quantitatively analyzed for structure and connectivity. Images taken using a Research SA+ Scanner Stratec, at slice thickness of 150 μm and effective pixel size 84 $\times$ 84.*

Results

For the Wharram Percy sample, no statistically significant difference between the sexes is seen in any of the image-analysis parameters when age and sex are considered as separate factors in a two-way ANOVA (tests of between-subjects effects; see Table 2a). Although age was shown to have a statistically significant effect on the bone trabecular parameters, neither sex, nor the interaction of sex and age, was found to have a statistically significant effect. Therefore, the biological sexes were not considered separately in the analysis of age-related change in trabecular architecture in the rural sample. In the Wharram Percy population as a whole, there is a significant loss of bone structure and connectivity by the middle-age group, with no significant difference in bone microarchitecture between the middle- and old-age group (see Figure 2a). These patterns of bone loss in young age, and the equal loss of bone in both sexes in old age, differ from modern populations that show females to suffer bone loss after menopause and typically greater loss of bone overall as compared to males (Agarwal et al. 2004).

In the case of the urban skeletal samples from St. Nicholas Shambles and the Royal Mint, both age and sex were found to have an independent statistical effect on the trabecular architecture parameters, when age and sex are considered as separate factors in a two-way ANOVA (tests of between-subjects effects; see Table 2b). Consequently, differences in age-related change in the bone parameters were considered separately in the biologically sexed male and female groups. Only the females show a significant change in trabecular architecture between middle and old age, showing a loss of bone structure and connectivity in the oldest age group (see Figure 2b). In the urban samples, there is a statistically significant sex difference in the oldest age group, with females clearly showing less bone structure and connectivity in old age as compared to males (see Figure 2b). This pattern is different than what is observed in the rural

TABLE 2a. *Two-Way ANOVA Test of Bone Volume (BV): Rural Sample*

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	1159.082(a)	5	231.816	3.891	.005
Intercept	51763.302	1	51763.302	868.736	.000
Age	1101.322	2	550.661	9.242	**.000**
Sex	1.542	1	1.542	.026	.873
Age * Sex	60.384	2	30.192	.507	.606
Error	2860.060	48	59.585		
Total	56600.965	54			
Corrected Total	4019.143	53			

(a) R squared = .288 (Adjusted R squared = .214)

TABLE 2b. *Two-Way ANOVA Test of Bone Volume (BV): Urban Sample*

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected Model	400.371(a)	5	80.074	4.231	.002
Intercept	24323.547	1	24323.547	1285.140	.000
Age	173.325	2	86.663	4.579	**.014**
Sex	126.983	1	126.983	6.709	**.012**
Age * Sex	101.021	2	50.510	2.669	**.077**
Error	1268.093	67	18.927		
Total	33501.069	73			
Corrected Total	1668.464	72			

(a) R squared = .240 (Adjusted R squared = .183)

Note. In both the rural and urban samples, a two-way ANOVA (tests of between-subjects effects, significance at $p < 0.05$) was first used to determine if age-related changes in the bone parameters were statistically different for each sex, allowing the consideration of age, sex, and their interaction as separate factors (see text also). Results for one bone parameter, bone volume (BV), are shown here. **2a.** Rural medieval sample: although age has a statistically significant effect on BV (significant result boldface), neither sex nor the interaction of sex and age (Age*Sex), has a statistically significant effect. **2b.** Urban medieval sample: both age and sex were found to have an independent statistical effect on BV (significant result boldface).

Wharram Percy medieval population but is similar to patterns of bone loss seen in modern populations (Agarwal et al. 2003).

Discussion

The patterns of age- and sex-related change in bone microstructure in the rural Wharram Percy sample differ from the expected biomedical paradigm of postmenopausal bone loss in modern Western women. The patterns of bone loss in the medieval urban sample also differ from those seen in the contemporary rural sample. Nutrition, reproduction, and physical activity, three factors that are well linked to bone maintenance, would have certainly played important roles in bone loss and fragility in both the rural and urban medieval populations. I argue that it is specifically gendered differences in these behaviors within and between the medieval populations that are key in understanding the observed differences in bone loss. The influence of these gendered behaviors changes over the lifecourse and is not fixed with biological sex, instead demonstrating fluidity in the different medieval settings.

If we first consider nutritional status, historic and isotopic evidence indicates that lower-class medieval diets were mainly based on cereals, with protein sources mostly from dairy products with limited animal protein (Müldner and Richards 2005). At rural Wharram Percy, both adults and children would have endured periods of seasonal nutritional deficiency with a diet composed primarily of grains possibly causing protein and iron malnourishment, and it has been suggested that as a consequence the overall amount of bone gained during growth would have been compromised under the influence of nutritional stress with a lasting effect on bone content and morphology into adulthood (Mays 1999a; McEwan et al. 2005). The equal loss of bone in early age seen in both males and females in the rural sample could reflect the effects of nutritional stress experienced earlier in life that would have compromised peak mass (the maximal amount of bone tissue present at the end of skeletal maturation in early age).The deficiency in key nutrients in bone maintenance, such as calcium and vitamin D, into adulthood however seems unlikely and could explain the lack of bone loss into old age. Cattle bones and fragments of pottery

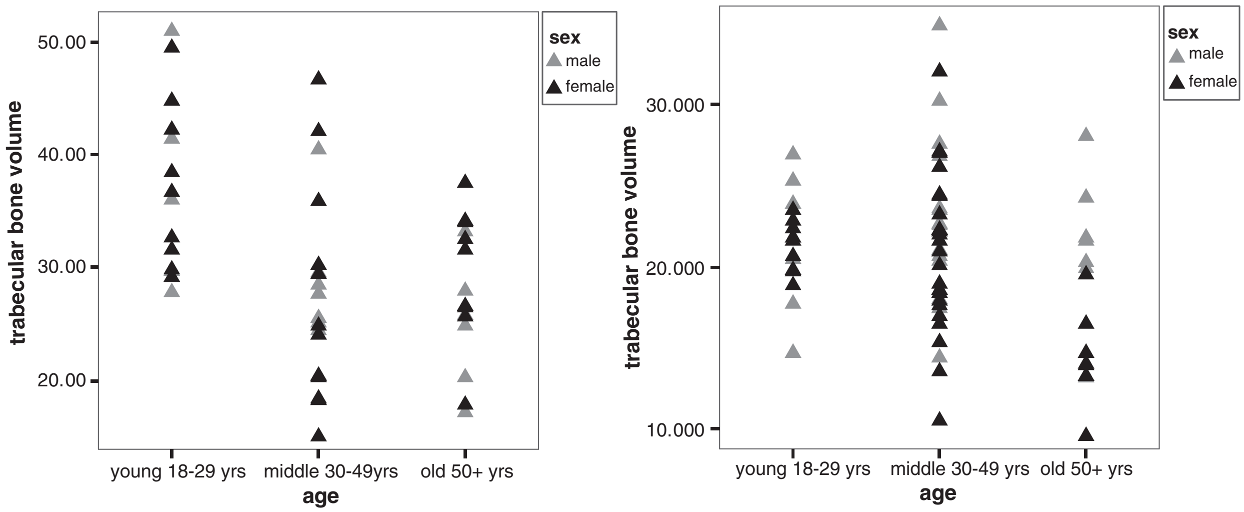

FIGURE 2. *A comparison of patterns of age- and sex-related change in one of the parameters of trabecular bone microarchitecture, trabecular bone volume (BV).* ***a.*** *Rural medieval sample (Wharram Percy): no statistically significant difference between the sexes is seen when age and sex are considered in a two-way ANOVA. Statistically significant change in BV is specifically seen between the young and middle age groups, pooled sexes (ANOVA, Tukey's post hoc test* $p < 0.05$*).* ***b.*** *Urban medieval sample (St. Nicholas Shambles and Royal Mint): both age and sex were found to have an independent statistical effect on BV when age and sex are considered in a two-way ANOVA. Statistically significant change in BV is specifically seen between the middle and old age group only the female group, with females in this older age group showing statistically significant less BV than male counterparts (two-way ANOVA, Tukey's post hoc test* $p < 0.05$*). (Note that absolute numbers between the medieval samples are not comparable as image analysis in the rural sample was conducted with radiographs as compared to pQCT images in the urban sample).*

vessels used for dairy products were found during excavation (Mays 1996, 2007). No signs of osteomalacia (adult vitamin D deficiency) were found in any of the medieval Wharram Percy skeletons, and the outdoor lifestyle of both male and female medieval peasants would have likely prevented vitamin D deficiency (Mays 1996).

Lower-class medieval diets in the urban towns would have been roughly similar to rural diets, but urban dwellers likely had somewhat higher living standards with a greater variety of fresh foods from the markets (Müldner and Richards 2005). Although the urban population would have been removed from direct hardship of lean seasonal harvests, they still endured a life immersed in urban disease and nutritional stress. The samples from both St. Nicholas Shambles and the Royal Mint do show evidence of skeletal physiological stress during growth (DeWitte 2010; DeWitte and Wood 2008; White 1988). It is known that populations of the early 14th century in northern Europe suffered greatly from the Great Famine, and this could have particularly affected the inhabitants who were buried at the later Royal Mint site (Antoine 2008; DeWitte and Wood 2008). Historical studies of urban medieval cities have underscored the poor living conditions that fostered acute disease and unsanitary conditions, and bioarchaeological studies have reported high prevalence of pathological indicators of stress and infection (such as porotic hyperostosis and enamel hypoplasia) in urban medieval skeletal samples (Grauer 1993; Lewis 2002). Although indicators of stress are generally greater in populations from the urban setting (Lewis 2002; Lewis et al. 1995), it is possible that the pathology endured did not impact bone loss in young adulthood as greatly as the possible influence of nutritional stress on bone loss in young adults observed in the Wharram Percy sample. Anne Grauer (1993) notes that a large percentage of lesions related to infection and anemia observed in an urban medieval sample from a parish in York are actually healed, which suggests that despite poor environmental conditions adults survived pathogenic episodes.

Although both sexes at Wharram Percy show similar patterns of trabecular bone maintenance, these patterns are different than those observed in the urban sample and in modern populations, particularly for the oldest age group. This may be related to gendered differences in young adulthood related to reproductive behavior. Nitrogen stable-isotope analysis of bone (Mays et al. 2002) and teeth (Fuller et al. 2003; Richards et al. 2002) samples from Wharram Percy suggests that infants were breastfed and weaned by two years of age. Parity would have been high in the rural medieval setting with estimates using breastfeeding duration indicating that a woman at Wharram Percy could have had up to eight children, although a somewhat smaller number is likely realistic (Mays 2007). Bone loss in young-aged females of reproductive age at Wharram Percy has been suggested to reflect the fact that these women were likely pregnant or nursing at the time of death (Agarwal et al. 2004; Mays et al. 2006). Such loss of bone related to reproduction would have been transient and not necessarily negatively impacted long-term bone maintenance.

Higher parity (number of viable offspring) and longer periods of breastfeeding as compared to modern women may actually have provided rural women long-term advantages to bone health. Biomedical studies of the effects of pregnancy and lactation on the skeleton have found conflicting results, but modern epidemiological evidence suggests that parity can decrease fracture risk and increase bone density (Murphy et al. 1994; Sowers et al. 1992), and longitudinal studies indicate that although bone loss can occur during initial lactation, there is substantial evidence of recovery of bone with extended lactation and during weaning (Kent et al. 1993; Pearson et al. 2004; Sowers et al. 1995). High parity and extended breastfeeding at Wharram Percy would have resulted in a dramatically different hormonal milieu for the rural women.

Together with a likely later age of menarche and possibly earlier age at menopause, these reproductive practices would have resulted in a dynamic and lower lifetime steroid exposure in comparison to modern Western females, who give birth to fewer children and practice little or no breast-feeding (Pollard 1999; Sperling and Beyene 1997). At menopause, the rural medieval women would not have suffered from the sudden loss of hormones and associated bone loss as did modern women, and the benefits of high parity and extended breastfeeding may have maintained their skeletons in old age to a similar degree as their male counterparts.

Historical studies suggest that urban women would have had different lifestyles and childrearing practices as compared to rural peasant women, much more similar to modern women (Gies and Gies 1981). Although parity could have been conceivably similar in urban and rural women, urban women likely had shorter periods of breastfeeding and more common use of wet nursing (Gies and Gies 1981). Mary Lewis (2002) reports that urban medieval skeletal samples show dental defects that indicate stress early in infant life that she suggests could be related in part to early weaning age. With chronically elevated hormonal levels that mirror modern women, urban women would have experienced the sudden change in hormonal exposure following menopause that can lead to a dramatic loss of bone. This could partly explain the observation in the urban sample of significant difference in bone loss between the sexes in the oldest group. Differences in the reproductive gender roles for urban medieval women as compared to rural peasant women are directly related to their urban lifestyle. This mirrors the more dramatic and often biologically adaptive differences in reproductive behavior and functioning that have been observed between modern Western societies and rural non-Western societies, as discussed in evolutionary medicine (Trevathan 2007; Valeggia and Ellison 2001; Vitzthum 2001). The differences observed in urban and rural populations in both the past and present demonstrate the biocultural plasticity of reproductive functioning and the consequences of this flexibility to health.

Along with the roles played by nutrition and reproduction, physical activity would have been a key component of bone growth and maintenance in the study populations. Biomechanical force (in the form of physical activity) directly affects bone remodeling and loss at the cellular level, influencing both the amount of bone gained during growth and maintained during life (Ruff et al. 2006). Both males and females at rural medieval populations such as Wharram Percy are thought to have been engaged in hard labor associated with a farming lifestyle (Mays 2007). Documentary evidence indicates that rural medieval peasants did not have a rigid sexual division of labor. Although females would have had duties in the domestic sphere, they frequently joined males in the fields with activities fluidly defined by seasons of harvest and maintenance of the household (Bennett 1987; Judd and Roberts 1999; Mays 2007). The equally strenuous lifestyles of rural men and women would have started early in life (Gies and Gies 1990; Mays 2007; McEwan et al. 2004), and this could have afforded both sexes the opportunity to gain and retain equal amounts and quality of bone across adulthood and into old age.

In a study of degenerative changes (osteoarthritis) in the Wharram Percy sample, Joanna Sofaer-Derevenski (2000a) found similar patterns of vertebral osseous change in both sexes that supports the assertion that both sexes at Wharram Percy were subject to broadly similar forms and levels of stress over the lifecourse. Several bioarchaeological studies have also compared the type and intensity of gendered activities between other medieval rural and urban populations. In a comparison of upper-arm robusticity and strength (as measured by cross-sectional geometry of the humerus) between rural Wharram Percy and urban skeletons from York Fishergate, Simon Mays (2007) found bone strength to be similar between Wharram Percy males and females but different between the urban sexes, again supporting the assertion of similar levels of activity between the sexes in the rural setting. Further, while men from Wharram Percy and York had similar values in bone strength, women from Wharram Percy showed higher values in upper-arm bone strength compared to women from urban York, again suggesting that the rural women were more engaged in activities that involved heavy biomechanical loading of the upper arms (Mays 2007).

Studies of adult long-bone fracture patterns in rural (Judd and Roberts 1999) and urban (Grauer and Roberts 1996) dwellers also support gendered differences in activity patterns. Grauer and Charlotte Roberts (1996) found that long-bone fractures were uncommon among the urban inhabitants of medieval York and suggest the data supports documentary evidence that medieval cities were a primary site of craft production, with most citizens involved in light labor, particularly as compared to rural farming-community inhabitants. Males at York also displayed more fractures than females. Grauer and Roberts (1996) argue that females were likely involved in household employment or as traders in the city, as medieval women were denied membership in craft guilds, perhaps minimizing their susceptibility to fracture as compared to males. In another study, Margaret Judd and Roberts (1999) compared long-bone fracture patterns in the rural medieval British sample from Raunds to other medieval samples, including the urban sample from York discussed above and St. Nicholas Shambles used in this study. They found that the rural Raunds individuals had much higher fracture frequency as compared to the urban individuals, with particularly the rural females showing higher fracture frequency compared to urban females across all the study samples, again supporting the case for highly intense labor and opportunity for injury in the farming setting for women (Judd and Roberts 1999).

Despite the high prevalence of trauma-related fractures in women from the rural setting, Judd and Roberts (1999) note that the fractures are not likely age related and suggest that the data indicate that a physically active farm life protected against osteoporotic bone fragility. It is interesting that in both the rural and urban samples used this study there are not a significant number of typical fragility related fractures. Although lifelong intense physical activity at Wharram Percy could have contributed to the retention of bone microstructure and reduced fracture risk in old-age rural women, the urban females do show a pattern of bone loss that in postmenopausal-age modern women is associated with high fragility fracture risk. The lack of intense physical activity in urban females as compared rural females probably contributed to their loss of bone following menopause. However, urban women likely led a more arduous lifestyle as compared to modern women, which could have protected them from fracture risk despite significant loss of bone in old age.

POTENTIALS AND LIMITATIONS IN INTERPRETATION

The comparative analysis of bone loss and fragility in mortality samples is complicated. Mortality and sampling bias, life expectancy, and skeletal-age estimates can all potentially influence our interpretations. The archaeological skeletal samples used in this study differ not only in their environmental context but also somewhat in their demographic profiles. The East Smithfield Black Death cemetery from the Royal Mint site in London is a plague cemetery and as such shows a catastrophic mortality profile, especially as in comparison to typical attritional mortality profiles of St. Nicholas Shambles and Wharram Percy, which show a high number of infant deaths with a low number of young-age adult deaths and a gradual increase in death in old age (Gowland and Chamberlain 2005; Margerison and Knüsel 2002). It is unclear how the differential fraility of individuals in each cemetery would have played out in terms of bone maintenance. However, a recent study of the East Smithfield cemetery by Sharon DeWitte and James Wood (2008) suggests that the Black Death did not kill indiscriminately; rather, it was selective with respect to frailty—that is, frail individuals were more likely to die, as in the other mortality samples.

Another concern in the interpretation of age-associated diseases in archaeological samples is the issue of life expectancy in the past. It is possible that perhaps few individuals in past populations would have reached extreme old age to suffer bone loss and some types of fragility fracture, specifically age-related hip fracture (Mays 1996). However, low life expectancy in the past is also related to high infant mortality. Having survived infancy, there was a good possibility of living to an old-enough age to suffer bone loss. Using manorial court records, Lawrence Poos (1986) estimates that even in times of severe mortality, a substantial number of individuals would have lived over 50 years of age. Using medieval demographic data from Josiah Russell (1948), Mary Jackes (2000) shows that the average age at death of males over the age of 15 is around 47 years during the plague and about 54 years in the periods before and after the plague years. Further, Jackes (2000) states that estimates of a ten percent survival beyond age 60 would actually be conservative, highlighting the demographic data of Russell (1985) that notes a number of individuals were expected to have lived beyond 60 across Europe and North Africa in the first 1,500 years C.E. Mays (2007) has shown the age distribution at Wharram Percy to be very similar to British documentary evidence. In both the rural and urban medieval populations, there certainly would have been only a small proportion of individuals living into their seventies or eighties. Although this could play a role in the observed patterns of bone loss and fragility that are related to senile osteoporosis, it should not limit our ability to see changes in bone maintenance in younger age, particularly following menopause.

A final concern in all bioarchaeological analyses is age-at-death estimations, particularly the accuracy of aging the skeletons of older individuals. It has been suggested that the current challenges in accurately estimating the age-at-death over 50 could limit the study of degenerative or age-related conditions such as osteopenia (Jackes 2000). Because of the inaccuracies of precise age estimates, a conservative approach was used in this study of assigning only broad age groups to skeletons with a final open-end age group of 50+, despite the attraction to investigate finer age cohorts. It is unclear if individuals in the oldest age groups in the urban and rural sample that have been skeletally assigned as 50+ differ greatly in their actual chronological ages. Although this may again limit our interpretation of age-related or senile bone loss and osteoporosis, the broad age categories used in this study are adequate to discern changes and patterns in bone structure and fragility in younger ages, including menopause.

Despite the limitations inherent in using mortality samples, the patterns of bone maintenance in the medieval samples in this study demonstrate that bone loss and fragility of the skeleton are not constrained by the biological processes of senescence and menopause. Instead, the careful piecing of evidence on nutrition, reproductive practices, and activity patterns in the medieval rural and urban settings, together with the skeletal data, demonstrates not only that these factors are influential on bone loss but also that these are clearly gendered behaviors that differ between the populations.

Most importantly, these influences vary over the lifecourse differently in each population, such that each group has its own trajectory for how bone will be maintained and lost in old age based on gendered life experiences. The practice in bioarchaeology of first dividing skeletal samples by biological sex, and the focus on bone loss in the female group, sets up the expectation that the most influential factor(s) in mediating bone loss will be closely linked to biological sex. As shown here, influential factors in bone morphology and loss, while gendered, are not tied exclusively to biological sex. The approach taken here of not automatically dividing the skeletal sample into sexed groups prior to analyses unless statistically justified is a subtle change in analysis that allows the consideration of other crosscutting variables within and between whole populations to be more readily discerned. This is not to say that it is impossible to consider crosscutting variables when groups are first divided by biological sex; statistical analysis of the urban sample in this study did justify a division by sex. The categorization of human skeletons into sexed groups is a valuable analytical technique in bioarchaeological analyses that is based on observed and known biological differences that exist within our species. However, the use of sexed categories as interpretive categories easily projects static and heteronormative representations of gender roles and aging onto the past (Geller 2009). Without the fixity of biological sex, it becomes easier to hypothesize the fluidity of change in morphology and the maintenance of the skeleton over the lifecourse.

CONCLUSIONS

The comparative patterns of trabecular bone loss and fragility in the archaeological samples discussed here provide us with an opportunity to conceive a new paradigm that focuses on how the cumulative product of life-history experiences forges the biological skeleton. Multiple factors such as the foods eaten, activities pursued, and child-rearing practices are woven into the fabric of the bone tissue over time. Contemporaneous and neighboring populations can have dramatically different patterns of bone maintenance and loss because each is unique in their biosocial environments. Each community, family, and individual experience contributes to the trajectory of skeletal health.

Because contributing experiences to skeletal health are not only biologically driven but also clearly socially and culturally mediated, influential experiences are, not surprisingly, gendered. In this model, the expectation of bone loss and osteoporosis as indicative of sex-related aging is more appropriately thought of as gender-related aging. The distinction is important, as sex-related aging implies a biologically certain and universal process, while gender-related aging implies a fluid and socially driven process. Gendered influences on the skeleton are cumulative, such that the aged skeleton is literally built by experiences over the lifecourse. Bone loss in the bioarchaeological record is commonly regarded as a natural outcome of senescence (Macho et al. 2005; Mays 1999b)—particularly as a snapshot of the menopausal defunct body. Although bone loss has been discussed in earlier points of the lifecycle, the tendency of bioarchaeologists is to focus again on only one particular event of the lifecycle. For example, bone loss observed in young-age females is focused on as an important indicator of reproductive stress (Martin and Armelagos 1985; Mays et al. 2006; Poulsen et al. 2001; Turner-Walker et al. 2001). However, the interpretation of the social identity of females from this is as a static "reproducer" (Geller 2009), and there is no attempt to view the changing and dynamic female identity over the lifecourse or to consider how the influence of reproductive practices would have cumulatively affected the skeleton in later age.

The assignment of biological sex anchors subsequent analyses within a finite range of interpretations that are difficult to push beyond. When differences in traits are seen between age groups but are not found between sex groups, and multivariate statistical analyses find sex to not be a significant factor (as in the case of trabecular bone loss in the rural medieval sample), statistical analysis actually permits the sex groups to be combined. However, bioarchaeological analyses of bone loss or any marker or trait of skeletal health in large enough skeletal samples would rarely consider analyzing adult male and female groups together, as biological sex differences in health are believed to exist universally. In publishing the initial analyses of the trabecular bone loss from the rural Wharram Percy sample, I was asked by journal editors and reviewers not to include the statistically significant data results for the sexes combined, as it was considered irrelevant until the sexes were divided. In the case of osteoporosis, female sex hormones are undoubtedly influential agents in bone maintenance and health, and the division of sex groups in (paleo)epidemiological analyses is perhaps natural. Bioarchaeologists are understandably reluctant to interpret indicators of skeletal health without the interpretive category of biological sex. However, it must be understood that sociocultural influences on the body are not layered on top of the primary influences of sex and age; rather, they mold and determine the sex- and age-related trajectory of bone health. Although this makes the analysis of skeletal variation in bone maintenance and loss harder to do, it widens the potential to visualize skeletons and bodies that are the result of developmental processes that have acted at the level of the individual, generations, or entire communities. This has great relevance for how bioarchaeologists observe variation in not only bone maintenance but also all aspects of bone morphology, as well as how we reconstruct age and gendered identity in the past.

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