Nexus: The Canadian Student Journal of Anthropology, Volume 21, July 2009: 1-15

Long bone bilateral asymmetry

in the nineteenth-century Stirrup Court Cemetery collection from London, Ontario

Heather T. Battles
McMaster University, Department of Anthropology

This study employs non-destructive methods to investigate patterns of long bone bilateral asymmetry in a skeletal sample from the nineteenth-century peri-urban Stirrup Court Cemetery collection from London, Ontario, Canada. The St. Thomas Cemetery skeletal sample from urban Belleville, Ontario provides additional data for comparison. While one objective of the study is to determine the etiologies of any asymmetries and to identify patterns in what measurements on which bones displayed the most asymmetry, another objective is to test the hypothesis that limbs indicating asymmetry due to pathology or trauma in one element would show bilateral asymmetries elsewhere in the same bone and limb, due to either atrophy alone or to additional compensatory hypertrophy. Overall, the Stirrup Court data shows a general pattern of crossed symmetry, and when compared with the Belleville data the pattern of high and low absolute asymmetries is consistent. The results reveal a lack of asymmetry in elements with obvious long-term damage, which may indicate that caution is required in making determinations about lived impairment/disability in such cases. The sexual dimorphism in asymmetry in both samples, with males displaying more asymmetry in humeral minimum shaft circumference in the Stirrup Court sample, likely reflects the division of labor and behavior patterns in these populations. Finally, this study suggests that the effects of osteoarthritis may mask non-age-related impairment/disability, and that the skeletal record of impairment/disability is likely affected by differential preservation, with consequences for the emerging field of the archeology of disability.

Introduction

The purpose of this study was two-fold. First, I wanted to investigate the patterns of bilateral long bone asymmetry in this peri-urban skeletal sample from the nineteenth century Stirrup Court Cemetery near London, Ontario, Canada and to compare these with a similar but larger skeletal sample from Belleville, Ontario and to other studies of asymmetry in the published literature. Specific questions included what the etiologies of the asymmetries were (such as atrophy or hypertrophy due to trauma, pathology, or activity patterns) and what measurements on which bones displayed the most asymmetry.

The second purpose was to examine cases of possible impairment/disability in the sample, Burial 21 in particular, and identify the associated asymmetries.[1] The starting hypothesis was that limbs indicating asymmetry due to pathology or trauma in one element would show bilateral asymmetries elsewhere in the same bone and limb, due to either atrophy alone or to additional compensatory hypertrophy.

In both cases, the methods of analysis were the non-destructive measurements of external dimensions of the long bones. This methodology was used because of the basic practical limitations of this study and because it provides

[1] The term 'impairment' in this paper generally implies a purely physical condition, while 'disability' encompasses both physical impairments and limitations imposed by societal or environmental structure as a result of the impairments.

Author correspondence should be directed to *battleht@mcmaster.ca* (Department of Anthropology, McMaster University, CNH Room 524, 1280 Main St. West, Hamilton, Ontario, Canada L8S 4L9)

Nexus is an annual graduate student publication of the McMaster University Department of Anthropology, Hamilton, Ontario, Canada. *http://digitalcommons.mcmaster.ca/nexus*

the greatest opportunity for comparison between samples, as skeletal analyses of many populations may be limited to simpler, non-destructive methods due to issues such as cost or political concerns. While many studies of the effects of activity and disuse on the skeleton have utilized destructive techniques such as histomorphometric analysis (Stout 1982) and chemical and stable isotope analysis (Whedon 1984; Katzenberg & Lovell 1999), Roberts (2002, 9) states that she believes non-destructive approaches will remain the dominant methods in paleopathology for the foreseeable future.

Background literature on asymmetry

Bone is a plastic and adaptive tissue, responding to changes in mechanical strain through the process of remodeling. New bone is deposited where there is an increase in strain, and bone is removed from areas affected by reduced activity or immobilization. This process has been demonstrated in studies of forms of exercise such racquet sports in terms of hypertrophy (i.e. Jones *et al.* 1977; Ruff *et al.* 1994; Bass *et al.* 2002) and of disuse in terms of atrophy (i.e. Biewener & Bertram 1994). However, nutrition, hormones, and genetics also play roles, and these systemic factors may alter the functional adaptive processes of bone (Lanyon & Skerry 2001, cited in Ruff *et al.* 2006).

Physical anthropologists and others have investigated bilateral asymmetry in long bones from a number of perspectives, from primate studies to shed light on evolution to variation among modern humans. Skeletal biology research into the evolution of handedness and laterality has extended across the disciplines (i.e. Morbeck *et al.* 1994 Steele 2004; Sarringhaus *et al.* 2005; Blackburn & Knüsel 2006). One recent study of the long bones in a collection of medieval skeletons found that the most bilaterally asymmetrical bone was the humerus, resulting from hand preference, while in terms of crossed symmetry the tibia on the opposite side of the body from the dominant arm was stronger and the femur was strongest on the left side regardless of hand preference (Čuk *et al.* 2001).

Studies of robusticity in the genus Homo (Ruff *et al.* 1993; Trinkaus *et al.* 1994; Ruff *et al.* 1994) found that modern human groups are less robust in the diaphyses but not in articular elements, indicating a mechanical rather than genetic cause for the trend. Auerbach & Ruff's (2006) study of bilateral asymmetry across modern human groups found patterns of crossed symmetry, sexual dimorphism of asymmetry, and decreased directionality and magnitude of asymmetry as well as decreased sexual dimorphism in more recent populations indicating changing labor patterns.

There have also been a number of studies on biomechanical responses to trauma (i.e. Churchill & Formicola 1997; Nystrom & Buikstra 2005) and pathology such as paralysis resulting from poliomyelitis infection in humans (Winkler & Großschmidt 1988) and chimpanzees (Morbeck *et al.* 1991). Studies of disuse atrophy resulting from pathology (i.e. Stout 1982), bed rest, and space flight (i.e. Whedon 1984) have shown that it may take many months for paralysis and immobilization to result in visible osteoporotic changes and that limbs in which partial use is retained may not show statistically significant asymmetries.

Knüsel (2000) outlines how diaphyseal diameters are better for examining activity-associated changes because they are subject to activity-related growth for a longer period of time than are long bone lengths or articular dimensions. Knüsel's (2000) results imply that asymmetries in articular dimensions in adults are the result of activity differences prior to maturity. In terms of disability, this conclusion would mean that asymmetries in diaphyseal and articular dimensions would indicate impairment of the limbs during childhood, while impairments acquired during adulthood would have a greater effect on the diaphyses (Knüsel 2000). Knüsel and colleagues (1992; 2000) provide an example of a medieval priest with a slipped proximal femoral epiphysis acquired prior to physiological maturity whose distal femoral condyles show asymmetries of the articular surfaces. This individual also displayed hypertrophies indicating the use of a crutch (Knüsel *et al.* 1992).

Skeletal evidence of impairment and disability may provide important information towards a number of larger theoretical and practical issues in human evolutionary biology and paleopathology. These issues include the effects of provisioning and healthcare altruism towards people with impairments on fitness and mortality rates (Sugiyama 2004), and questions of what constitutes evidence of care (Lebel *et al.* 2001; DeGusta 2002) or compassion (Dettwyler 1991; Hawkey 1998). Although the archeology of disability has only recently emerged as a distinct field of study, according to Roberts (2000, 46, 57) archeologists and bioarcheologists should be "inherently interested" in disability because it exists in all populations and cultures and how disability is perceived and treated reflects the human environment in which it is found.

Materials and methods

The Stirrup Court Cemetery near London, Ontario was first excavated in 1982, with the collection since kept at the University of Western Ontario. Parish (2000) describes the sample as representing a peri-urban population, with family farms located within a short traveling distance of the city. ("Peri-urban" refers to a place on the outskirts of an urban area, beyond the suburbs.) For comparison, the St. Thomas Cemetery sample from Belleville, Ontario, excavated in 1989, is described as being mainly urban (Parish 2000). Both are mid-nineteenth century middle class populations of British ancestry (Parish 2000). The advantage of using the Belleville data for comparison to Stirrup Court, besides the similarities stated above, is that the former is a much larger sample, with 295 adults complete enough for study out of 604 individuals total (Saunders *et al.* 1995, cited in Parish 2000), although data for certain measures used for comparison was not available for all individuals, reducing the sample size for each comparative analysis slightly, down to around 250 individuals, depending on the particular measurements.

In the Stirrup Court collection, data was collected from the 13 adult skeletons described as nearly-complete by Parish (2000), 8 of which have been identified by Parish with specific individuals or, in the cases of Burials 19 and 20, as part of one family. A total of 33 different measurements were taken on each side, 30 adapted from Buikstra & Ubelaker (1994) and 3 added: minimum shaft circumferences of the humerus, radius, and fibula. Some measurements on some individuals were unobtainable due to missing bones or damage to certain elements. For instance, at the lesser extreme Burial 5 provided only complete tibial and fibular and partial humeral measurements. Femur lengths were unavailable for 5 individuals (Burials 5, 11, 18, 19, and 21) due to previous cross-sectioning. A Paleo-Tech™ Field Osteometric Board was used to determine lengths, spreading calipers for physiological lengths, Mitutoyo digital sliding calipers for widths, breadths, and diameters, and a soft measuring tape for circumferences.

Measurements were taken to the nearest millimeter (mm), taking the median of 3 measurement attempts. Data collection was conducted by a single investigator over the course of 3 days, with Burial 21, which was measured first on the first day, being measured a second time at the end of the third day, with the second attempt used for the calculations, according to the assumption that measurement technique would have improved with experience. Intra-observer error was calculated for Burial 21 only (for the first of the two attempts), for 4 reasons: first, because it is the burial which receives individual attention in this paper; second, because of time constraints; third, because the error rate in any one burial of sample of 13 is either not expected to differ significantly from any of the others, or will be slightly higher; and finally, because it is one of the most complete skeletons in the sample with 31 out of the 33 measurements available. Intra-observer error was calculated by subtracting each of the 3 measurements in every category (ie humeral maximum length in left limb) from each other, with the mean for each side calculated simultaneously: (((L3-L1)+(L2-L1)+(L3-L2))/3). The average error (in mm) for the right and left sides was then calculated.

For each measurement on each individual, 4 calculations were made: 1) directional asymmetry (DA) [(r-l)/((r+l)/2)x100] and 2) absolute asymmetry (AA) [|(r-l)|/((r+l)/2)x100], after Mays *et al.* (1999) and Mays (2002) SDA (Standardized Directional Asymmetry) and STA (Standardized Total Asymmetry), and 3) directional difference (DD) [(r-l)] and 4) random difference (RD) [|(r-l)|]. For each of the 33 measurements, the minimum-maximum range, mean, median, and standard deviation were calculated for the sample. Additionally, individuals were roughly ranked according to the number of measurements in which the individual held the maximum RD.

For the Belleville sample, DA, AA, DD, and RD were calculated in each individual for 11 measurements for comparison to the equivalent in Stirrup Court. Minimum-maximum ranges, mean, median, and standard deviation were also calculated for the sample for each measurement, and these were compared to the statistics from Stirrup Court. DA and AA only were also calculated for humeral minimum shaft circumference at a later stage for sexual dimorphism comparison purposes. On this measure, the Belleville sample consisted of 26 males and 16 females (those individuals for whom sex was known and which provided measurements on both the right and left humeral shafts).

Results

Intra-observer error in Burial 21

The average mean error of right and left sides in Burial 21 (first attempt) ranged from 0.00mm to 0.83mm, while the maximum mean error on either side was 2.00mm on the left humeral minimum shaft circumference. The mean of the average mean error for all 31 measurements was 0.05mm with a standard deviation of +/-0.31mm, with the average mean error of the left side being slightly higher at 0.09mm with a standard deviation of 0.56mm compared to an average mean error on the right side of 0.02mm with a standard deviation of 0.31mm.

Stirrup Court

When the Stirrup Court burials were ranked for their asymmetry scores, excluding Burial 5 due to its high percentage of missing elements (Table 1), 5 individuals tied for highest asymmetry scores and one individual ranked lowest. The 5 individuals at the high end were those showing the most trauma and pathology in the long bones with 4 out of the 5 belonging to one family (Table 2); the individual with the lowest score was described by Parish (2000) as robust and active with well-healed fractures.

Burial	B3	B4	B6	B7	B10	B11	B14	B17	B18	B19	B20	B21
Sex	F	M	M	F	M	M	M	M	F	M	M	M
Score by random difference	3	5	2	4	2	1	3	4	5	5	5	5

Table 1. Stirrup Court asymmetry scores and rankings, sex according to Parish (2000)

Burial	*Observations*
Burial 4	Elderly and osteoarthritic
Burial 18	Unhealed fracture of femur with bone loss
Burial 19	Fractured femur; old fracture on ulna; osteoarthritic
Burial 20	Young with little pathology; violent death; son of B18 and B19
Burial 21	Necrosis of right hip joint; atrophy of right femur; scoliokyphosis; humeri supinated; son of B18 and B19

Table 2. Stirrup Court burials with highest asymmetry scores with observations from Parish (2000)

Burial	*Asymmetry pattern*	*Highest/lowest asymmetries*	*Observations (Parish 2000)*
3	R-dominant	Highest on femoral A-P subtroch. diameter	Cancerous lesions
4	R-dominant by length; L-dominant in LL diameter (probable)		Elderly, osteoarthritic
5	Fairly even mix (only tibia, fibula, and partial humerus)		Osteoarthritic
6	Even or R-dominant UL; L-dominant tibiae; possible crossed symmetry	Highest in ulnar M-L diameter	Osteoarthritic; normal and healthy
7	R-dominant UL; L-dominant LL; crossed symmetry		Robust with systemic arrested growth
10	R-dominant UL; L-dominant LL (femora); x-symmetry		
11	R-dominant (tentative due to missing measurements)		Robust; well-healed fractures (R femur)
14	R-dominant UL; L-dominant LL; x-symmetry	Low overall	Partial spina bifida; possible herniated disk; periostosis
17	R-dominant	Fairly low overall	All bones porous and light; severe lesions on feet and spine
18	R-dominant UL (missing femur lengths and fibulae make x-symmetry difficult to assess)	Highest on humeral length; tied highest on ulnar length; high in prox. and distal tibial epiphyseal breadths	Unhealed fracture of femur resulting in bone loss
19	Mixed results in UL (including high L-bias in radii); L-dominant LL		Fractured right femur; old fracture of L ulna
20	R-dominant UL; consistent L-dominance in LL; x- symmetry	Highest in tibial lengths	Violent death
21	Mixed	2nd-highest on humeral length; very high L-dominance in max femoral head diameter; very high on femoral M-L diameter, w/ none on A-P diameter	Necrosis of R hip joint with atrophy of R proximal femur; scoliokyphosis; humeri supinated

Table 3. Description of asymmetry patterns in the Stirrup Court burials with the most relevant observations by Parish (2000). R=right, L=left, UL=upper limbs, LL=lower limbs, x-symmetry= crossed symmetry.

Overall, the Stirrup Court data showed a general pattern of crossed symmetry (right-bias in the upper limbs and left-bias in the lower limbs). Table 3 describes and summarizes the patterns of asymmetry for each burial, with the most relevant paleopathological and biographical observations by Parish (2000) included.

To answer the question of what measurements on which bones displayed the most asymmetry in this sample, both mean and median absolute asymmetries were used. They were similar, with the same 5 measurements above 5% on both mean and median (Fig. 1; Fig 2). However, there was a sixth measurement with the highest AA by mean that was not above 5% by median, which was the medial-lateral subtrochanteric diameter of the femur (Fig. 2). In terms of sexual dimorphism in the sample, the absolute asymmetries in humeral minimum shaft circumference were compared for all 13 individuals (9 males, 4 females), with the males showing higher asymmetries, though these are mainly concentrated in two individuals (Fig. 3).

Of particular interest, Burial 21 showed high asymmetry in femoral head diameter and medial-lateral subtrochanteric diameter (Figs. 4 and 5), due to necrosis of the right hip joint, but almost no asymmetry in the anterior-posterior subtrochanteric diameter (Fig. 6).

Stirrup Court vs. Belleville

When the statistics from Stirrup Court were compared with Belleville's, a similar pattern became apparent. When graphed by median absolute asymmetries to reduce the impact of the highly asymmetrical individual measurements such as on Burial 21's proximal femur, generally the Belleville asymmetries were high for the same measurements on which Stirrup Court was high, and low for the ones on which Stirrup Court was low (Fig 7). The same graph by mean is provided for comparison (Fig. 8). By median, the femoral proximal and midshaft anterior-posterior asymmetries are higher in Stirrup Court than in Belleville, and the femoral midshaft medial-lateral absolute asymmetry is higher in Belleville than in Stirrup Court.

A comparison of sexual dimorphism of asymmetry in humeral minimum shaft circumference between Stirrup Court and Belleville showed lower dimorphism in Stirrup Court with males slightly more asymmetrical than females, while in the Belleville sample the females were slightly more asymmetrical (Table 4).

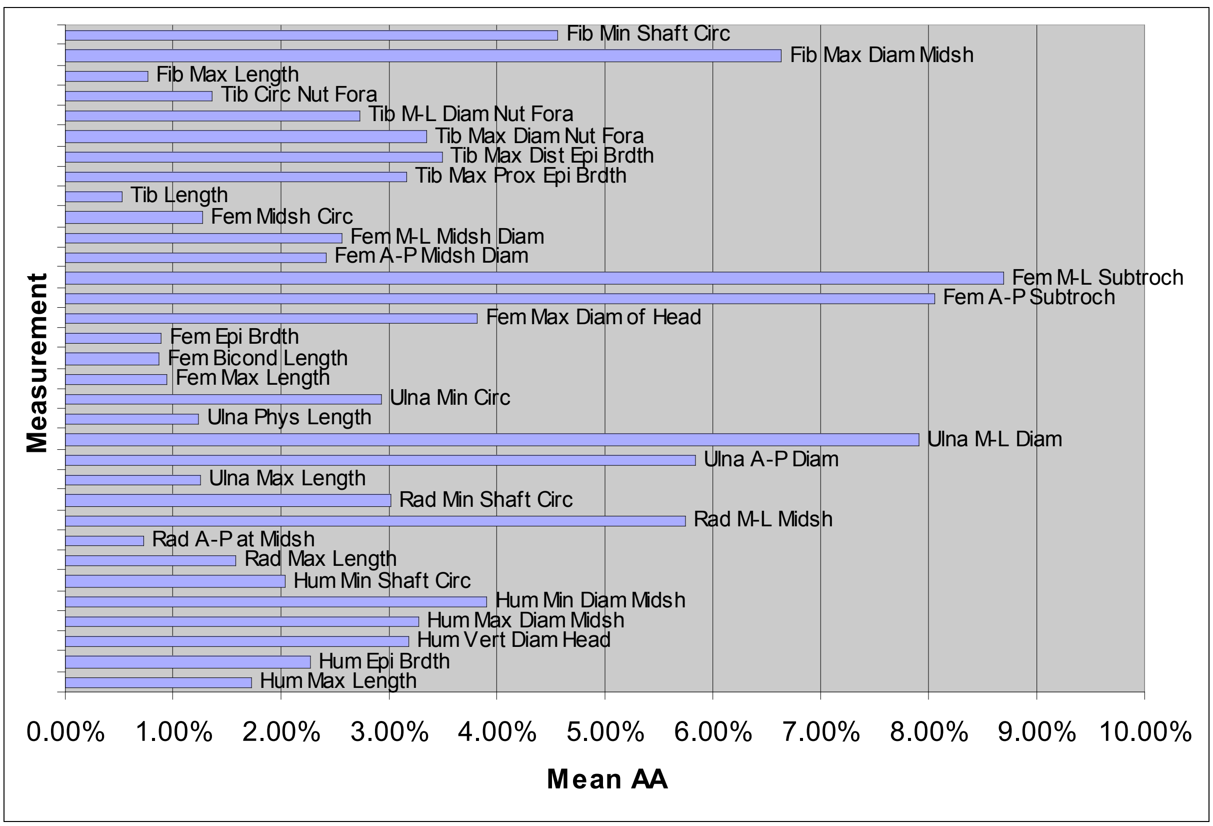

Figure 1. Stirrup Court: mean asymmetries in the sample by measurement.

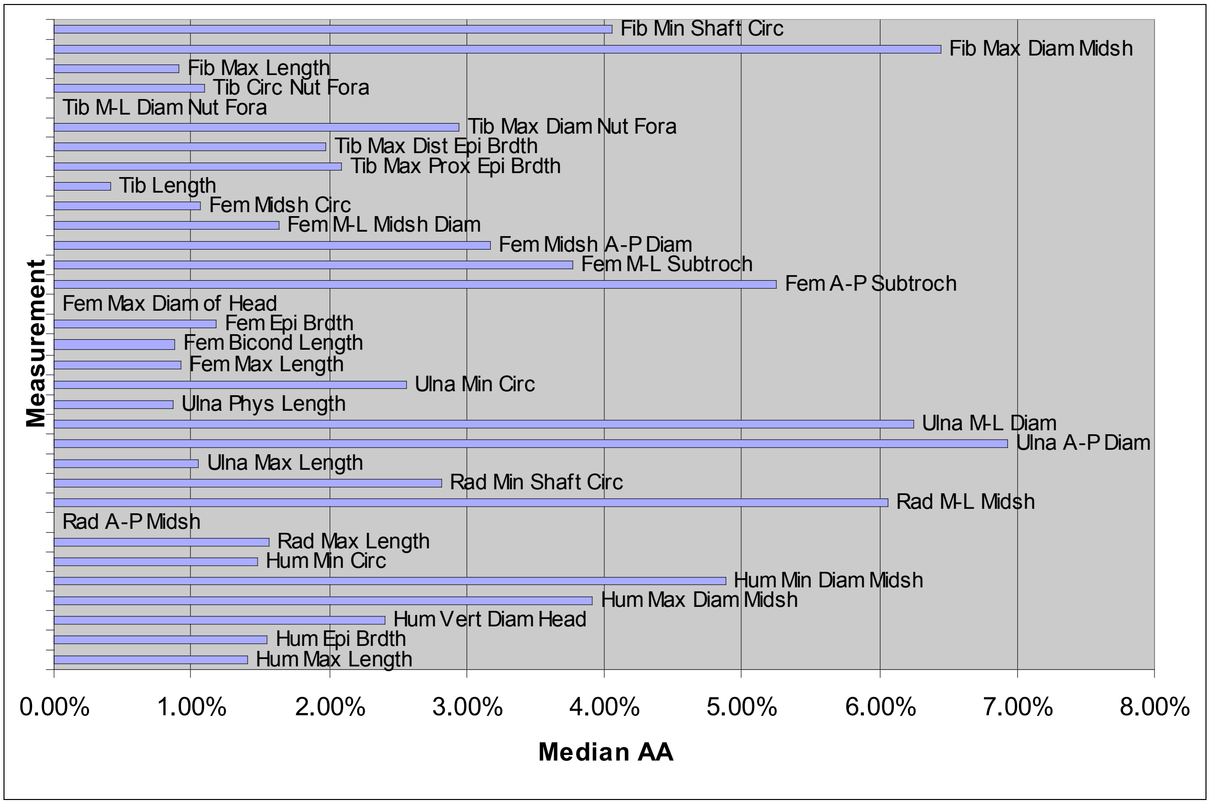

Figure 2. Stirrup Court: median asymmetries in the sample by measurement

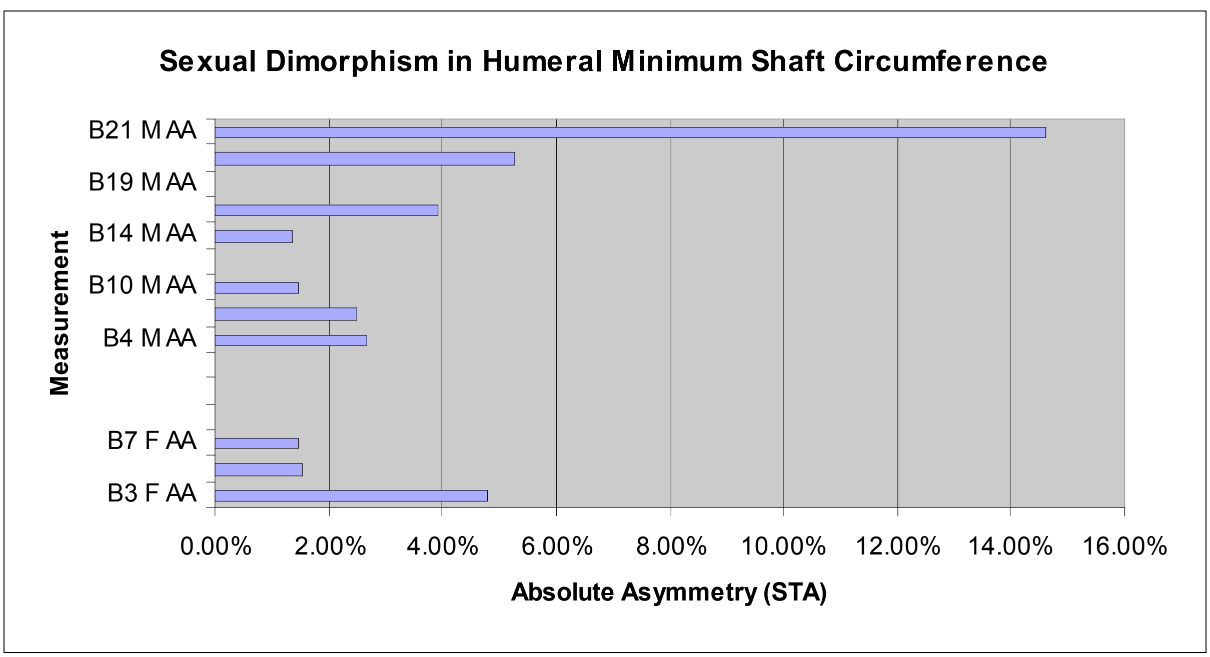

Figure 3. Sexual dimorphism in humeral minimum shaft circumference in Stirrup Court sample.

Figure 4. Anterior view of proximal femora of Burial 21, showing asymmetries in the femoral head and medial-lateral subtrochanteric diameter.

Figure 5. Posterior view of proximal femora of Burial 21, showing asymmetries in the femoral head and medial-lateral subtrochanteric diameter.

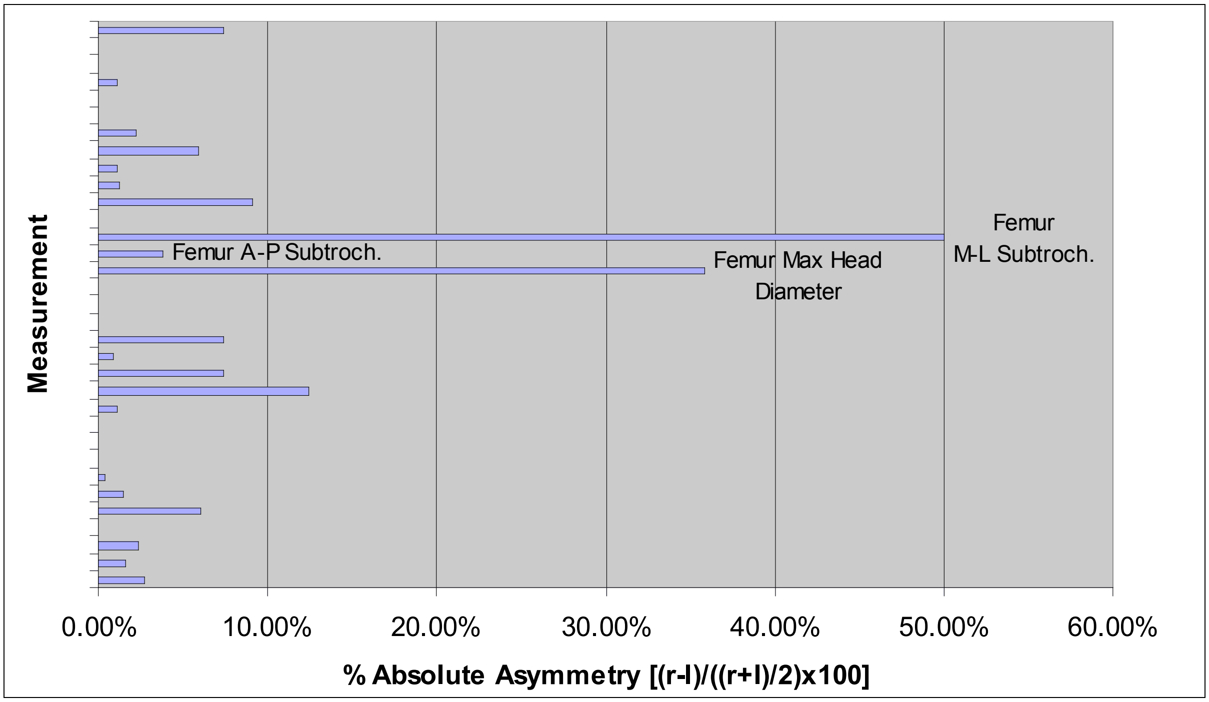

Figure 6. Burial 21 absolute asymmetries.

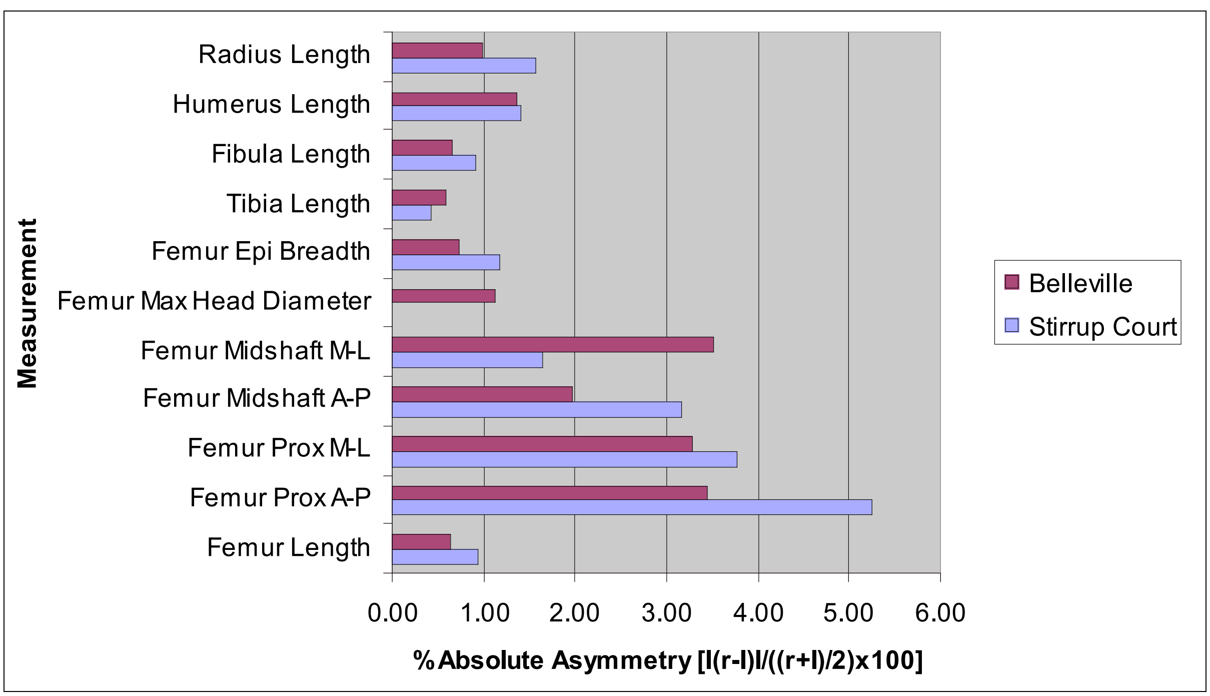

Figure 7. Stirrup Court and Belleville median absolute asymmetries compared.

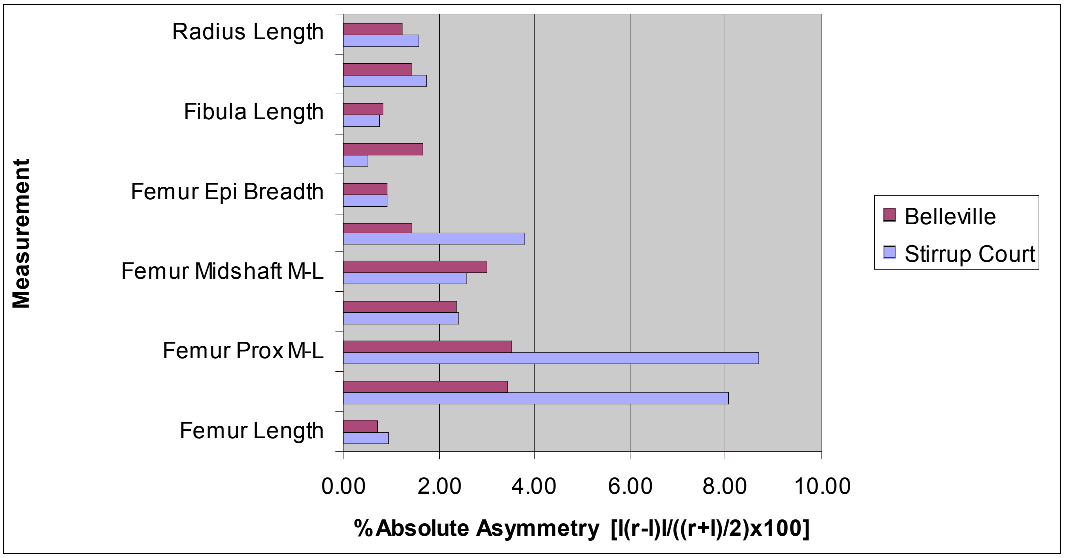

Figure 8. Stirrup Court and Belleville mean absolute asymmetries compared.

	Stirrup Court (M) n=9	*Stirrup Court (F) n=4*	*Belleville (M) n=26*	*Belleville (F) n=16*
Min AA	0.00%	0.00%	1.30%	0.00%
Max AA	14.60%	4.80%	21.9%	28.10%
Mean AA	3.53%	1.96%	9.99%	11.16%
Median AA	2.50%	1.52%	8.51%	10.36%
Std. Dev. AA	4.49%	2.03%	6.64%	8.81%

Table 4. Stirrup Court and Belleville sexual dimorphism on humeral minimum shaft circumference absolute asymmetry (AA). M=male, F=female.

Discussion and conclusions

Methods

The most difficult measure to take was the minimum circumference of the fibula. In the future, the use of string to measure circumferences of less than 50mm would be advised, and perhaps for all circumferences in the sample for the sake of consistency and comparability.

Burial 21

This individual was identified by Parish (2000, 113, 150) as John Robotham, aged 42-47 years, and described as suffering from a "highly debilitating neuromuscular disorder" likely genetic in origin. In their analyses of the femora of "Peg Leg Brown", Lazenby & Pfeiffer (1993) found that their results were consistent with the model of femoral loading proposed by Ruff & Hayes (1983), in which the proximal femoral diaphysis experiences maximum medial-lateral loading and minimum anterior-posterior bending moments, with these being equal at midshaft. Burial 21's femoral measurements are consistent with this, with a femoral proximal medial-lateral difference of 12mm and only 1mm of difference on the proximal anterior-posterior diameter.

Regarding my initial hypothesis about impairment and asymmetry in Burial 21, the results did not show what had been expected. The limb was apparently used enough that the external dimensions measured in this study did not reveal signs of impaired function or decreased use other than the specific limited asymmetries previously noted. Rather, significant asymmetry on one measure, on part of one bone, did not necessarily mean there will be more asymmetries found elsewhere in the bone or limb. If this statement is true, when applied more generally, differential preservation could result in many missed cases of disability in the archeological record, especially since atrophied elements, or those otherwise weakened by trauma or pathology, may be less likely to preserve.

Also, the lack of any asymmetry in Burial 21's distal femoral epicondylar breadth might indicate, in contrast to the case provided by Knüsel and colleagues (1992; 2000; discussed above in the "Background literature on asymmetry" section) that the necrosis in his right hip joint either did not occur prior to physiological maturity or began in childhood but did not progress to the severity seen at death until into adulthood. However, the extensive remodeling of the right femoral head and acetabulum, combined with other paleopathological indicators would indicate that this condition likely had a subadult onset, and that perhaps the explanation for the lack of asymmetry elsewhere in the limb is that the necrosis in the hip joint did not impair the function of the limb as much as might be assumed, which is consistent with Parish's (2000, 118) analysis of the articular facets of the lower right limb indicating high mechanical loading.

As Dettwyler (1991), Roberts (2000), and DeGusta (2002) argue that we should not make assumptions about the quality of life or ability to survive without care and assistance of people with disabilities in the past on the basis of skeletal evidence alone, perhaps participants in this field of study should also be cautious in making determinations about the extent of disability experienced by a person exhibiting indications of physical impairment such as asymmetrical atrophy, especially in cases without such good preservation as seen in this skeletal collection.

Stirrup Court and Belleville

Both samples show low overall asymmetry, excepting the specific instances of trauma or pathology. It is possible that the median differences between the Stirrup Court and Belleville samples in femoral proximal anterior-posterior and midshaft medial-lateral and anterior-posterior midshaft diameters mentioned above may be due to differences in measurement technique between the observers who collected the data in the different samples, so that no conclusions can be drawn from these discrepancies at this time. Furthermore, the Stirrup Court sample size is too small to thoroughly investigate sexual dimorphism of asymmetry. If the higher asymmetries in some of the males are representative, the graph of humeral shaft circumference absolute asymmetry does appear to fit with other studies' findings regarding gender-specific activities such as agricultural labor for males versus domestic labor for females, with males showing greater asymmetry in the upper limbs (Sladek *et al.* 2007). However, if the 2 males with higher asymmetries are outliers and the more accurate pictures is one of a lack of significant differences between males and females, this might reflect changing behavior patterns and division of labor in this peri-urban sample (Auerbach & Ruff 2006).

The median AA of 2.50% in humeral minimum shaft circumference in the Stirrup Court males appears to fit well within the Euro-American category in Churchill & Formicola's (1997, 27-28) analysis of percentage asymmetry in humeral shaft circumference in both recent and fossil males, with the Euro-American sample having a range of 0.00% to 7.80% and a quartile range of 1.60% to 3.30%. However, the median AA on the same measure in the sample of Belleville males is above this range at 8.51%. Statistical analyses showing the Belleville females as slightly more asymmetrical than the males in humeral minimum shaft circumference, and basically even on mean and median, would appear to support the hypothesis that the Stirrup Court data, despite the small sample size, indicate that sexual dimorphism in the upper limbs was relatively low in this nineteenth-century population, with males slightly more asymmetrical than females, and that this reflects changing behavior and labor patterns in the move towards urbanization, as Stirrup Court is 'peri-urban' and Belleville is a more urban population.

Finally, articular measures are ones affected by osteoarthritis and many of the cases of asymmetry in the Stirrup Court sample occurred in elderly individuals showing signs of osteoarthritis. Therefore, perhaps asymmetry studies using older individuals are less useful in detecting non-osteoarthritic, or non-age-related, impairment and disability.

Future directions for research

In terms of population asymmetry and sexual dimorphism, the difference between the two samples in their humeral minimum shaft circumference absolute asymmetries requires further investigation, especially to consider the higher asymmetries in the Belleville sample and its apparent pattern of greater asymmetry in the females versus the males, which may have been affected by the heterogeneity of age in the samples. Further research into differences between rural, peri-urban, and urban populations would also contribute to greater insight into the processes of urbanization; Waldron (2000, 43) notes, for example, that more people with disabilities may be found in towns or cities, where they might be better able to support themselves.

Regarding skeletal evidence of disability, as Roberts (2000) has noted the archeology of disability is a relatively new field of study and one which can potentially gain much from bioarcheological research. Finlay (1999, 4), editor of the "Disability and Archaeology" themed issue of the Archaeological Review from Cambridge, stated that this volume "mark[ed] the tentative beginnings of a disability discourse in [archeology]." In this new area of study, there is a need for better understanding of how to interpret impairment and disability in the bioarcheological record and, as Sofaer (2006) argues, for physical anthropology and bioarcheology/osteoarcheology to contribute to archeological theories about the body. As the archaeological body is reimagined as "the nexus between biology and culture" (Sofaer 2006, 9, 30), perhaps the archaeology of disability will not only take on greater significance within the field of archaeology but also aid in bridging the divide across the discipline and contribute to the creation of a broader 'anthropology of disability'. Shakespeare (1999, 99) takes the same view, noting that "archaeology has the capacity to revisit and problematise issues of the human body in time, and to connect the physical to the socio-cultural".

Some impairments/disabilities may be more difficult to observe and interpret than others. Loss of a limb may be obvious, while loss of sight or hearing may not leave skeletal evidence short of signs of injury to the associated areas of bone or paleopathologic indications of diseases which cause vision or hearing loss. There are also mental or cognitive disabilities to consider. In the Stirrup Court sample, for example, John Robotham (Burial 21) was recorded in the 1871 London census as "Over 20, unable to read", "Over 20, unable to write", and "Deaf and dumb" (Parish 2000, 150), yet these particular disabilities were not necessarily apparent in the paleopathological analysis of his remains even though he was an individual with extensive physical evidence of a serious disorder (Parish 2000, 113). Finally, as Knüsel (2000, 395) suggests that "further insights into activity-related change will come from anthropological and human biological studies of modern individuals" with documented personal circumstances and social and cultural contexts, so too would further insights into the skeletal consequences of disability be gained from studies of modern individuals with disabilities.

This distance between lived disabilities and what is present in the osteological data alone suggests that individuals with physical impairments and disabilities are underrepresented in the bioarcheological record due to a gap in interpretative ability, even without the potential issue of differential preservation of impaired skeletal elements. However, perhaps more research is warranted on the latter as well, whether through the use of taphonomic experimentation or by comparing the archival and skeletal data on individuals with documented impairments to see if the affected elements are less likely to preserve overall and what kinds of impairments show greater or lesser preservation. As Waldron (2000, 43) has observed, while it appears that most individuals with disabilities "will remain hidden from archaeological gaze, diligent searching should reveal at least some to view." Greater attention to issues surrounding the visibility of impairment/disability in the archeological record and in bioarcheological theory would contribute to building the field of the archeology of disability and to producing insights into disability in the past with relevance to archeology and anthropology more broadly.

Acknowledgements

I wish to thank first of all the late Dr. Shelley Saunders for her help and guidance along every step of the project's progress and for providing access to the Belleville data. I also wish to thank Dr. Andrew Nelson and Anna Jung at the University of Western Ontario for their help in accessing the Stirrup Court collection and Dr. Joseph Parish of Cape Breton University. And finally, thanks to Bonnie Kahlon and Hagen Kluge for their help with various technical issues and to the two anonymous Nexus reviewers for their feedback and suggestions.

References

Auerbach, Benjamin M. and Christopher B. Ruff. 2006. Limb bone bilateral asymmetry: Variability and commonality among modern humans. *J of Hum Evol* 50: 203-18.

Bass, S.L., L. Saxon, R.M. Daly, C.H. Turner, A.G. Robling, E. Seeman, and S. Stuckey. 2002. The effect of mechanical loading on the size and shape of bone in pre-, peri-, and postpubertal girls: A study in tennis players. *J Bone Miner Res* 17: 2274-80.

Biewener, A.A., and J.E.A. Bertram. 1994. Structural response of growing bone to exercise and disuse. *J Appl Physiol* 76: 946-55.

Blackburn, Amanda, and Christopher J. Knüsel. 2006. Hand Dominance and bilateral asymmetry of the epicondylar breadth of the humerus: A test in a living sample. *Current Anthropol* 47(2): 377-82.

Buikstra, Jane E., and Douglas H. Ubelaker. 1994. *Standards for Data Collection from Human Skeletal Remains*. Fayetteville, AK: Arkansas Archeological Survey Research Series no. 44.

Churchill, Steven E., and Vincenzo Formicola. 1997. A case of marked bilateral asymmetry in the upper limbs of an Upper Palaeolithic male from Barma Grande (Liguria), Italy. *Int J of Osteoarch* 7: 18-38.

Čuk, Tonka, Petra Leben-Seljak, and Marija Štefančič. 2001. Lateral asymmetry of human long bones. *Variab and Evol* 9: 19-32.

DeGusta, David. 2002. Comparative skeletal pathology and the case for conspecific care in Middle Pleistocene hominids. *J of Archaeol Sci* 29: 1435-38.

Dettwyler, K.A. 1991. Can paleopathology provide evidence for "compassion"? *Am J of Phys Anthropol* 84(4): 375-84.

Finlay, Nyree. 1999. Disabling archaeology: An introduction. *Archaeological Review from Cambridge* 15(2): 1-6.

Hawkey, Diane E. 1998. Disability, compassion and the skeletal record: Using musculoskeletal stress markers (MSM) to construct an osteobiography from Early New Mexico. *Int J of Osteoarch* 8: 326-40.

Jones, H.H., J.D. Priest, W.C. Hayes, C.C. Tichenor, and D.A. Nagel. 1977. Humeral hypertrophy in response to exercise. *J Bone Joint Surg* 59: 204-8.

Katzenberg, M. Anne, and Nancy C. Lovell. 1999. Stable isotope variation in pathological bone. *Int J of Osteoarch* 9: 316-24.

Knüsel, Christopher J. 2000. Bone adaptation and its relationship to physical activity in the past. In *Human Osteology in Archaeology and Forensic Science*, ed. Margaret Cox & Simon Mays, 381-401. Cambridge: Cambridge University Press.

Knüsel, Christopher J., Zoë C. Chundun, and Peter Cardwell. 1992. Slipped proximal femoral epiphysis in a priest from the medieval period. *Int J of Osteoarch* 2: 109-19.

Lanyon, L., and T. Skerry. 2001. Postmenopausal osteoporosis as a failure of bone's adaptation to functional loading: A hypothesis. *J Bone Miner Res* 16: 1937–47.

Lazenby, Richard A., and Susan K. Pfeiffer. 1993. Effects of a nineteenth century below-knee amputation and prosthesis on femoral morphology. *Int J of Osteoarch* 3(1): 19-28.

Lebel, Serge, Erik Trinkaus, Martine Faure, Philippe Fernandez, Claude Guérin, Daniel Richter, Norbert Mercier, Helène Valladas, and Günther A. Wagner. 2001. Comparative morphology and paleobiology of Middle Pleistocene human remains from the Bau de l'Aubesier, Vaucluse, France. *Proceedings of the National Academy of Sciences USA* 98(20): 11097-102.

Mays, S.A. 2002. Asymmetry in metacarpal cortical bone in a collection of British post-mediaeval human skeletons. *J of Archaeol Sci* 29(4): 435-41.

Mays, Simon, James Steele, and Mark Ford. 1999. Directional asymmetry in the human clavicle. *Int J of Osteoarch* 9: 18-28.

Morbeck, Mary Ellen, Alison Galloway, Kenneth M. Mowbray, and Adrienne L. Zihlman. 1994. Skeletal asymmetry and hand preference during termite fishing by Gombe chimpanzees. *Primates* 35(1): 99-103.

Morbeck, Mary Ellen, Adrienne L. Zihlman, Dale Richman Sumner, Jr., and Alison Galloway. 1991. Poliomyelitis and skeletal asymmetry in Gombe chimpanzees. *Primates* 32(1): 77-91.

Nystrom, Kenneth C., and Jane E. Buikstra. 2005. Trauma-induced changes in diaphyseal cross-sectional geometry in two elites from Copan, Honduras. *Am J of Phys Anthropol* 128: 791-800.

Parish, Joseph M. 2000. *The Stirrup Court Cemetery: A comparison of peri-urban and urban health in nineteenth-century Ontario.* MA thesis, University of Western Ontario.

Roberts, Charlotte. 2000. Did they take sugar? The use of skeletal evidence in the study of disability in past populations. In *Madness, Disability and Social Exclusion: The Archaeology and Anthropology of "Difference"*, ed. Jane Hubert, 46-59. London: Routledge.

Roberts, Charlotte. 2002. Palaeopathology and archaeology: The current state of play. In *The Archaeology of Medicine: Papers given at a session of the annual conference of the Theoretical Archaeology Group held at the University of Birmingham on 20 December 1998*, ed. Robert Arnott, 1-20. Oxford: Archaeopress.

Ruff, Christopher B., and Wilson C. Hayes. 1983. Cross-sectional geometry of Pecos Pueblo femora and tibiae – a biomechanical investigation. *Am J Phys Anthropol* 60(3): 359-400.

Ruff, Christopher B., Brigitte Holt, and Erik Trinkaus. 2006. Who's afraid of the big bad Wolff? Wolff's Law and bone functional adaptation. *Am J Phys Anthropol* 129: 484-98.

Ruff, Christopher B., Erik Trinkaus, Alan Walker, and Clark Spencer Larsen. 1993. Postcranial robusticity in *Homo*. I: Temporal trends and mechanical interpretation. *Am J of Phys Anthropol* 91: 21-53.

Ruff, Christopher B., Alan Walker, and Erik Trinkaus. 1994. Postcranial robusticity in *Homo*. III: Ontogeny. *Am J of Phys Anthropol* 93: 35-54.

Sarringhaus, L.A, J.T. Stock, L.F. Marchant, and W.C. McGrew. 2005. Bilateral asymmetry in the limb bones of the chimpanzee (*Pan troglodytes*). *Am J of Phys Anthropol* 128: 840–45.

Saunders, Shelley R., Ann Herring, Lawrence A. Sawchuck, and Gerry Boyce. 1995. The nineteenth century cemetery at St. Thomas' Anglican Church, Belleville: Skeletal remains, parish records, and censuses. In *Grave Reflections: Portraying the Past Through Cemetery Studies*, ed. Shelley R. Saunders and Ann Herring, 93-117. Toronto: Canadian Scholars' Press.

Shakespeare, Tom. 1999. Commentary: Observations on disability and archaeology. *Archaeological Review from Cambridge* 15(2): 99-101.

Sládek, Vladimír, Margit Berner, Daniel Sosna, and Robert Sailer. 2007. Human manipulative behavior in the Central European Late Neolithic and Early Bronze Age: Humeral bilateral asymmetry. *Am J of Phys Anthropol* 133: 669-81.

Sofaer, Joanna R. 2006. *The Body as Material Culture: A Theoretical Osteoarchaeology*. Cambridge: Cambridge University Press.

Steele, James. 2004. Handedness in past human populations: Skeletal markers. *Laterality* 5(3): 193-220.

Stout, Sam D. 1982. The effects of long-term immobilization on the histomorphology of human cortical bone. *Calcif Tissue Int* 34: 337-42.

Sugiyama, Lawrence S. 2004. Illness, injury, and disability among Shiwiar forager-horticulturalists: Implications of health-risk buffering for the evolution of human life history. *Am J of Phys Anthropol* 123: 371–89.

Trinkaus, Erik, Steven E. Churchill, and Christopher B. Ruff. 1994. Postcranial robusticity in *Homo*. II: Humeral bilateral asymmetry and bone plasticity. *Am J of Phys Anthropol* 93: 1-34.

Waldron, Tony. 2000. Hidden or overlooked? Where are the disadvantaged in the skeletal record? In *Madness, Disability and Social Exclusion: The Archaeology and Anthropology of "Difference"*, ed. Jane Hubert, 29-45. London: Routledge.

Whedon, G. Donald. 1984. Disuse osteoporosis: Physiological aspects. *Calcif Tissue Int* 36: S146-50.

Winkler, E., and K. Groβschmidt. 1988. A case of poliomyelitis from an Early Medieval cemetery at Georgenberg/Upper Austria. *Ossa* 13: 191-205.