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BILATERAL ASYMMETRY PATTERNS IN LINEAR DIMENSIONS OF THE HUMERUS AND FEMUR IN THREE HUMAN SKELETAL POPULATIONS

By

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ABSTRACT

BILATERAL ASYMMETRY PATTERNS IN LINEAR DIMENSIONS OF THE HUMERUS AND FEMUR IN THREE HUMAN SKELETAL POPULATIONS

By

Brian David Brown

Analysis of bilateral asymmetry in human limb bones is an increasingly prominent aspect of the biocultural approach to human skeletal biology, and several recent studies have assessed asymmetry in the cross-sectional geometry of long bone diaphyses. While the presence of directional asymmetry in linear dimensions of long bones is well documented, the nature of these asymmetry patterns among human populations has not yet been well characterized. This study lays a foundation for future biocultural work with linear asymmetry by assessing two skeletal samples from Georgian-era London church crypts (St. Bride's, Fleet Street, and Christ Church, Spitalfields), and comparing their asymmetry with figures derived from the Forensic Data Bank (at the University of Tennessee). The analysis focuses on six paired measurements: maximum length, vertical head diameter, and biepicondylar width of the humerus; and maximum length, head diameter, and biepicondylar width of the femur. Study hypotheses test whether the samples and the sexes display statistical independence in the distribution of (a) direction of asymmetry, (b) signed and unsigned magnitude of asymmetry; and (c) size of the linear dimensions themselves. The two Georgian samples are first assessed separately, then pooled and compared with the Forensic sample, and in each case the sexes are treated separately. All male-female comparisons display significant differences in each

of the long bone dimensions, with both Georgian samples significantly smaller than their Forensic counterparts in each of the dimensions. The Georgian females display the greatest asymmetry in humerus length, and the Georgian males display the greatest asymmetry in femur length. Asymmetry patterns are more often significantly different in Georgian-Forensic comparisons than in comparisons between the sexes of each sample, or between same-sex subgroups of the Georgian samples; this indicates that setting in time and space, but not sex, is a determinant of asymmetry patterns in long bone dimensions. Several methodological issues involving the assessment of asymmetry and historic skeletal populations are also discussed.

To my parents

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No work of this magnitude can be accomplished by a single person working in isolation, and this certainly is no exception. I wish to acknowledge the assistance of a multitude of professional colleagues, friends, and family; without their support this project would never have come to any level of completion.

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CHAPTER 1—AN INTRODUCTION

There is popular appeal to the belief that a physical anthropologist can construct a meaningful narrative about the life of an individual or a group of people by carefully examining skeletal remains. This appeal is exemplified by a recent series of mystery novels which feature the exploits of the affable forensic anthropologist Gideon Oliver.[1] In each book Oliver is presented with troublesome cases of death under mysterious circumstances. He proceeds to decipher seemingly obscure aspects of skeletal morphology to reveal facts about a deceased individual—facts which could only be determined by the trained eye of an anthropologist, and facts which lead to resolution of an engrossing mystery.

In recent years the Gideon Oliver mysteries have been joined by nonfiction accounts written by or about real-life physical anthropologists. They include Bones: A Forensic Detective's Casebook (Ubelaker and Scammell 1992), Witnesses from the Grave: The Stories Bones Tell (Joyce and Stover 1991), and What the Bones Tell Us (Schwartz 1993). One need not even read past the titles of these three volumes to grasp their fundamental message that skeletal material is a text that can be read and accurately interpreted by an expert. It is a message that comes as little surprise to skeletal biologists, for whom Reconstruction of Life from the Skeleton is not just the title of a specialist volume (İşcan and Kennedy 1989) but an explicit statement of a dominant theme in contemporary human skeletal biology.

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[1]Although Gideon Oliver is a fictitious character, he is modeled on a composite of contemporary forensic anthropologists. The creator of the series, Aaron Elkins, authored Old Bones, which was recipient of an Edgar Award for Best Mystery in 1988. Other Gideon Oliver Mysteries include Icy Clutches (1990) and The Dark Place (1983).

For physical anthropologists the task of reconstructing life from skeletal remains is fraught with difficulty. Recent exchanges in Current Anthropology regarding "the osteological paradox" offer the sobering suggestion that enthusiastic researchers have lost sight of the limits of osteological analysis as a tool for reconstructing lifeways (Wood et al. 1992, Byers 1994). The paradox arises when the same skeletal evidence can be employed to support contradictory views about human lifeways. For example, one may consider a scenario in which one of two contemporaneous and spatially local skeletal populations consists of many individuals who display lesions associated with tuberculosis, while the other population exhibits no such lesions. One researcher may conclude that the population manifesting the disease markers displays a deterioration in health status relative to the population without the markers. Another researcher might argue that the population with the disease markers is the one which is relatively healthier, since its members were able to survive the disease adequately to be able to develop the skeletal lesions. In the latter interpretation, the absence of disease markers in the second population indicates not that the disease is absent, but rather that individuals succumbed to the disease process before it could progress to the extent that they could develop skeletal lesions. The paradox is that skeletal markers of disease may be viewed as both a sign of good health and a sign of poor health when comparing skeletal populations.

Even if there are potential pitfalls to the interpretation of skeletal biology, human remains are often the only primary data available for deriving information about an individual or a population from the past. However, a physical anthropologist can only successfully reconstruct facets of an unknown person's life by drawing on the research of others who have studied known individuals and have identified meaningful aspects of their skeletal morphology. While such research has traditionally employed both qualitative and quantitative strategies, the popular accounts cited above focus primarily on non-metric techniques of osteological analysis. The contemporary emphasis on qualitative assessments contrasts markedly with the basic osteometric analyses which were prevalent earlier this century. In the early 1900s two major journals, the American Journal of Physical Anthropology and the British Biometrika, reported numerous craniometric studies performed on skulls from around the world. The popularity of craniometry at that time reflected what were thought to be the interesting anthropological questions of the day. Specifically, craniometry was employed as a tool for discriminating genetic relationships between human populations, and it was often the basis for drawing conclusions about the relative intelligence of different human racial groups (Gould 1981, Armelagos et al. 1982).

While early researchers subjected human crania to intense study, they showed relatively little interest in the postcranial skeleton. The few published studies which did address the major limb bones, however, still emphasized the comparison of long bone morphology among racial groups (Hrdlička 1932, Münter 1936, Schultz 1937). Like most so-called "racial" characteristics, variation in limb morphology between populations did not serve as a particularly useful analytical tool for categorizing humans into discrete groups. As a result, the perceived value of postcranial morphology as an indicator of broader patterns in human biological variation waned as the century progressed. At the same time so did the number of descriptive reports based on the osteometry of major limb bones.

In their place, today's osteometric analyses of limb bones serve primarily to aid researchers in determining two pieces of information about an unknown individual: sex and living stature.[2] Sex determination on the basis of long bone measurements reflects the general size dimorphism between human males and females. For example, the diameter of the head of the humerus or the femur is commonly employed as a univariate technique for attributing sex to skeletal material when the cranium and pelvis are not present. Even more accurate multivariate techniques have been developed for assessing sex from the post-cranial skeleton, and these are widely reported in the standard osteological texts.[3] Because the long bones of the lower limb contribute significantly to an individual's stature, skeletal biologists have developed a series of formulae for estimating living stature based on the lengths of limb bones among several different human groups. Stature formulae have not been limited to the bones of the lower limb, although upper limb measurements tend to give less accurate estimations of stature. These formulae have also been well documented in the standard osteological texts and are commonly in use by physical anthropologists.

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[2]Estimation of sex, stature, age, and ethnic affiliation are the four most fundamental aspects of human identification based on skeletal criteria. There are published discriminant functions for the latter which employ a combination of pelvic and femoral characteristics (DiBennardo and Taylor 1983), but none which rely solely on measurements of limb bones. Likewise, limb bone osteometry is not a useful tool for estimating the age of an unknown individual.

[3]Bennett (1993) provides currently the most up-to-date reference guide for skeletal identification, and the univariate and multivariate techniques described here are outlined in his volume. Bass (1987), Steele and Bramblett (1988), Krogman and İşcan (1986), and Stewart (1979) are other commonly cited references, and these constitute the "standard osteological texts."

THE BIOCULTURAL PERSPECTIVE

Recent decades have seen an expansion in osteological research that reflects the popularity of a biocultural approach toward skeletal biology. The biocultural perspective is predicated on the empirical finding that the skeleton is a dynamic organ system which is constantly being modified in interaction with the environment (Bush and Zvelebil 1991). This fresh perspective has led skeletal biologists to focus their energy on assessing lifeways based on characteristics of the skeleton that have been subjected to modification by factors in the environment (Armelagos et al. 1982).

Notwithstanding the popularity of qualitative techniques for assessing skeletal elements in the biocultural approach, quantitative assessments of long bone morphology have not been totally supplanted. For example, patterns which indicate an increase in mean femur length over time within a population have been put forward as evidence for secular increase in the population's mean stature. The argument follows that an increase in a population's stature over time reflects a general improvement in that population's general health status.[4]

OSTEOMETRY AND THE BIOCULTURAL PERSPECTIVE

One prevailing theme in the biocultural literature is that the skeleton retains features which are indicative of an individual's health status during life (Cohen 1989;

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[4]The relationships among stature, nutrition, and health status have been discussed widely among clinicians (Acheson and Fowler 1964), skeletal biologists (Steegman 1985, 1986, 1991), and historians (Floud et al. 1990, Floud et al. 1993; Fogel et al. 1983; Fogel 1986; Komlos 1993). Researchers generally agree that the issues are linked, but there is debate about the historical significance of the differences. Henneberg and VandenBerg (1990) report that secular trends are not obviously associated with socioeconomic status.

Goodman et al. 1988). These features include markers of generalized stress, such as enamel hypoplasias in the dentition (Goodman and Rose 1990); they also include markers of a specific type of stressor such as porotic hyperostosis, which is associated with anemia (Stuart-Macadam 1989a; 1989b; 1992).

Increasingly sophisticated osteometric techniques have also been developed in recent years to reconstruct patterns of lifeways from postcranial skeletal material. Beginning in the 1980s studies which assessed diaphyseal morphology of limb bones began to appear in the literature (Ruff and Jones 1981). In these studies new technologies, such as three-dimensional scanning of gross skeletal morphology, were applied to examine the cross-sectional geometric characteristics of long bones. Diachronic studies of spatially local native North American skeletal populations revealed that the diaphyseal geometry of long bones—most notably the humerus—showed significant modifications over time. Researchers hypothesized that such changes in the shape of the bone shaft were caused by changing patterns of mechanical loading on the long bones. In short, they argued that evidence for changes in physical activity patterns were preserved in the cross-sectional geometry of the bone shafts. They suggested further that changes in the size and shape of the shaft of the humerus provide evidence for modifications in subsistence patterns within the population over time (Bridges 1989, Fresia et al. 1990).

METRIC ASYMMETRY

One component of diaphyseal morphology which has been subject to considerable recent research is bilateral asymmetry (Ruff et al. 1993, Trinkaus et al. 1994, Roy et al.

1994). As Ruff (1992:50) suggests, "differences in the average degree of asymmetry present within populations or subsets of populations may be indicative of significant differences in behavioral characteristics."

Fresia et al. (1990) offer a typical example of how asymmetry patterns in long bones have been addressed from a biocultural perspective. Specifically, they draw attention to changes in patterns of bilateral asymmetry in humerus morphology which, they argue, accompanied the shift from a pre-agricultural to an agricultural way of life among Native Americans in Georgia. While Fresia et al. are primarily interested in the nature of bilateral asymmetry in diaphyseal cross-sectional geometry, they also briefly report findings related to asymmetry in the length of the humerus.

The growing prominence of cross-sectional analysis appears to have eclipsed contemporary critical examination of bilateral asymmetry in the linear dimensions of long bones. For example, the discussion by Trinkaus et al (1994) of humerus morphology in modern and premodern Homo populations briefly notes the presence of linear asymmetry, indicating that the magnitude of the asymmetry among their studied individuals is relatively small. The magnitude of asymmetry in the length of the humerus they cite (less than two percent, in most cases) is consistent with that reported in most studies of long bone asymmetry published to date. Missing from their discussion, however, is a systematic appraisal of how patterns of linear asymmetry vary within and between the skeletal populations.

The fact that the magnitude of asymmetry is relatively small appears to be commonly used as a prima facie argument for neglecting a methodical appraisal of bilateral asymmetry patterns in linear dimensions of human long bones across populations. This may be an unfortunate circumstance, since patterns of asymmetry may reveal valuable and heretofore unrecognized information about the lifeways of past and present populations. Such an assessment would have been difficult for Trinkaus et al (1994), since they were employing small samples—sometimes only single individuals from a particular site. It is striking, however, that no one to date has reported a study of linear asymmetry patterns within or between human skeletal populations of a reasonable size.

The Assumption of Symmetry

Stirland (1986) describes the median sagittal plane as "the central plane of the body which passes along the central sagittal suture in the top of the skull, and about which the body is bilaterally symmetrical and divided into right and left halves" (p. 15) All unpaired bones (mandible, sternum, vertebrae, etc.) are regarded as virtually symmetrical across the median sagittal plane. Likewise, all paired bones in the skeleton are paired left and right, never anterior and posterior or superior and inferior, and "side identification" is one of the fundamental techniques described in introductory osteology texts.

In spite of the general assumption that paired bones are symmetrical, the empirical finding that asymmetry occurs regularly in human skeletal elements has been well documented since the mid-nineteenth century; Ruff and Jones (1981) cites several of these early reports. In general, these studies have briefly acknowledged the phenomenon of bilateral asymmetry in the skeleton, but almost always as an aside to discussing other aspects of skeletal morphology in general. As a result, the nature of asymmetry in skeletal elements among members of skeletal populations has eluded systematic investigation to date.

Explanations for Asymmetry

If researchers assume that bilateral asymmetry is the normal condition for paired skeletal elements, then they require some way to explain the presence of asymmetry in bones. A number of studies (which are reviewed in detail in the following chapter) indicate that a certain level of asymmetry is, in fact, the norm for both the length of the humerus and femur. The current understanding of the factors associated with the presence of asymmetry in the skeleton is summarized by this passage from Helmkamp and Falk's study of rhesus macaque forelimb asymmetry:

> In sum, we must consider that there could be numerous and pervasive genetic, epigenetic, hormonal factors, among others, that vary with age and sex and when combined with environmental interaction present a complex causal hierarchy that is played out through ontogenetic stages of development. (Helmkamp and Falk 1990:212)

It is difficult to assess the relative importance of the various factors that interact to affect the direction and magnitude of long bone asymmetry,. To come to a better understanding of how they interact, it would be necessary to compare asymmetry patterns among fairly closely controlled and well-documented series of skeletal material. Individuals in the series would also need to be unambiguously identified with respect to age and sex. Unambiguously identified means that individuals are identified on the basis of documentary evidence; this is set in contrast to the identification of skeletal material on the basis of anatomical criteria alone. In addition, environmental factors such as health and socioeconomic status would also need to be documented and accounted for in the analysis.

Two skeletal populations from London appear to meet the criteria for a uniquely informative study of skeletal asymmetry. The research program which forms the basis of this dissertation is designed to study patterns of postcranial metric variation patterns among Georgian-era skeletons which had been interred in the crypts of two London churches: St. Bride's (Fleet Street) and Christ Church (Spitalfields). These two crypt populations are unusually well-documented, as well as being essentially contemporary and spatially local. A twentieth century American population, culled from the Forensic Data Bank at the University of Tennessee, provides a further basis for comparing asymmetry patterns.

PLAN OF THE FOLLOWING CHAPTERS

Chapter 2 reviews current and historic literature relating to quantitative assessments of long bone morphology—in particular, issues surrounding studies of skeletal asymmetries. Chapter 3 addresses the nature of skeletal reference populations in general, and then focuses on the specific skeletal series that form the basis for the study. The description of the two core populations, the crypt interments from St. Bride's (Fleet Street) and Christ Church (Spitalfields) are placed in context by a discussion of eighteenth century London life. Chapter 4 describes the particular measurements which were taken on the skeletal samples, and also describes the strategy by which the study hypotheses are tested. The specific hypotheses of this study are presented at the end of the chapter. Chapter 5 presents the results of the quantitative analyses and hypothesis testing. Chapter 6 discusses some of the implications of the findings. In addition, it outlines a number of interesting findings related to the study which were unexpected, but which may provide important direction for future research. Finally, it summarizes the major conclusions of the study and suggests avenues for further research with these populations.

CHAPTER 2—THE PROBLEM

The past fifteen years have seen an increase in studies focusing on asymmetry in the diaphyseal geometry of human long bones (for example, Fresia et al. 1990; Ruff 1992; Ruff and Hayes 1983a, 1983b; Ruff and Jones 1981; Trinkaus et al. 1994). These studies interpret asymmetry patterns, particularly of the humerus, to address research questions generated by the biocultural approach to human osteology. A handful of studies from earlier in the century acknowledged the presence of asymmetry in the linear dimensions of long bones. This earlier research was not driven by a biocultural perspective, resulting in a gap in the literature regarding the biocultural significance of asymmetry patterns in the linear dimensions of long bones.

Researchers of diaphyseal asymmetry have asserted that patterns of variation may be influenced by population variation, sex, and physical activity, and the same may well be true of linear dimension asymmetry. However, because there has been no standard protocol for reporting patterns of linear dimension asymmetry there is no basis for studies that compare asymmetry patterns across populations. Comparative studies may reveal variation based on sex or physical activity, among other factors; once these factors are documented then it would be possible to construct research programs which explicitly address biocultural questions.

Before asking the biocultural questions researchers must first address these more basic questions about asymmetry in the linear dimensions: Are there documentable sex-related patterns to asymmetry in the dimensions of long bones? Do patterns of dimensional asymmetry in long bones vary widely among disparate populations, and are they consistent among related populations? Is there evidence that long bone length asymmetry is associated with activity patterns?

This dissertation seeks to answer these questions through the analysis of long bone asymmetry patterns among related populations and between unrelated populations. The answers to these questions will set the stage for future studies of linear asymmetry with an explicitly biocultural focus. They will also provide a methodological basis for future comparative studies of linear dimensional asymmetry in a variety of human skeletal populations. This chapter reviews issues surrounding the phenomenon of bilateral asymmetry in long bones. The following chapter describes the populations selected and the rationale for their inclusion in this study.

ASYMMETRY ASSESSMENT AS AN ANALYTICAL TOOL

> Use of bilateral asymmetry to address structure/function questions has several inherent advantages, including control over total body size, systemic physiological environment (e.g., diet, hormone status), and various life history variables (e.g., age, general activity level, past disease stress, etc.). (Roy et al. 1994:203-4).

In this statement Roy et al. succinctly summarize the value of postcranial asymmetry analysis as a tool for osteometry, a tool that is particularly appropriate for the biocultural approach to osteology. However, assessing patterns of bilateral asymmetry among skeletal dimensions is a complicated proposition. Linear osteometric dimensions vary only in terms of magnitude, but there is an additional discrete aspect of direction in the asymmetry of any paired skeletal elements. There is no single statistical strategy that fully characterizes both aspects; this problem has led to wide variation in how postcranial asymmetry is assessed and reported in the literature, hindering attempts at comparing work involving different studies. In addition, there are practical difficulties with using assessments of postcranial asymmetry as analytical tools: the definition of asymmetry, the measurement of skeletal material to determine the extent of asymmetry, and the interpretation of asymmetry as a biological phenomenon.

Defining Asymmetry

Because it is highly unlikely that any pair of long bones is truly symmetrical in any linear dimension, attributing labels of symmetrical or asymmetrical to paired biological structures is dependent on the precision with which they are measured. In practical terms this means that any apparent symmetry in paired structures results essentially from a lack of precision in measurement technique. This is an important methodological issue since any reference to paired skeletal elements as being symmetrical is essentially a designation based on the limitations of the measurement instrument; if one were to remeasure the bones with increasingly higher levels of precision, then the prevalence of symmetry would be reduced. That is, there is less likelihood that both elements of a bone pair would produce the same measurement value when humerus length is measured to the nearest tenth of a millimeter, rather than to the nearest millimeter; in the former instance, a smaller proportion of paired bones would be labeled as symmetrical.

A factor that complicates the assessment of osteometric asymmetry is the difficulty in distinguishing actual asymmetry from apparent asymmetry which may be attributable to such factors as variations in measurement technique or measurement error. It is particularly important to distinguish between inaccuracy due to measurement error and the seemingly random variation associated with the phenomenon of fluctuating asymmetry, which is associated with organisms subjected to high levels of physiological stress.[5]

One strategy for reducing the possibility of inaccuracy is to increase the threshold for making the distinction between symmetry and asymmetry. The standard osteometric board, the tool with which long bone lengths are measured, is calibrated in increments of one millimeter; as a result, a one-millimeter threshold might be inferred for the distinction between symmetrical and asymmetrical paired bones. One might consider the scenario wherein the length of a left humerus is recorded as 310 mm and a right humerus is recorded as measuring 311 mm in length. It is possible that both bones are really closer to 310.5 mm in length, and the recorded difference can be attributed to intraobserver variation. If the threshold for asymmetry were one millimeter, then the bone pair would be mistakenly labeled as asymmetrical. However, if the asymmetry threshold were increased to two millimeters, that bone pair would be considered symmetrical. This would diminish the intraobserver variation in decisions concerning asymmetry, provided that measurements are performed with consistent technique.

Unfortunately, this strategy also risks masking actual asymmetry that is small in magnitude. Table 1 presents a series of observations for two hypothetical samples of paired humeri. In both samples, the length of the left humerus is subtracted from the length of the right, and the direction and magnitude of the asymmetry are recorded as signed values. That is, if the left humerus is 310 mm in length and the right is 311 mm

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[5]Fluctuating asymmetry is perhaps the form of asymmetry most widely reported in the literature, and is discussed below in the section on "Interpreting Asymmetry".

long, the signed magnitude is 1 mm; if the left humerus were the longer of the pair, the signed magnitude would be -1 mm. Table 1 lists the number of individuals from each

Table 1 Asymmetry Distributions: Normal vs. Skewed (Signed Values)

(Right - Left) (mm)	-4	-3	-2	-1	0	1	2	3	4	5	6
Normal	0	2	6	12	15	12	6	2	0	0	0
Skewed	0	2	3	6	9	12	14	13	10	5	2

sample who exhibit a given signed magnitude of asymmetry. The first sample has a normal distribution and the second sample is skewed.

The Table demonstrates that if asymmetry has a normal distribution with a mean value of zero, then changing the threshold from one millimeter to two would draw equally from both the right-dominant individuals and the left-dominant individuals, both in terms of the number of individuals and the proportion of the study sample being shifted. Using the figures in the sample data Table, the shift would result in an increase from fifteen to thirty-nine symmetrical individuals. However, if the distribution pattern of the asymmetry is skewed, then a shift in the threshold will draw a greater <u>number</u> of individuals from the more dominant side into the symmetrical category. In the sample data, this means a shift of twelve individuals from the more dominant side and six from the less dominant side. At the same time, the shift draws a greater <u>proportion</u> of individuals from the less dominant side into the symmetrical category. In the case of the sample, the six individuals from the less dominant side represent 55% of the left-dominant cases; the twelve from the more dominant side represent 21% of the right-dominant cases. Thus, the researcher's choice of a threshold value may have a significant effect on the appearance of asymmetry in a population if the actual distribution is skewed. There are practical implications in this distinction because past studies have indicated that the distributions of length asymmetry in the human humeri and femora are consistently skewed.

Table 2 Asymmetry Distributions: Normal vs. Skewed (Unsigned Values)

	0	1	2	3	4	5	6
Normal	15	24	12	4	0	0	0
Skewed	9	18	17	15	10	5	2

Table 2 displays the same distribution scenario, but in this case the figures represent the magnitude of asymmetry alone, without direction being taken into account. In this case the mean value for the normal population is 1.09, in contrast with 2.29 for the skewed population. If the signed values are used to calculate means, the mean for the normal sample is zero, and the mean for the skewed population is 1.82. Shifting from the use of signed to unsigned values results in a greater increase in the calculated mean for the normal distribution than for the skewed distribution.

The points raised in the preceding paragraphs are neither profound nor new, but they indicate that the strategies that researchers choose to employ in defining asymmetry in long bones can have a significant impact on the results they report. They also underscore the difficulty of making comparisons between studies in which researchers apply different techniques for evaluating asymmetry in paired skeletal elements.

Measuring Asymmetry

In 1936 A. Heinrich Münter published a comprehensive review of the existing literature regarding comparative studies of long bone lengths among humans. Münter lamented the difficulties he confronted in assessing long bones from archaeological contexts, as well as the problems that arise when he compared his findings with those reported by other researchers. For example, Münter recognized that the summary statistics he reported might not be those which would prove most useful to future researchers, so he published his raw measurement data as well. This strategy allows contemporary researchers to apply their own statistical techniques to the data. The methodological issues that Münter identified offer insight into the difficulties inherent in designing a research program involving an osteometric analysis of postcranial skeletal material. His observations also provide a basis for a critical review of more recent studies of postcranial osteometry.

Münter's research was designed to assess the lengths of the six major long bones of Anglo-Saxon individuals from a number of a skeletal collections in the United Kingdom. In the majority of cases he determined bone lengths by "obtaining the maximum separation between the fixed and movable vertical surfaces of the [osteometric] board making contact with opposite extremities of the bone" (1936:260). In fact, Münter's method parallels that which is recommended in the University of Tennessee's "Data Collection Procedures for Forensic Skeletal Material," which is the reference document for the Forensic Data Bank at the University of Tennessee (Moore-Jansen and Jantz 1989). It is also the method recommended by standard osteological reference texts (Hrdlička 1939; Bass 1987).

One might easily assume that all researchers would assess the maximum length of long bones in the same way. However, Münter found that methods could vary considerably among researchers. The interobserver variations he noted fall into two general categories: (1) the positioning of the bone on the osteometric board for taking the length measurement; and (2) the use of specific landmarks on bones to measure length—landmarks which do not necessarily correspond to the "extremities of the bone".

The manner in which a bone is postured on the osteometric board can influence the resulting measurement if a researcher does not shift the bone adequately to determine the true maximum length. Indeed, Münter himself chose to deviate from his stated method when he determined the maximum length of the femur. Specifically, he chose to measure femur length with the bone resting on the horizontal surface of the osteometric board. That is, he moved the bone from side to side on the board, but not up and down, to determine the maximum length. As a result, the value that he recorded was slightly smaller than the actual maximum length of the bone.

In describing his methods, Münter did explicitly describe his modified technique for measuring femur length. However, his choice to identify the measurement as "maximum length" was misleading, since other investigators might easily assume that Münter was referring to the actual maximum. This may lead to spurious comparisons with other data sets if investigators were to examine the Münter's raw data tables without first consulting his narrative description of measurement technique. Münter's discussion of his modified method suggests that he chose the modified femur measurement to maintain consistency with what he saw to be the predominant technique listed in the literature at the time. While Münter's choice of technique might seem rational in that context, that fact that it is at variance with what is considered the standard technique today underscores the problem of ambiguous standards for measurements in the literature.

A recent example from the literature reaffirms the persistence of such methodological issues in long bone measurements. Jantz et al. (1994) report that the measurement techniques employed by Trotter in determining maximum length of the tibia to construct stature formulae were remarkably inconsistent. Even though her narrative description of her technique unambiguously indicates that the medial malleolus is to be included in the measurement, in fact her reported values appear to have been derived from measurements that exclude the malleolus. The inconsistency uncovered by Jantz et al. is particularly unsettling, because Trotter's description of measurement techniques was so clearly spelled out in her reports—and yet they are clearly in conflict with her published data.

The work of Adolph Schultz (1937) provides another example of how postcranial measurements may be assessed differently by different researchers. Schultz determined his length measurements using specific anatomical landmarks which might appear counterintuitive to a researcher interested in the maximum lengths of long bones, and which are not consistent with the standards listed in the standard reference texts of human osteology. In humans, the maximum length of the humerus extends from the most proximal aspect of the humeral head through the tip of the trochlear projection at the distal end of the bone. When Schultz measured humerus length, he consistently interpreted the furthest extension of the capitulum as the most distal point on the bone. In much the same way, Schultz measured the length of the femur from the most distal aspect of the lateral epicondyle to the most superior projection of the greater trochanter. In humans, the true maximum length of the femur is measured from the head of the femur to the lateral epicondyle (Bass 1987). As a result, Schultz's measurements were less than the actual maxima.

Like Münter, Schultz unambiguously described his measurement techniques. Unlike Münter, Schultz took care not to use the term maximum to refer to his length measurements. It is important to note that Schultz's choice of landmarks was not arbitrary, but rather driven by his research problem. The goal of his study was to compare the length of human bones with those of chimpanzees, gorillas, orangutans, siamangs, gibbons, and macaques. In these non-human primates, the landmarks he employed are coterminous with the extremities of the long bones. As a result, he was compelled to use consistent measurement landmarks among the different species. Researchers reviewing Schultz's figures, however, would risk making inaccurate comparisons if they did not note the modification in his measurement technique.

Interpreting Asymmetry

Even if researchers could agree on a standard technique for measuring linear dimensions of long bones, such as the guidelines set out in Moore-Jansen and Jantz (1988), they still have to contend with the problem of interpreting the results of their observations in a consistent manner. For example, researchers typically have chosen to focus on only the magnitude of asymmetry, and not its direction. One possible reason why direction of asymmetry has not been well studied to date is the tradition of using parametric statistics to assess the significance of osteometric variation. Because the direction of asymmetry is a nominal variable, testing its statistical significance requires the use of nonparametric techniques. In contrast, asymmetry magnitude has generally been assessed using parametric tests, such as t-test comparison of sample means. However, the small magnitude of asymmetry coupled with the small sample sizes which are typical of most skeletal populations reduces the likelihood of generating a statistically significant refutation of a null hypothesis on the basis of parametric techniques.

Theoretically, asymmetry in bilateral structures can occur in one of three basic

Table 3 Examples of Three Fundamental Asymmetry Patterns.

(Right - Left) (mm)	-4	-3	-2	-1	0	1	2	3	4
Non-directional	1	2	5	8	10	8	5	2	1
Directional	0	1	2	5	8	10	8	3	1
Anti-symmetric	2	4	6	4	2	4	6	4	2

patterns: non-directional, directional, and anti-symmetric. The distribution pattern of non-directional asymmetry resembles a typical bell-shaped curve; it is unimodal and normal, with a mean value of zero. Directional asymmetry is typically also unimodal, but the curve is shifted such that the mean value is not at zero; in most cases a directional distribution is not normal but skewed. An anti-symmetric distribution is bimodal, with one peak located on each side of the zero value. Table 4 contrasts these three asymmetry patterns, with the top row indicating the difference in size between the right and left sides of a paired skeletal element (like humerus length, for example).

Fluctuating Asymmetry

Most published studies of morphological asymmetry focus on the phenomenon of fluctuating asymmetry (Van Valen 1962). Fluctuating asymmetry is understood to reflect the effects of physiological stress (nutritional stress, environmental stress, etc.) on bilaterally symmetrical body elements (Parsons 1990). In theory, organisms that are subjected to increased levels of physiological stress will display an increased range of morphological variation. This means that there is an increased likelihood that within paired elements a feature on one side (buccal-lingual diameter of a tooth, for example) would manifest a difference in size from its partner. Within individuals subjected to higher levels of stress there is a concomitant increase in the likelihood that the size difference between the two sides will be greater as well. As a result, asymmetry magnitude would be relatively high in a population of organisms that has been subject to higher levels of stress.[6] It is important to note that a defining characteristic of fluctuating asymmetry is that it is non-directional. That is, there is equal likelihood that either the right-sided or the left-sided element would be the larger of the pair.

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[6]Møller and Pomiankowski (1993) suggest that the presence of increased levels of fluctuating asymmetry in an evolutionary population may be an indicator of rapid evolutionary change. Drawing on the theoretical phenomenon of punctuated equilibrium, they argue that rapid evolutionary processes render organisms more susceptible to stress, and hence more likely to display patterns of asymmetry.

The presence of fluctuating asymmetry in humans has received much attention over the past two decades, particularly in studies of human dermatoglyph patterns (Markow and Martin 1993). Fluctuating asymmetry has been demonstrated in non-human postcranial skeletal morphology (reviewed in Livshits and Kobylianski 1990), but research involving human skeletal material has traditionally focused on the dentition (Bailit et al. 1970; Perzigian 1977, Hershkovitz et al. 1993). Recent studies of dental asymmetries have involved prenatal exposure to tobacco smoke (Kieser and Groenevel 1993) and maternal consumption of alcohol (Keiser 1992). Manning and Chamberlain (1994) have also studied the relationship between asymmetry in the canines of lowland gorillas and environmental stressors associated with the degradation of their habitat.[7]

Trinkaus et al. (1994) suggest that linear asymmetry in humerus length may be ultimately attributed to the effects of fluctuating asymmetry. However, the fundamental nature of fluctuating asymmetry is inconsistent with it being presented as a comprehensive explanation for humerus length asymmetry in humans. By definition, fluctuating asymmetry is a non-directional characteristic, and yet virtually all studies (including those cited in Trinkaus et al.) report asymmetry in humerus length as highly directional in nature. That is, most studies of skeletal samples report a much greater prevalence of right-dominance in the length of the humerus compared with left-dominance. Therefore, while there may be a fluctuating asymmetry component to humerus asymmetry patterns, there must be other factors operating as well.

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[7]Some researchers have criticized the methodology associated with quantifying fluctuating asymmetry (Smith et al. 1982), and with the difficulty in distinguishing between measurement error and actual fluctuating asymmetry in odontometric and anthropometric observations (Fields et al. 1995).

Table 4 Humerus and Femur Asymmetry Direction (Lowrance and Latimer 1957)

	Humerus	Femur
Left-dominant	17.2%	50.5%
No difference	9.5%	19.0%
Right-dominant	73.3%	30.5%

Very few researchers have addressed the issue of asymmetry in linear dimensions of human limb bones. In 1957 Lowrance and Latimer assessed the length of humeri and femora in a series of 105 skeletons, identified as Asian in origin, which had been purchased from a commercial supplier for student use. Table 4 summarizes their findings, with the figures representing the percentage of the sample in each of three categories. The authors did not explicitly state the criteria by which they made the distinction between symmetrical (i.e., No difference) and asymmetrical bone pairs. Because length of major long bones is typically measured on an osteometric board graduated at one-millimeter intervals, it is likely that bones with the same measurement were labeled as symmetrical in their study--that is, with precision to the nearest millimeter.

In 1965, Latimer and Lowrance reassessed the same Asian adult skeletons from their 1957 publication, this time to compare the relationship between symmetry in the humeri and femora. They found that fifteen individuals showed no remarkable level of asymmetry, but that 50% of those which showed asymmetry manifested a pattern called crossed symmetry (Table 5).

Table 5 Crossed Symmetry in Humeri and Femora (Latimer and Lowrance 1965)

	Left Humerus	Right Humerus
Left Femur	8.9%	47.8%
Right Femur	2.2%	41.4%

The concept characterizes a pattern of asymmetry wherein upper limb bones are larger on one side (typically the right) at the same time that lower limb bones are larger on the opposite side (typically the left). The term itself was first introduced into the literature by Schaeffer (1928), and the phenomenon has received brief comment by researchers over the subsequent decades (Singh 1970; Chhibber and Singh 1972). However, the extent of crossed symmetry has not been well documented among human populations, nor has there been comment on whether there are any sex-related patterns of crossed symmetry.

There is a significant gap in the literature surrounding an important series of questions: Is the directionality of asymmetry that is reported in population means the result of broad and regular patterns of asymmetry across a population? Alternatively, does it reflect a high level of asymmetry among a small subgroup of the population, with the greater majority being essentially symmetrical? At first glance, these questions might appear to be somewhat trivial. Their importance, however, lies in the testing of assumptions related to the nature of skeletal asymmetry in general.

An obvious suggestion is that asymmetry in long bones is linked to differential levels of physical activity on the two sides of the body; a recent review is found in

Stirland (1993a; see also 1993b). In his comparison of limb asymmetry patterns in humans and martens, Pierre Jolicoeur (1963) acknowledges the theory that "the greater stability of bilateral symmetry in external organs is interpreted as a locomotor adaptation: the symmetrical development of limbs and sense organs would make it easier for an animal to reach its goal directly" (1963:410). In another often-cited study in the limb asymmetry literature, Buskirk et al. (1956) demonstrated that unilateral physical activity in the upper limb of tennis players is associated with asymmetrical development of bone as well as muscle. In humans, then, this type of activity would result in relatively symmetrical lower limbs; the upper limbs, however, would not require the same levels of symmetry, and unilateral activity would result in greater levels of asymmetry in upper limb bones. It has been found that asymmetry in the length of the humerus is generally greater than asymmetry in the femur (Schultz 1937), but the relationship between activity and asymmetry is not straightforward, and has been subject to debate in recent years.

Ruff and Jones extended this cautionary note followed their assessment of Native American remains from California wherein they observed apparent sex-related differences in cortical asymmetry of the tibia and humerus:

> the evidence for a direct activity-bone response explanation for bilateral asymmetry is somewhat conflicting. One of the problems in evaluating different hypotheses in this area has been the lack of data on relevant bone dimensions in a normal unselected population sample. . . . Another area which has not been systematically investigated is the effect of physiological factors other than activity levels, such as sex and age, on bilateral asymmetry. (Ruff and Jones 1981:71)

They were not the first to suggest that there was a component to long bone asymmetry that was not attributable to physical activity. Hrdlička, too, observed sex-related variation in humerus length:

> [Another] point, both striking and quite new, I believe, is the behavior of the bones on the two sides. The relation of the female to the male humerus on the two sides of the body shows that in all the groups of the whites, and equally in the Indians and the negroes, the left female bone is on the average and relatively to the male, shorter than the right. a harmony in details such as these goes far toward convincing one of the fundamental unity of the human species. (Hrdlička 1932:437).

It is obviously very difficult to isolate the effects of physical activity from other features that affect the development of skeletal limb asymmetries. For example, Baskerville (1992) has suggested that asymmetries in the forelimb may be associated with asymmetries in the main trunk of the body—and Helmkamp and Falk agree "that sex hormones probably play a significant role in causing asymmetrical development" (1992:498).

ISSUES IN THE POSTCRANIAL ASYMMETRY LITERATURE

Published studies of asymmetry in the humerus and femur of humans (Trotter and Gleser 1952, Laubach and McConville 1967, etc.) are in general agreement on three points. First, the length of the major upper limb bones show a greater magnitude of asymmetry than lower limbs. Secondly, on the upper limb the right humerus is generally larger than the left and, thirdly, on the lower limb, the left femur is generally larger than the right. One intriguing exception to this pattern is reported in Graham and Yarbrough's (1968) study of the Shell Mound population, where they found a consistent pattern of longer left humeri and longer right femora in both males and females.

These conclusions are based on comparing mean values of asymmetry observations within skeletal series, and are presented with little if any discussion of their meaning, except perhaps for a reference to Schaeffer (1928). If these patterns have significance in a biocultural context they have not been addressed. Instead, recent years have seen an apparent reduction in the number of straightforward osteometric studies of human postcranial skeletal material. They appear to have been overtaken by more technologically sophisticated metric studies designed to explore the lifeways of individuals represented by the skeletal material. In the past two decades, reference to asymmetries in studies of long bone morphology have addressed biocultural hypotheses by focusing on geometric properties of the diaphyses. While contemporary authors (for example, Bridges 1989; Fresia et al. 1990) may make a passing reference to asymmetry in bone lengths, they generally dismiss the phenomenon as inconsequential to their biocultural analyses.

Ruff and Jones (1981) provide one of the first attempts to investigate age- and sex-related patterns of bilateral asymmetry in cortical bone. They assessed paired humeri and tibiae from seventy-nine archaeological specimens from California. Based on skeletal criteria, the authors divided their adult study population into four groups on the basis of age and sex; that is, older males, younger males, older females, and younger females. They found males showed a good deal more asymmetry than females, and that cortical bone area decreased with age.

The phenomenon of bilateral asymmetry in the morphology of long bones has recently become popular as a strategy for addressing biocultural questions, as reviewed by Ruff (1992). One particular study by Fresia et al. (1990) exemplifies the biocultural approach to studies of humerus morphology. Specifically, Fresia et al. compared bilateral asymmetry of the humeri in three temporally discrete groups from the Georgia coast (see Table 6). They found that bilateral asymmetry in humerus length increased over time, while asymmetry in humerus strength (based on cross-sectional biomechanical analysis) decreased. The authors suggested that the difference in strength was related to changes in side-dominant activity patterns (but did not speculate on why the length of the humeri varied).

Their study population consisted of fifty-one individuals from five sites in Georgia. The authors assessed the humeri of fifty-one individuals which they partitioned into three categories: Precontact preagricultural, Precontact agricultural, and Contact. Their study samples are small, and it is somewhat speculative to draw conclusions from such small numbers, but the limits of sample size is a problem which commonly arises in analyses of skeletal remains.

Fresia et al. characterized length asymmetry of the humerus by use of Equation 1, one of several which have been applied to the studies of asymmetry. This particular

$$Asymmetry = (100)\left(\frac{Right - Left}{Right}\right) \tag{1}$$

equation characterizes asymmetry in percentage terms, using the right humerus as a baseline. If both humeri are the same length, then the asymmetry value is zero. If the right humerus is greater in length than the left, the value is positively signed, and if the left humerus is longer the value is negatively signed.

Using this formula, Fresia et al. reported that asymmetry in the preagricultural group was less than 0.5% for both males and females, and that the same held true for the females in the precontact agricultural group. In contrast, they found that the males of the precontact agricultural group, as well as both the males and females of the Contact group,

Table 6 Changes in Humerus Asymmetry Over Time (from Fresia et al. 1990)

	Male	**Female**
Precontact Preagricultural	< .5 %	< .5 %
Precontact Agricultural	1 %	< .5 %
Contact	1 %	1 %

presented approximately 1% asymmetry in humerus length (Table 6).

The findings for humerus length asymmetry reported in this Table exemplify the ambiguity of summarizing asymmetry patterns in terms of population means. It is unclear whether a stated mean asymmetry value of .5% means that the right humerus was longer than the left in all cases, or whether there were some pairs where the left humerus is longer than the right. In the latter instance a few left-dominant pairs, being negatively signed, would substantially reduce the mean asymmetry value for the population from what it would be if the absolute (unsigned) values of asymmetry magnitude were assessed. To date there have been no studies which have addressed the issue of bilateral asymmetry in linear dimensions of long bones at the level of the population.

CHAPTER 3—THE STUDY POPULATIONS

THE NATURE OF SKELETAL STUDY POPULATIONS

The term population has several meanings in the context of skeletal biology. At the most elementary level, the individuals who comprise a skeletal collection or a subgroup of a skeletal collection are collectively referred to as a population (Steegman 1991; Waldron 1991; Whittaker and Hargreaves 1991). The larger group of living persons whom the skeletal material represents is a population in a more restricted and more analytically valuable sense. That is, inferential statistics can be applied to observations taken from the sample of the larger population to draw inferences about the nature of the population as a whole (Weiss and Hassett 1982). These conceptions are distinct from the population genetics definition of a population as "a local or breeding group; a group in which any two individuals have an equal probability of mating with each other" (Campbell 1992:539).

One cannot assume that a skeletal sample necessarily corresponds to a population in the latter sense of the term. As Wood et al. (1992:344) warn, "There is one, and perhaps only one, irrefutable fact about the cases making up a skeletal series: they are dead." Nonetheless, osteologists commonly assess skeletal series as a collective whole when they engage in osteometric analyses, and draw conclusions about the populations that they supposedly represent.

In general terms, analytical osteometry research of populations is directed toward one of two goals. The first of these is to examine a known reference series in order to construct a set of standards or guidelines which are meant to be applied to future investigations of other skeletal material. The second goal is to assess an unknown individual (or population) in terms of the standards which have previously been derived from a reference source, in order to come to a better understanding of the unknown(s).

As noted in the previous chapter, estimating stature on the basis of long bone lengths illustrates these complementary goals of contemporary osteometry. In a number of studies, researchers have collected measurements from sufficiently large skeletal series for which living stature is known (for example, Trotter and Gleser 1951; 1952; 1958). Based on their observations, the researchers have derived formulae which reflect the relationship between bone lengths and stature. These formulae are then applied to measurements taken from bones belonging to an unknown individual in order to determine living stature—within a reasonable margin of error.

The assessment is not quite as straightforward as this simplified description suggests. For example, males and females from a single homogeneous population tend to show different patterns of relationship between bone lengths and living stature. Researchers typically contend with this problem by constructing two different series of stature formulae—one for males and another for females. Likewise, persons of different ancestry tend to show dissimilar patterns of relationship between bone length and stature. As a result, stature formulae for different "racial" groups have been derived and they feature prominently in skeletal biology reference volumes.

In addition to stature estimation, another common application of analytical osteometry is the determination of an unknown individual's sex from differences in linear dimensions of long bone elements. In humans the long bones of males are, on average, larger than females; this fact has been used by several researchers to construct univariate and multivariate discriminant functions for sex estimation. Bone lengths, head diameters, and biepicondylar widths of the humerus and femur have all been used to assign sex to skeletal material (Dittrick and Suchey 1986; France 1988).

Table 7 Attributing Sex from Femur Head Diameter (adapted from Bass 1987)

Diameter (mm)	Female	Female?	Indeterminant	Male?	Male
Pearson	<41.5	41.5-43.5	43.5-44.5	44.5-45.5	>45.5
Stewart	<42.5	42.5-43.5	43.5-46.5	46.5-47.5	>47.5

Differences between populations affect the attribution of sex to skeletal remains, just as they affect stature estimation. Bass's (1987:219-20) field manual acknowledges the population difference phenomenon by reporting Pearson's (1919) "Rules for Sexing the Femur" on the basis of femoral head diameter, as well as Stewart's (1979) modification of Pearson's figures for sexing "American Whites" (Table 7).[8] The difference between Pearson's and Stewart's figures can be attributed to the different "White" populations they use as their sources. Pearson used seventeenth century Londoners as his reference series while Stewart used a series of specimens from the Terry Collection in the United States as his reference. The greatest certainty that a stature or sex estimation is accurate occurs when the unknown individual is drawn from the same population as the reference source. In other words, a researcher asked to attribute sex to a femur from a 17th century London plague pit would more wisely employ Pearson's standard than Stewart's.

[8]The figures Bass attibutes to Pearson are taken from Pearson and Bell (1919).

Unfortunately it is rarely the case that there is such a close match between skeletal unknowns and available reference series. Therefore, researchers choose the next best strategy by assessing an unknown individual with reference to skeletal standards derived from a series that is most representative of the living population associated with the individual being investigated. Thus, if a femur to be sexed were from a 20th century forensic case, then it would be more appropriate to employ Stewart's standard than Pearson's. Likewise, a femur from 18th century France would be best assessed using Pearson's figures. In either case, since any reference skeletal series is limited in its ability to be broadly enough representative of the larger population from which it is drawn, there will always be a measure of uncertainty in the assessment.

The limited number of available reference series also complicates comparative approaches to osteometry. Over the past century published research of human long bone morphology has involved a considerable range of skeletal series. The osteological collections which form the basis for the research vary widely in terms of numbers of individuals represented, level of supporting documentation, preservation quality, and a number of other factors. These differences influence the choice of the questions that can be addressed by studying a given skeletal collection, as well as the explanatory power of the results of an analysis. As a result, it can be difficult to make direct comparisons between the findings of different research programs.

Reference Series Populations

Traditionally, skeletal biologists have drawn on five types of reference series for skeletal analysis: (1) anatomical collections; (2) military dead; (3) undocumented prehistoric and historic archaeological series; (4) documented historic archaeological series; (5) living clinical populations; and (5) forensic cases. Each of these groups possesses a series of characteristics that make them appropriate for comparative osteometric studies; at the same time, each has other characteristics which make them less suitable for making legitimate comparisons.

Anatomical Collections

Many osteological and osteometric standards in the United States have been derived from research involving two anatomical series: the Terry Collection which is housed at the National Museum of Natural History, and the Hamann-Todd Collection located at the Cleveland Museum of Natural History (Stewart 1979:84). These particular skeletal series appeal to researchers because they consist of a relatively large number of individuals and the skeletal material itself is typically well preserved. Perhaps most importantly, the individuals in these collections are well documented with respect to age and sex.

On the other hand, the individuals which comprise the collections are not representative of a well-defined living population. Their lifeways are not well-documented, insofar as their diet and physical activity patterns are understood only in general terms. In many cases the skeletons represent indigent members of society who were relegated to anatomical collections; as such, they may not be adequately representative of the larger society from which they are drawn (Ericksen 1982).

Military Dead

Several of the most commonly cited studies which estimate human stature resulted from research performed on the skeletal remains of American war casualties (Trotter and Gleser 1951, 1952, 1958; Trotter 1970). Like the anatomical collections, the number of individuals in these collections is relatively large. Also like the anatomical collections, the individuals themselves are well documented with respect to sex and age at death. In contrast with the anatomical collections, military dead offer the additional advantage of being particularly well documented in other ways. The living stature of military personnel, for example, is recorded as part of a documentary record which is atypical of most skeletal samples.

Perhaps the most obvious disadvantage of military dead as a reference skeletal series is that it represents a relatively restricted population of living persons. All of the individuals from these collections are men; in addition, these men represent a narrow range of ages that is not representative of the larger population. Like the anatomical collections the reference populations of military dead do not represent a genetically or culturally homogeneous group of people. As a result, their value in comparative studies of populations is somewhat limited.

Undocumented Archaeological Series

Archaeological series of undocumented individuals provide some of the largest skeletal series available to researchers today (Graham and Yarbrough 1968). The advantage gained by the large number of individuals represented in these series is countered by a number of shortcomings related to their undocumented nature. For example, the age and sex of individuals can only be determined by anatomical criteria, which lack the certainty of the documentary record.

A more substantial concern for comparative studies is that, in many cases, an archaeological skeletal series may represent a series of occupations of a given site which took place over a period of several hundred years. During that time a number of changes may have occurred in lifeways and migration patterns which may call into question whether indeed the skeletal material can be said to represent a single population of interbreeding individuals who lived at a place over an extended period of time .

Arguably the most prevalent and challenging difficulty with assessing long bones from archaeological contexts is that the majority of the bones are often too fragmented to provide accurate length measurements. In cases where there might be only one or two specimens from a population, this can be a very serious problem. Trinkaus et al. (1994) were required to contend with this issue in their assessment of humerus morphology in early Homo.

In studies of asymmetry in paired skeletal elements a study series can be reduced significantly in size if only a relatively small proportion of individuals retain paired long bones which are sufficiently preserved to provide accurate bilateral observations. For example, Münter's (1936) study of postcranial measurements on Anglo-Saxon remains from British museum sources was based on measurements taken from 233 male and 93 female skeletons. Only 113 males and 43 females retained paired femora and 67 males and 30 females retained paired humeri for which maximum length measurements could be obtained. Of these, only 53 males and 18 females retained both paired humeri and paired femora.

Another problem with assessing archaeological skeletal material is the ambiguity of anatomical sexing. The problem of attributing sex to skeletal remains is a challenging one. In those cases where entire discrete skeletons are available, the morphology of the pelvis is typically used to assess sex, and this technique is regarded as being quite accurate (Dittrick and Suchey 1986, Ruff and Jones 1981). In cases where the skeletal material is commingled, such as the plague pit skeletons reported in Biometrika (Morant 1926; Hooke 1926) in the early part of this century or where an intact pelvis is not available, long bones can only be sexed on the basis of intrinsic anatomical criteria, which are even more subject to various degrees of error (MacLaughlin 1987). One way to avoid the sexing problem is to assess only those series for which each individual's sex is identifiable by non-anatomical (i.e., documentary) criteria.

A significant problem for analytical osteometry is the relatively small number of females in many reference series. As noted above, the larger skeletal series which have been used to develop standard osteometric formulae for assessing stature, for example, are military dead and anatomical collections which consist predominantly of males. Even in archaeological reference series there is a relative paucity of female representation. One cause of this may involve bias in anatomical sexing techniques which over-classifies males and under-classifies females (Weiss 1972).

The less than optimal preservation of skeletal material exacerbates the problem of female under-representation. Because human males tend to have larger and more robust skeletons than females, male skeletons are more likely to remain well preserved in harsh environmental conditions. Münter's study series, for example, only had a relatively small number of females in his sample—much less than the 50:50 ratio that would be expected in a normal population.

Documented Historic Series

In contrast with non-documented archaeological series, historic cemetery or plague pit samples have the advantage that the lifeways of the populations represented are often well described by supporting documentation. Unfortunately, in the case of most cemetery series the individuals themselves are not identified (Angel et al. 1987; Lanphear 1988, 1990; Saunders et al. 1993, Sirianni 1993). In the case of plague pit or cemetery clearance series, the skeletons of hundreds of individuals may be represented (MacDonell 1904, 1906; Hooke 1926). However, their appropriateness as reference populations is severely restricted because bones from many individuals are commingled. In spite of their commingled nature, several seventeenth century London plague pit and clearance series form the basis for Pearson and Bell's (1919) extraordinarily comprehensive three-volume study of the English femur.

Living Clinical Populations

There have been a number of studies on clinical populations of contemporary humans for which radiographs or computed tomography are used to represent skeletal morphology. Such populations offer a powerful tool for contemporary research because they are typically well documented by data from clinical records. One difficulty with employing clinical populations in osteological research is that they typically represent a pathological subset of the larger population. That is, generally healthy individuals are not selected for radiographic study; for example, dialysis patients were studied by Garn et al. (1976) to investigate patterns of skeletal asymmetries. Another methodological consideration is that radiographic examination is relatively expensive, which means that relatively few groups have been studied in this way. However, in a few cases longitudinal analyses of individuals have included the radiographic assessments of healthy individuals, and there have been cases where specialized series have been studied radiographically (for example, athletes and early humans in Trinkaus et al. (1994)).

Forensic Cases

One of the most common applications of analytic osteometry in skeletal biology today is the assessment of skeletal material in forensic cases to identify the individual(s) represented by the remains. It follows that the most appropriate reference source for standards of forensic analysis should be other contemporary forensic cases. Recognizing this, forensic anthropologists at the University of Tennessee have collected data from forensic cases provided by their colleagues and have formed a computerized database of these cases (Jantz and Moore-Jansen 1988). The information in the Forensic Data Bank has already been used by Bennett (1993) to derive updated discriminant functions for determining sex and ethnic affiliation (see also Giles 1970).

The individuals listed in the Data Bank themselves are typically well-documented with respect to age at death, year of birth, sex, and ethnic affiliation. In many cases, they have also been subjected to a comprehensive battery of metric and non-metric analyses. Most importantly, the individuals in the Forensic Data Bank represent members of contemporary American society. On the other hand, they cannot truly be said to represent a single population, since they are, by definition, drawn singly from unique locations across the United States. In addition, the lifeways of the individuals themselves are not well documented.

One other potential difficulty with the Forensic data is that it consists of measurements made by a number of researchers, so there is a possibility that differences in measurement technique might influence some observations. The curators of the Data Bank have attempted to mitigate this problem by explicitly stating the techniques that should be applied in taking measurements (Moore-Jansen and Jantz 1989), but there is no assurance that all contributors to the Data Bank follow those techniques to the letter.

London Crypt Populations as a Basis for Study

None of the types of skeletal series described here is ideal for deriving standards for a phenomenon such as long bone asymmetry. Indeed, finding an ideal skeletal series is problematic since those populations which have the highest level of supporting documentation either reflect a small sample size or are representative of a only a limited subset of the larger living population. At the same time, those series with the largest sample sizes are typically those which are the least well-documented, or those which consist of commingled skeletal material.

While there may be no ideal reference series available to osteologists, the crypt populations from two churches on the periphery of the City of London—St. Bride's (Fleet Street) and Christ Church (Spitalfields)—offer a unique basis for a comparative study of long bone morphology. Not only are the churches themselves well-documented by historical records, but each person represented in the sample is individually identified with respect to name, sex, age, and year of birth.

The two churches' crypts contain individuals who are contemporaries of the Georgian era, with dates of death ranging from the early 1700s to the mid-1850s.[9] The fact that these two skeletal populations are localized in terms of time and space suggests that they were subject to the same environmental conditions. In addition, because crypt interment in central London churches usually required a reasonably high level of income or social status, there is evidence for a commonality in socioeconomic status between the two groups (Cox and Molleson 1993; Scheuer personal communication). In short, taken together these skeletal series offer a unique and valuable opportunity to engage in a comparative study with a particularly high level of documented control over environmental factors.

By typical standards of time and space, the two churches (and their crypt populations) are very much alike. The most obvious similarity is their close proximity to each other, as they are separated by a distance of only approximately 2.5 kilometers. Each is found just outside the boundary of the City of London proper, St. Bride's to the west, and Christ Church to the east (Figure 1). Their crypt populations are also roughly contemporaneous; the earliest identified crypt interment at Christ Church was in 1729, and the latest in 1859. The earliest identified crypt interment at St. Bride's was in 1740, and the latest in 1852. The earliest born individual in the St. Bride's crypt, Mr. Samuel Holden, was born in 1676 and died in 1740. In the Spitalfields population, Miss

[9]The two crypt populations are referred to here collectively as the "Georgians," even though technically the Georgian era ends in 1837 when the reign of Queen Victoria begins. Virtually all of the individuals in both series were born prior to 1837.

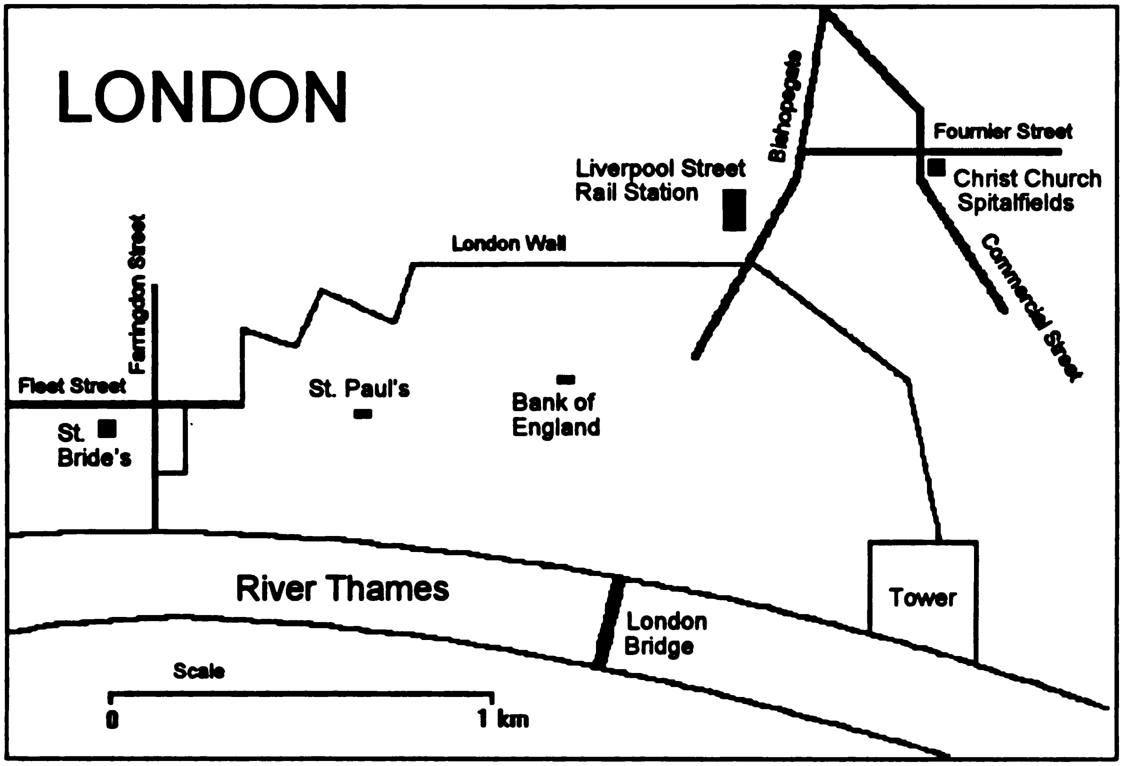

Figure 1 Relative Location of St. Bride's and Christ Church, Spitalfields.

Susannah Hull was born in 1647 and died in 1732. Crypt interments were halted in both churches within a few years of each other; the mandate which ended interments at St. Bride's was dated 1854, and for Christ Church was dated 1858.

The demographic patterns of the two populations are also similar. The adult population from both crypts show a roughly even ratio of males to females. The Spitalfields crypt showed a substantially larger number of juveniles than St. Bride's; this was likely due to the number of family vaults excavated at Christ Church. Age at death for the adults of both populations also showed a comparable pattern. In both groups, approximately half of the population died between the age of 55 and 75 years.

Finally, there is a basis for arguing that the two crypt populations had a roughly equivalent socioeconomic status. In Georgian London the financial cost of interment in a crypt was substantial, and the poorer members of a parish were typically relegated to the churchyard for burial (Litten 1991). This is not always the case, though, since a few individuals of rather meager income were interred in crypts, either because of specific ties to the Church, or because more well-to-do members of the family were associated with the Church. Nonetheless, the parishoners of St. Bride's and Christ Church reflected a fairly broad range of middle-class Londoners, which included shopkeepers, artisans, weavers, and businessmen.

Since individuals are identified by name in both the St. Bride's and the Spitalfields series, previous researchers have referred to trade and vestry records to clarify the social and economic context in which specific individuals lived and worked (Cox 1989; Waldron and Cox 1989; Bowman and Scheuer, personal communication). Cox (1989) divided members of the male Spitalfields population into occupational subgroups of artisans, master craftsmen, and professionals, and others. Cox and Scott characterize the women of Spitalfields as "a middle-class group, they were largely of high nutritional status and, by the standards of the day, lived in sanitary and comfortable conditions" (Cox and Scott 1992:431). In addition, twelve skulls from Spitalfields showed evidence of dental restorations or artificial teeth, another indication of middle-class socioeconomic status (Whittaker and Hargreaves 1991).

Bowman suggests that the St. Bride's males be partitioned into two main occupational groups—one consisting of lawyers, doctors, and gentlemen; and the other consisting of businessmen and shopkeepers. It appears that few if any artisans are present in the St. Bride's series, while many are available in the Spitalfield's sample; this is not surprising, given that weaving was a well-known occupation in Spitalfields, but not in the area of Fleet Street (George 1965).

One way in which the Spitalfields and St. Bride's collections have already effectively been compared is with respect to specific indicators of stress on the skeleton, such as cribra orbitalia, and enamel hypoplasias. The Spitalfields material shows some cribra orbitalia, but none that could be regarded as severe; the St. Bride's series shows very little cribra orbitalia. Neither series shows vault lesions of porotic hyperostosis, and enamel hypoplasias are uncommon. These findings are not totally unexpected, given that London middle-class crypt populations not be likely to suffer the significant nutritional deficiencies which are commonly associated with these markers (Molleson and Bowman, personal communication).

On the basis of these criteria it would appear that it would be difficult to find a better matched pair than the St. Bride's and Spitalfield populations. However, there are three reasons for considering the populations as distinct: geographic separation, the possible occupational differences discussed above, and population history. The majority of persons in Spitalfields in the early decades of the crypt sample appear to represent an immigrant population—primarily Huguenots from France and their descendants. As time went on, the proportion of individuals with French surnames became smaller, but it is not certain if this was due primarily to intermarriage or to a replacement of the Huguenots with persons of strictly British heritage (Cox and Molleson 1993). Secondly, there are no surnames held in common between the documented persons interred in Christ Church and t

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and those from St. Bride's.[10] Even the existence of common surnames would not necessarily indicate interbreeding between the two groups, but the fact that there appears to be no commonality would suggest that these are indeed two distinct populations.

Even if there are meaningful differences between these skeletal series, there is a marked disadvantage to relying on two skeletal populations which are as closely linked in time, space, and social status as the St. Bride's and Spitalfields crypt collections for a comparative study of long bone morphology. Even if there were apparent sex-related patterns in asymmetry in both skeletal series, it would be impossible to discount the possibility that the patterns were also associated with environmental conditions in London at the time. For this reason, a reference population drawn from the computerized Forensic Data Bank at the University of Tennessee is employed in this study (Jantz and Moore-Jansen 1988). This is a skeletal series of documented twentieth-century Americans, and therefore drawn from a very different setting in time and space from the Georgians. Although the individuals comprising the Forensic series are identified with respect to age, sex, and year of death, they are not documented with respect to their ways of life. They cannot be understood to represent a population in any other sense than having lived in the United States this century; nonetheless, these characteristics are sufficient to set them apart for a comparative study with the Georgians.

The individuals comprising the Forensic Data Bank sample are drawn from a much broader range of socio-economic background and geographic area than the Georgians. It is likely, therefore, that the former group would manifest a much greater

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[10]The records associated with married women in the Georgian populations typically list the maiden name as well as the married name of the individuals. There is no evidence that there any common surnames in either married or maiden names.

range of variation in asymmetry patterns—particularly asymmetry magnitude—than the latter. If setting in time and space does affect asymmetry patterns, the difference should be recognizable in the comparison of these skeletal samples.

GEORGIAN LONDON AND THE CRYPT POPULATIONS

While there is no documentation that characterizes the lifeways of the individuals comprising the Forensic series, there is a rich documentary record of Georgian-era London. Samuel Johnson provided the world with perhaps the most famous—and certainly the most succinct—characterization of eighteenth century London ever written in his diary entry of 20 September 1777: "When a man is tired of London, he is tired of life; for there is in London all that life can afford." In the preceding century London had undergone a tremendous transformation. The 1660s had been disastrous for the city, which had suffered in quick succession from both the Great Plague (1665) and Great Fire (1666). By the 1770s Britain had emerged victorious from the Seven Years War, making London the capital of the greatest colonial power of its time. The country had also begun to feel the economically vitalizing effects of the Industrial Revolution. Although not itself an industrial center, London's population grew substantially as immigrants from the provinces, as well as from other countries, flocked there in search of prosperity. By 1800, London had surpassed Paris in size to become the largest city in all of Europe (Rudé 1971).

Even at the beginning of the eighteenth century the area popularly referred to as "London" radiated well beyond the boundaries of the City, which is itself only one square mile in area (Beeton and Chandler 1969). The City itself lies on the north bank of the River Thames, with the Tower of London marking its easternmost point. Its western boundary is formed by the Fleet River, now covered over by Farringdon Road and Bridge Street, which is the approach to Blackfriars Bridge.

For hundreds of years the City was enclosed by a protective wall which ran in a roughly semicircular arc from the mouth of the Fleet northward, eastward on the southern boundary of the Moor Fields, and back southward to the Tower. The wall was punctuated by seven access gates: Ludgate was easternmost, and nearest the Fleet; continuing clockwise it was followed in turn by Newgate, Aldersgate, Cripplegate, Moorgate, Bishopsgate, and finally Aldgate, located just north of the Tower. St. Bride's Church is located just a few hundred meters west of Ludgate, on the south side of Fleet Street, which was (and is) the major thoroughfare running westward from the City parallel to the Thames. Christ Church is located at the southeast corner of Fournier Street (formerly Church Street) and Commercial Street in the area called Spitalfields that extends northeastward from the area around Bishopsgate on the east side of the City.

If one were to take notice of the multitude of people passing by on Fleet Street or Commercial Street in London today, it would be difficult to find a representative Londoner. Likewise, it would have been almost as difficult in the eighteenth century, because of the wide diversity of the population. The increase in London's population following the Plague and Fire of the mid-1660s had many causes. In part, London's growth in the eighteenth century reflected the general increase in the population of England as a whole. However, patterns of migration within the country were dominated by a net shift in population from rural to urban areas (Wrigley 1987; Wrigley and

Schofield 1989). As a result, London's population grew at a greater rate than most of the country.

The majority of social historians agree that living conditions in urban areas across England improved with the social and sanitary reforms of the mid-nineteenth century (Walvin 1984). There is less agreement about the preceding 150 years. A prominent debate among social historians of eighteenth- and early nineteenth-century England is referred to, in fact, as the standard-of-living controversy (Floud, Wachter, and Gregory 1990; Royle 1987). Resolving the controversy is challenging because researchers can cite valid evidence supporting contradictory positions. For example, economists can point to the fact that per capita income increased consistently in England across the century as evidence for an ever increasing standard of living (Burnett 1969). On the other hand, the plight of the growing industrial working class is also well-documented (Thompson 1966).

From the mid-eighteenth through the mid-nineteenth century the Industrial Revolution brought about changes in the standard of living across the nation, particularly in larger cities. When the rural poor flocked to the cities to find work, they simply added to the growing number of poor working-class urban dwellers. At the same time that the disparity between the very rich and very poor was increasing, there was also a growing number of persons who could best be described as "middle class" (cf. Cox and Molleson 1993). Dorothy George (1965) argues that London differed significantly from other urban areas in England during the years of the Industrial Revolution—that is, in the years 1750 through 1850. While the large cities of the industrialized North were burdened by the Industrial Revolution, she posits that London was able to escape large-scale industrialization yet still benefit from the economic growth that resulted from the output of the industrial centers further north. George's conclusion from a comprehensive review of available documentary evidence was that, with the exception of a setback between 1720 and 1750, living conditions for most inhabitants of London progressively and consistently improved throughout the century. Nonetheless, she agrees with other historians (Burnett 1969; Porter 1990; Royle 1987; Thompson 1966; Walvin 1984) that any general improvement in living conditions during the eighteenth century benefited the middle and upper classes much more than the working class.

In addition to migration from rural to urban areas within the country, another factor leading to the tremendous increase in London's population was the large number of immigrants who descended upon London from abroad to escape religious persecution and economic deprivation. Because of their alien status, they were not eligible to become citizens, and they could not live within the City itself. However, they wanted to live as near as possible to the population center to be able to engage in a reasonable livelihood. Liberties on the fringe of the City, which were not under control of the City, became their refuge.

One of the most famous immigrant groups was the Huguenots, the French Protestant followers of John Calvin. For decades they had lived in relative peace in their predominantly Catholic homeland, owing to the religious tolerance they enjoyed following the Edict of Nantes in 1598. When the Edict was revoked by Louis XIV in 1685, the Huguenots were forced to flee religious persecution by emigrating to other countries. They established a number of expatriate communities in England, as well as Germany, Switzerland, and the Dutch Republic (Gwynn 1985; Cottret 1991).

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Unfortunately for France, the loss of the Huguenots meant the loss of a large number of highly skilled weavers and artisans. A substantial community of these weavers found their refuge in an area of London just northeast of the City known as Spitalfields. Gwynn (1985) notes that "There they congregated in the outskirts, where food and housing were cheaper and guild control less effective..."; Rose (1951:43) adds that the Huguenots were drawn to Spitalfields "partly by the opportunity of practising their craft, and partly by the cosmopolitan and non-conformist atmosphere which was already typical of the area."

Although the Huguenots were clearly an ethnic minority in Spitalfields, their community was well-respected and prospered for generations (Smith 1939). Until the time of the Industrial Revolution, the market for Huguenot hand-woven fabrics was stable. But while the Industrial Revolution was a boon for most of the country, the effect on the Spitalfields silkweavers was devastating. Large mechanical looms located in the northern part of the country could produce fabric now at a price significantly lower than that which had been charged by the handloom weavers. For a short time the Spitalfields Act of 1773 saved the handloom weavers from financial ruin. Unfortunately, the stopgap measures were not enough and the prosperity of the weavers community was reduced significantly in the early nineteenth century. In short, Spitalfields suffered from economic decline in the midst of the Industrial Revolution (Smith 1939). This fact was reflected in the population of Christ Church: looking at the burial register at Christ Church, Cox noted that "the ratios of master craftsmen to artisan are almost reversed on either side of 1800" (1989:30), with a marked reduction in master craftsmen post-1800.

It is a truism that the East End of London and the West End are worlds apart—and have been since before the Great Fire of 1666. More prosperous individuals have moved westward from the City proper, while those persons living to the east and north of the Tower lived in relative squalor. This assessment is clearly an oversimplification, since many of the merchants and master weavers living in the area of Spitalfields, for example, were quite prosperous themselves in the years preceding the Industrial Revolution. However, the arrival of mechanical looms introduced for the manufacture of cloth did tremendous damage to the livelihood of the Spitalfields weavers (Smith 1939). The relative poverty of the Spitalfields neighborhood has persisted throughout the nineteenth and twentieth centuries, as has its reputation as an abode for recent immigrants.

Margaret Cox and Theya Molleson have outlined these circumstances in The Middling Sort, their monograph of the anthropology of the individuals from the crypt of Christ Church, Spitalfields. The term "middling sort" has traditionally been used as a reference to the rising middle class of the 18th century. A true picture of the communities represented by the two crypt populations is certainly more complex that what could be recorded in that simple phrase, but it does characterize the lifeways of the people of St. Bride's, Fleet Street, and Christ Church, Spitalfields.

St. Bride's (Fleet Street)

The Great Fire of 1666 decimated roughly eighty percent of the area within the Wall; only the northeastern reaches of the City were spared. However, the Fire had also been allowed to spread several hundred meters westward from the City. At the end of three days, 13,000 houses and eighty-seven churches were destroyed (Morgan 1973:134).

One church which fell victim to the Fire was St. Bride's on Fleet Street. St. Bride's is located just outside the west boundary of the City proper, a few hundred meters beyond Ludgate (today's Ludgate Circus). As one of his efforts in the reconstruction of London, the architect Christopher Wren designed a new St. Bride's, and the church was rebuilt on its original site in 1708. During World War II, catastrophe again struck St. Bride's. On the evening of 29 December 1940, the church was gutted by fire following an incendiary bombing raid by the German air forces (Morgan 1973). Several years after the War a decision was made to rebuild the Church yet again on the same site, and the newest incarnation of St. Bride's was completed in 1957.

Excavations on the building site in preparation for the construction revealed an array of archaeologically intriguing findings. Human remains which have been identified as Celtic in origin, dating to the fifth century AD, were unearthed below Wren's crypt. In addition, a medieval charnel house was located below the floor of the church.

As noteworthy as these pre-Norman and medieval remains were, the find of greatest osteological significance was excavated from Wren's crypt itself. Here researchers discovered that well over two hundred individuals had been interred in coffins which bore name plates listing the occupant's name, age, and year of death. Dr. J. C. Trevor, then Director of the Duckworth Laboratory of Physical Anthropology at Cambridge University, asserted that this was "outstandingly the most important collection in the world" (Harvey 1968:63).

Trevor's enthusiasm was fueled by the realization that it was possible now, for the first time in history, to study a skeletal population wherein each individual was unambiguously identified with respect to age, sex, and year of birth. Unlike dissecting room populations, St. Bride's could offer a reference source of individuals who represented a middle class lifestyle.[11] By itself, this information could form the basis for a range of studies on the effects of age and sex on skeletal morphology. Moreover, it was thought that this data could be corroborated with church records to determine family relationships, and reference to guild records could reveal further evidence about occupation and lifeways.

In the years following the excavation, the St. Bride's material was used primarily by researchers to study the relationships among age, sex, and the morphology of the skeleton. F. L. D. Steel, in particular, published metric analyses of the skeletal material (Steel 1962), and as recently as 1987 Sue Maclaughlin used the St. Bride's sample to test the effectiveness of techniques for sexing the human skeleton based on morphological criteria.

Although some of the St. Bride's material was removed to Cambridge for study for a short period of time in the 1950s, all of the identified individuals were returned to the crypt and placed in storage containers. Acknowledging the continued scholarly value of the collection, the Church has allowed the skeletal material to remain accessible to bona fide researchers who wish to study it—with a stipulation that the skeletal material is

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[11]At the time there were virtually no published studies of the skeletal biology of middle class individuals. Since then, Angel (1975) has broached the subject, but a lack of available skeletal material makes it difficult undertake such analyses. In this respect, Trevor's enthusiasm was and is quite fitting.

not to physically leave the crypt. The stipulation that material not leave the crypt makes it impossible to undertake a radiographic study of the St. Bride's long bones. Even if permission could be granted for transporting a portable radiographic instrument into the crypt, there is only a very limited supply of electricity to the crypt laboratory. It would be extremely valuable to have radiogrpahic data from St. Bride's available as a comparative sample for studies of asymmetry in diaphyseal morphology.

Rosemary Powers undertook comprehensive cataloguing of the identified St. Bride's material in 1960. In addition to listing the names and coffin plate information of the individuals, she included a series of pen and ink drawings showing the extent of preservation of each skeleton and a typewritten description of the skeletal elements and dentition. In some cases, she was also able to offer comments about documented family relationships.

Recognizing that further deterioration of the collection had taken place since Powers' catalogue was completed, a team of researchers (Louise Scheuer, Susan Maclaughlin-Black, and Jacqui Bowman) secured funding from the Leverhulme Foundation in the mid-1980s to recatalogue the material and establish a modest laboratory facility within the crypt itself. In addition, they attempted to further explore the historical background related to the St. Bride's individuals. By making reference to guild and municipal records, they were able to determine the cause of death for 64% and address at death for 84% of the adults, as well as the occupation of 20% of the males. This project is just being completed and the skeletal material is now again being made available for osteological analysis. The study on which this dissertation is based is the first since the re-establishment of the St. Bride's crypt.

All told, there are 237 individuals currently in the identified St. Bride's series; of the 212 adults, 110 are males and 102 are females. As might be expected, there is wide variation in the degree of preservation of the St. Bride's material. Many of the individuals are nearly completely intact, but the majority have shown significant deterioration over the years. Indeed, for a small number of individuals skeletonized remains are virtually nonexistent.

Christ Church (Spitalfields)

One consequence of London's population increase in the decades following the Great Fire was the establishment of an ambitious mandate by Queen Anne in 1711 to construct fifty new churches in and around the city to accommodate the increasing population (Smith 1939:99-100). One of the seventeen which was eventually completed was Christ Church, located in Spitalfields, a neighborhood situated just to the north of Whitechapel village, and northeast of the segment of the Wall bounded by Aldgate and Bishopsgate. In terms of modern geography, Christ Church is located approximately one-half kilometer north of Aldgate Underground station on Commercial Street, between Fournier Street and Fashion Street.

Thomas Hawksmoor, a student of Wren, was commissioned to design Christ Church. Construction was begun in 1714, and the church was completed and consecrated in 1729 (Adams and Reeve 1987). The first recorded interment in the crypt was listed in the Burial Register that same year. The crypt of the church was used for interments until 1859, when it was decreed that the further crypt interments be prohibited, in the interests of public health. In 1867 a further mandate was executed that the crypt be sealed.

While Christ Church has never experienced fiery tragedies like those which befell St. Bride's, deterioration over the years brought about the need for a broad program of restoration to the physical infrastructure of the Church. These repairs necessitated that the crypt be cleared. The eastern half of the crypt vaults had already been cleared in the 1960s to provide space for a shelter for transients within the church (Adams and Reeve 1987). However, the western half of the vaults still held the remains of nearly 1000 individuals. In the early 1980s an agreement was reached with staff at the British Museum (Natural History) to conduct a scientific excavation of the crypt, with the stipulation that the skeletal remains would be made available for a period of time for osteological study (Cox 1989; Adams and Reeve 1987).

As was the case at St. Bride's, several hundred persons from Spitalfields were interred in coffins with lead plates that provided unambiguous documentation of name, age, sex, and year of death. However, the number of identified individuals at Christ Church far exceeded that of St. Bride's. Of the 968 total individuals whose remains were excavated from the crypt at Christ Church, 378 could be identified on the basis of coffin plate information. There were a relatively large number of juveniles in the Spitalfields collection: 50 males and 37 females under 20 years of age. Of the remaining 290 adults, 144 were identified as male, and 146 as female.

Unfortunately, the general state of preservation of the Spitalfields sample is poorer than that of St. Bride's. Nonetheless, they still have provided a reference population which parallels St. Bride's. To date, studies of the Spitalfields identified skeletons have provided new criteria for determining the sex of juvenile skeletons (Schutkowski 1993), as well as provocative assessments of bone density in the women of

Spitalfields (Lees et al. 1993) and the presence of osteoarthritis among the silkweavers (Waldron 1991).

THE SKELETAL COLLECTIONS

St. Bride's

The entire identified St. Bride's collection is currently housed in a laboratory located in the crypt of the Church itself. A large segment of the crypt is currently utilized to house an public exhibition on the history of St. Bride's—and London in general—from Roman times to the present. However, the area of the crypt which houses the skeletal material and lab is not accessible to the public. The skeletal remains are individually boxed, and are located within the confines of the laboratory. Typically there are two boxes per individual, one containing the cranium and the other containing postcranial remains. Each box is labeled with an identification code, as well as an indication of the age and sex of the individual. Names and other useful information are available in Powers' (1960) catalogue, which has now been superseded by a card file developed by the Leverhulme project.

Spitalfields

The Spitalfields collection is currently housed in the basement storage area of the British Museum (Natural History). Like with the St. Bride's collection, cranial and post-cranial remains are boxed separately. Unfortunately, the Spitalfields collection differs from St. Bride's in that there is no listing of the skeletal elements associated with each individual. The situation is further complicated by the fact that the identified as well as the u

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the unidentified Spitalfields individuals are stored together. Storage boxes indicate the catalogue number, but not whether a given individual is from the identified subsample or not.

Each of the Spitalfields individuals is identified by a four-digit catalogue number, beginning with the digit 2. That is, the Spitalfields catalogue numbers run from 2001 through 2987. Because the St. Bride's collection has no four-digit catalogue numbers, any potential problem of confusion between the two collections is easily avoided.

CHAPTER 4—METHODS

THE MEASUREMENTS

This study tests hypotheses that characterize the relationship between apparent sex-related factors and environmentally-related factors that affect the phenomenon of long bone asymmetry. It employs specific osteometric observations which (a) extract the greatest possible amount of information from a relatively small number of measurements and (b) meaningfully supplement the existing literature regarding long bone asymmetry. To meet this goal, the measurements included in this study were selected to satisfy four criteria:

1. Standardization. To facilitate comparison of the results with others in the literature, each measurement is associated with an unambiguous measurement technique and has also been employed by previous researchers.
2. Precision. To reduce as much as possible the potential for measurement error, each measurement employs distinct and unambiguous anatomical landmarks.
3. Preservation. To permit the largest available study samples, each measurement involves skeletal elements which are best preserved in skeletal series.
4. Relationship to Activity. To allow an assessment of the relationship between asymmetry and activity, selected measurements include both those that are subject to activity-related morphological changes as well as those that are not likely to be directly modified by physical activity.

These criteria are best met in three paired measurements of the humerus and their counterparts in the femur. Because these two long bones are large and robust, they are likely to survive intact in skeletal samples (Dittrick and Suchey 1986). Moreover, detailed

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detailed analyses of the morphology of the humerus and femur have a long tradition in the skeletal biology literature (Aiello and Dean 1990). The humerus and femur are analogous components of the upper and lower limbs; however, the femur is a weight-bearing bone, while the humerus is not. This suggests that the humeri would be more likely subject to activity which favors one side over the other. In contrast, the femora experience a greater amount of loading, but loading which would be shared more equally between the paired bones.

The specific measurements are maximum length, head diameter, and biepicondylar width.[12] Each is a standard measurement that has been well studied by other researchers in the past. Because the epicondyles are sites of muscle and tendon attachments, biepicondylar widths are subject to activity-related changes in morphology. Head diameters are located on the articular surfaces of the humerus and femur; as such, their morphology is not directly subject to activity-related variation in size.[13]

The specific techniques for taking the six paired measurements are based on the guidelines outlined in Data Collection Procedures for Forensic Skeletal Material

[12]The terms "biepicondylar width" and "epicondylar width" are used interchangeably in the skeletal biology literature. Some authors use the term "biepicondylar breadth" or "epicondylar breadth" to refer to the same measurement.

[13]While humerus and femur head diameters are not directly subject to activity-related morphological variation, France suggests that their sexually dimorphic character is associated with their being positioned in close proximity to areas of large muscle insertion (France 1988:523).

(Moore-Jansen and Jantz 1989), as described below. The measurements were taken on both the St. Bride's and Spitalfields material in accordance with these guidelines.[14]

Maximum Length

> 40. Maximum Length of the Humerus: The direct distance from the most superior point on the head of the humerus to the most inferior point on the trochlea....
>
> Instrument: osteometric board
>
> Comment: Place the humerus on the osteometric board so that its long axis parallels the instrument. Place the head of the humerus against the vertical endboard and press the movable upright against the trochlea. Move the bone up, down and sideways to determine the maximum distance.... (Moore-Jansen and Jantz 1989:72; references to figures and literature citations omitted).
>
> 60. Maximum Length of the Femur: The distance from the most superior point on the head of the femur to the most inferior point on the distal condyles....
>
> Instrument: osteometric board
>
> Comment: Place the femur parallel to the long axis of the osteometric board and resting on its posterior surface. Press the medial condyle against the vertical endboard while applying the movable upright to the femur head. Raise the bone up and down and shift sideways until the maximum length is obtained.... (Moore-Jansen and Jantz 1989:79; references to figures and literature citations omitted).

The proximal and distal ends of both the humerus and femur are located on the articular surfaces of the bones. In contrast, the distal ends of the other major long bones are sites of muscle and ligament attachments (the malleoli of the tibia and fibula, and styloid processes of the radius and ulna). These latter attachment sites are prone to osteophytic deposits which can modify the length measurements of the bones, and render those bones unsuitable for analysis of length asymmetry.

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[14]The numbers associated with each measurement reflect the measurement number in the Data Collection Procedures manual.

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Head Diameter

> 42. Maximum Vertical Diameter of the Head of the Humerus: The direct distance between the most superior and inferior points on the border of the articular surface....
>
> Instrument: sliding or spreading caliper
>
> Comment: Measure the vertical distance perpendicular to the maximum transverse diameter of the head of the humerus. This diameter is not necessarily equal to the maximum diameter.... (Moore-Jansen and Jantz 1989:72-3; references to figures and literature citations omitted).
>
> 63. Maximum Diameter of the Femur Head: The maximum diameter of the femur head measured on the border of the articular surface....
>
> Instrument: sliding caliper
>
> Comment: Place the femur head between the branches of the instrument to find the maximum diameter. This measurement is in contrast to the separate vertical and transverse diameters recommended by Martin.... (Moore-Jansen and Jantz 1989:79; references to figures and literature citations omitted).[15]

In both the humerus and femur, the proximal articular surface—the head—is located within a joint capsule. As a result, the morphology of the head is not subject to osseous modification at sites of tendon and ligament attachments. Although the area surrounding the head of the humerus is a site of attachment for a number of rotator cuff muscles, they are all located beyond the margin of the head. At the proximal end of the femur, the major sites of muscle attachment are the greater and lesser trochanters. The ligamentum teres is attached to the foveal depression in the center of the femoral head, but in no case does that site of attachment complicate the measurement of maximum head diameter.

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[15]The reference to Martin in the description of measurements is Martin and Saller (1957)

Biepicondylar Width

> 41. Epicondylar Breadth of the Humerus: The distance of the most laterally protruding point on the lateral epicondyle from the corresponding projection of the medial epicondyle....
>
> Instrument: osteometric board
>
> Comment: Place the bone with its posterior surface resting on the osteometric board. Place the medial epicondyle against the vertical endboard and apply the movable upright to the lateral epicondyle.... (Moore-Jansen and Jantz 1989:72; references to figures and literature citations omitted).
>
> 62. Epicondylar Breadth of the Femur: The distance between the two most laterally projecting points on the epicondyles....
>
> Instrument: osteometric board
>
> Comment: Place the femur on the osteometric board so that it is resting on its posterior surface. Press one of the epicondyles against the vertical endboard while applying the movable upright to the other condyle. The measurement is parallel to the distal surfaces of the condyles.... (Moore-Jansen and Jantz 1989:79; references to figures and literature citations omitted).

By definition, biepicondylar width of the humerus and femur is measured as the maximum distance between the medial and lateral epicondyles, which are found at the distal end of the bone. The epicondyles are located outside the joint capsule of the elbow and knee, and are the sites of muscle and ligament attachments.

In the humerus, the medial epicondyle is a common origin site for several of the flexor muscles of the forearm, as well as the pronator teres muscle. The lateral epicondyle is a common origin site for several of the extensor muscles of the forearm and the anconeus. As such, variation in the size and morphology of the humeral epicondyles have been linked to patterns of physical activity (France 1988, Dittrick and Suchey 1986). The epicondyles of the femur are primarily sites of ligamentous attachments. Specifically, the medial (tibial) collateral ligament attaches to the medial epicondyle; the lateral (fibular) collateral ligament and the lateral head of the gastrocnemius muscle are associated with the lateral epicondyle.

STUDY SAMPLE SELECTION

The guiding principle for assessing the two Georgian series was to measure all available adult skeletal material from each that met documentation and preservation criteria. No juvenile skeletons were measured because the epiphyses of the humerus and femur would not be sufficiently fused to ensure that maximum length measurements would be accurate. Both crypts contained a large number of undocumented individuals; that is, those for whom name, age, and sex are not identified on the basis of information listed on coffin plates. At Spitalfields, for example, over 950 individuals were removed from the crypt, but less than 400 were "identified" (Adams and Reeve 1987).

Individuals are included in the study sample only if they retain a sufficient level of preservation for accurate maximum length measurements to be taken on either paired humeri or paired femora. In many cases, however, these bones also displayed variable levels of disintegration of the head or epicondyles, and a substantial number of humeri manifest osteophytic lesions, particularly on the medial epicondyle. Because the presence of osteophytes has a strong potential to distort asymmetry assessments for the biepicondylar humerus widths, those bones which presented with osteophytic lesions are discarded from the analysis sample. In the case of the femora, there is virtually no evidence of osteophytic lesions on the epicondyles; however, the distal ends of femora often suffer disintegration of the trabecular bone to the extent that it is impossible to accurately measure the biepicondylar width.

Likewise, arthritic changes can be observed on the margins of the head of the humerus and femur in some mature adults. Osteophytic lipping, in particular, can distort the measurement of vertical head diameter of the humerus, which is measured from the most superior to the most inferior margins of the head. In the femur, osteophytic lipping rarely deforms the aspect of the head where diameter is measured. In a few cases, it is possible that arthritic eburnation can distort the shape of the femoral head to the extent that its diameter cannot be accurately measured. In any case where the diameter of the humerus or femur head appeared to be grossly modified by pathological conditions that bone pair was removed from the study sample.

There is a necessary trade-off in assessing osteometric patterns in skeletal samples which are not well-preserved. If one were to only include those paired bones for which all three measurements (length, head diameter, and biepicondylar width) are available, the resulting sample size is relatively small. If one were to investigate each measurement individually, then the sample sizes increase accordingly. However, because these larger samples consist of different individuals it is not possible to make accurate comparisons between them. To resolve this problem the assessment of humerus length patterns are based on two samples. The <u>paired</u> sample is larger, and consists of all humeri for which paired length measurements are available. The smaller <u>intact</u> sample consists of humeri for which all three paired measurements are available. To be included in the intact sample then, a bone pair would need to show no osteophytic lipping on either head, and no osteophytic deposits on either of the epicondyles. In addition, the head and epicondyles would need to be sufficiently preserved for accurate measurements to be taken. Likewise, each series consists of two samples of femora, partitioned in the

Table 8 Sample Size—Georgian Subpopulations

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Paired Humeri	42	53	30	32
Paired Femora	18	33	36	35
Paired Humeri and Femora	16	30	23	25
Intact Humeri	36	47	27	22
Intact Femora	17	27	24	19

same manner as the humeri. Therefore, each of the series is partitioned into six subgroups, each with a different sample size, as summarized in Table 8.

The St. Bride's and Spitalfields skeletal series are considered both as individual populations and also as combined "Georgians" when they are compared with the Forensic Data Bank sample. This two-level assessment of the Georgians is designed to help assess the problem of whether two contemporaneous and spatially local skeletal groups can be legitimately understood to be a single population.

Data from a total of 225 individuals (130 males and 95 females) were provided from the Forensic Data Bank at the University of Tennessee. The individuals culled from the Data Bank for the comparative sample were adults unambiguously identified with respect to age and sex, coded as "Caucasian" in the Data Bank, and expressing the six paired measurements as outlined above. The criteria by which individuals were selected for inclusion in the final study series was the same as for the Georgian populations. The resulting sample sizes are summarized in Table 9 as well.

Table 9 Sample Size—Identified Subpopulations

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Paired Humeri	72	85	85	64
Paired Femora	54	68	93	65
Paired Humeri and Femora	39	55	75	58
Intact Humeri	63	69	80	58
Intact Femora	41	46	82	58

Reduction in Size of the Skeletal Series

Among the methodological problems which plague studies of asymmetry in human bones, probably the most serious is that researchers draw conclusions from skeletal populations with relatively small sample sizes. The problem of small sample size is common to studies of human skeletal biology—particularly in comparative studies of archaeological populations. Given the size of the St. Bride's and Spitalfields skeletal collections, it was first thought that small sample size would not be an issue for this study. The two collections seemed to provide an abundant study population, with 212 adults in the total St. Bride's identified population and 290 in the Spitalfields identified population.

Difficulties arose, however, with individuals lacking an adequate level of preservation to enable accurate measurements to be taken on the appropriate skeletal elements. It was disheartening to remove a well-preserved individual removed from consideration on the basis of a minor deterioration at the distal end of femur, or if a chip of bone had been removed from the trochlear projection of the humerus. It was even more disheartening as the number of individuals who fell into this category increased steadily as the measuring process progressed. One way to mitigate the problem is to divide the skeletal series into multiple subsamples in an attempt to retain the largest possible sample sizes for each measurement without having a separate study sample for each paired measurement. This application of this strategy is described in the following chapter.

Degree of preservation was not the only factor which determined which individuals were selected for inclusion in the skeletal samples. The greatest difficulty with selecting a sample from the St. Bride's collection for analysis (once degree of preservation was accounted for) was that of non-secure identification. When the crypt population was initially excavated following WWII, the environment for methodological data collection was clearly less than optimal. One consequence was that the skeletal remains from a substantial number of individuals was mixed during initial storage.

The extent of the mixing was perhaps underestimated prior to the systematic recataloguing of the collection in the Leverhulme project. In some cases, it was relatively easy to separate the major skeletal elements of mixed individuals. For example, in a few instances the remains of a husband-wife pair were placed in the same storage box; if the sex of the individuals was obvious from observing the length and robusticity of the skeletal elements, then the separation of the two persons was a fairly straightforward process. In cases where two persons of the same sex and similar age were placed in the same storage box, it was much more difficult to accurately associate the elements with discrete individuals (Scheuer, personal communication).

The Leverhulme researchers divided the St. Bride's population into three categories, based on certainty of identification. Those individuals for whom identification was certain were placed in the "secure" category. If the researchers felt confident about the identification of an individual, but could not be absolutely certain that there was no mixing of some skeletal elements, it was placed in a second "likely secure" category. A third "unsecure" category consisted of those individuals about whose identification researchers could not feel confident. While it may well be that the majority of the "unsecure" individuals are in fact correctly identified, they were excluded from consideration for the study. On the other hand, personal observation of the skeletal material, in conjunction with conversation with Dr. Scheuer, confirmed that the researchers were conservative in her designation of "secure" skeletons, to the extent that individuals with "likely secure" designations were included in the study. The opportunity to discuss the nature of skeletal material directly with the curators of the collection has a value that cannot be overstated, and it made much easier the task of sorting through possible inconsistencies in the St. Bride's collection.

THE SHRINKAGE PROBLEM

In the early stages of the study, a particularly vexing problem arose. The team of researchers who originally excavated the crypt of Christ Church (Spitalfields) recorded a substantial number of qualitative and quantitative observations shortly after the skeletons were removed from their coffins. Among these were a series of post-cranial measurements, including paired measurements of the long bones of the upper limb, and measurements taken from the left lower limb bones. The data from these measurements were then compiled into a computerized database (Cox and Molleson 1993).

When approached with the proposal for this project, the staff of the British Museum of Natural History generously offered to make available those data files in order to reduce the task of measuring the skeletal elements again. Given that the measurements selected for this study were chosen in part because they were not subject to idiosyncrasies in measurement technique, the possibility that an accurate data set could be constructed without remeasuring the skeletal elements was viewed with optimism.

A small series of measurements had been collected on a number of Spitalfields humeri and femora in a pilot study during the previous summer. To be certain that there indeed was no difference in measurement technique, figures from the computerized database were matched with those from the pilot study to ensure that the results were consistent. The comparison showed a small but marked difference in the two series of measurements. A few of the bones which showed the widest discrepancy were measured yet again, and the results were consistent with those taken in the pilot study, and not consistent with those taken shortly after the skeletons were excavated. As a result, no figures from the initial data collection in the 1980s were used in the current study; instead, each of the bones was remeasured.

The discrepancy between the measurements taken in the 1980s and the 1990s was troubling. The most obvious explanation for such an inconsistency is simple random interobserver variation. Interobserver error has been well-documented in the physical anthropology literature, both in relation to metric and non-metric analyses (Utermohle and Zegura 1982). However, interobserver error did not seem to be the case in this instance. In fact, the discrepancy appeared to be markedly unidirectional, since literally none of the recorded measurements from the 1980s were larger than the 1990s measurements. The great majority of them were smaller, but a few showed no difference; the magnitude of the difference averaged approximately 2 mm. If all measurements were within 2 mm of each other, it might have been possible to regard some manner of interobserver error as the cause of the difference, but here the difference was too great in magnitude in too many cases. Likewise, the 1990s measurements were taken using the British Museum's own osteometric board, which ruled out the likelihood that the difference could be attributed to a miscalibration of the measurement device.

The next suggested possibility was a systematic difference in measurement technique. As noted earlier, in this study the true maximum length of the bones were measured, positioning the bone against the ends of the osteometric board until a maximum separation of the uprights is attained. Any alternative technique would have resulted in a shorter value for a length measurement, since by definition there is no other measurement technique that could have resulted in a larger value than the true maximum.

The only remaining possibility appears to be that the bones literally were shorter in the 1990s than in the 1980s. Studies have shown that exposure of cranial material to humidity is associated with larger values for craniometric measurements (Albrecht 1983; Utermohle and Zegura 1982; Utermohle et al. 1983), but there has not been a recent comparable study for long bones. However, Krogman and İşcan report that Rollet's 1888 thesis indicated a 2 mm difference in the length of cadaver bones when measured in a "fresh state" and a "dry state" ten months later (Krogman and İşcan 1986:302).

According to Cox and Molleson's monograph (1993) the state of the skeletal material when removed from the crypt at Christ Church was highly variable. Most of the individuals were interred in sealed lead coffins which contained various amounts of coffin fluid, which is consistent with the suggestion that some of the skeletal material was maintained in a humid environment from the time of interment until the excavation in the 1980s. The most likely explanation is that the bones were indeed longer when they were removed from the coffins than they were when remeasured after several years in storage in the relatively dry environment of the Natural History Museum.

This explanation is supported by the finding that, on average, the femora in the Spitalfields populations presented a greater magnitude of discrepancy in the length measurements than did the humeri. Such a finding is consistent with the phenomenon of shrinkage, since the amount of shrinkage would be relative to the length of the bone. Because femora are consistently longer than humeri, it would be expected that the absolute magnitude of shrinkage associated with the femora would be greater than that associated with the humeri. It is also important to note that the finding that the humeri and femora manifest different magnitude of discrepancy also effectively rules out the likelihood that a problem with the calibration of the osteometric board led to the inconsistent measurements. If the osteometric board were poorly calibrated, there would have been a more consistent magnitude of length differences for the humeri and femora.

Indeed, the magnitude of discrepancy in length measurements among the femora was not consistent, nor was the magnitude of shrinkage among the humeri. Given an explanation that humidity-related shrinkage caused the different measurements, this is not a surprising finding. The environment in the coffins from which the skeletal material was removed showed a range of variation. In some cases, the original researchers reported that bones were in a much drier state than others. Even in 1919, Pearson and Bell were critical of studies which attempted to compare the findings of "wet" bone and "dry" bone studies. It is important to consider that interment in humid coffin environments may lead to different osteometric observations than would be evident in dry bones.

ASSESSING DISTRIBUTION OF THE LINEAR DIMENSIONS

Before addressing the issue of asymmetry, frequency distributions and summary statistics are generated and reported for each of the six paired measurements in each of the ten subpopulations listed in the previous section. Characterizing the distribution patterns of the linear dimensions themselves is an important prelude to assessing asymmetry in that it clarifies the extent and nature of variation in general long bone morphology among the study populations. For example, if the patterns of femoral head diameter figures reported by Dwight (1905) and by Stewart (1979) persist in the populations involved in this study one should observe that the modern forensic population would consist of long bones which are consistently larger than those of the Georgians. If the Forensic sample consists of bones which are larger than the Georgians, then it would not be surprising if they displayed an equally larger magnitude of asymmetry in the linear measurements. However, if the smaller Georgian bones were to display an absolutely greater magnitude of asymmetry the findings would be more notable.

A consistent strategy was used in determining the frequency distribution patterns for the linear dimensions. Patterns are reported only for those individuals who have paired measurements available. In each case, the mean of the observations from the right and left bones is used to calculate the value of that dimension for each individual. For example, a person with a right femur length of 420 mm and a left femur length of 423 mm would be listed as having a mean femur length of 421.5 mm. The findings for each subpopulation, partitioned by sex, are assessed for mean, standard error of the mean, standard deviation, and .95 confidence level.[16]

The subgroups were tested for independence on the basis of standard *z* or *t* tests. Both tests assess the likelihood that two samples are drawn from the same population. The *z* test is appropriate if both series under consideration consist of thirty or more individuals; the *t* test is employed for smaller samples. As the number of individuals in the study samples increase, the *t* score approaches the value of the *z* score.

$$z = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)}} \tag{2}$$

The *z* score is calculated on the basis of Equation 2, where $\bar{x}$ is the sample mean, s^2 is the sample variance, and n is the sample size; the subscripts refer to the two samples. The *z* score is defined as the number of standard deviations by which a sample mean differs from another population mean, and can be used to test the significance of the

[16]These figures were calculated using the built-in routines in Quattro Pro for Windows, Version 5.0 (Borland).

difference between two sample means. That is, a comparison of two samples that results in a *z* score of 1.5 means that their means differ by 1.5 standard deviations. In a two-tailed test of statistical significance at an alpha of .05, the critical value of *z* is 1.96; if a *z* score exceeds this value, the hypothesis that the samples are drawn from the same population must be rejected. For an alpha of .01 the critical value of *z* is 2.58.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)}} \qquad (3)$$

The significance of differences in small sample means are assessed by the *t* test. The typical *t* test requires that the two samples under study be normally distributed with equal variances. Because equal variances cannot be assumed for this study the *t* statistic is calculated using Equation 3.

$$d.f. = \frac{\left[\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)\right]^2}{\left(\frac{s_1^2}{n_1}\right)^2\left[\frac{1}{(n_1 - 1)}\right] + \left(\frac{s_2^2}{n_2}\right)^2\left[\frac{1}{(n_2 - 1)}\right]} \qquad (4)$$

The calculated value for *t* is essentially the same as the *z* score, but its significance is assessed not by using the normal curve but rather the *t* distribution with degrees of freedom calculated by the formula in Equation 4 (rounded to the nearest integer).

The presentation of the results follows a pattern which is applied consistently throughout the following chapter. Two general Tables are presented for each measurement; one compares the Spitalfields and St. Bride's males and females, the other pools the Georgian samples and contrasts them with the Forensic Data Bank sample. This underscores a dominant theme in this research, since in one case the two Georgian groups are assessed as different sample populations, while in the other they are presented as representative of a single population. Along with the Tables of summary statistics, the distribution patterns are graphically represented in a series of Figures which follow the same format as the Tables. That is, in one set of Figures the Georgians are compared as if they were separate populations, while in the other they are pooled and contrasted with the Forensic Data Bank. In all cases the males and the females of each skeletal group are treated separately.

ASSESSING ASYMMETRY

The methodological caveat from Chapter 2 bears repeating: To designate paired skeletal elements as symmetrical is to apply a label which is directly related to the precision with which the skeletal elements are measured. One of the thorny problems that one confronts in assessing asymmetry is that intraobserver measurement error may be misconstrued as an indication of asymmetry. Chapter 2 suggested that since the standard osteometric board is calibrated in increments of one millimeter, intraobserver variation in recording an observation could understandably be 1 mm. However, it would seem unlikely that intraobserver variation would be 2 mm or larger, provided that measurements are performed with consistent technique. It is important to recognize that if one were to restrict the label "asymmetric" to bone pairs whose lengths differ by a magnitude of two millimeters or larger, an indeterminant number of cases of true asymmetry are being lost in the process.

With respect to the maximum lengths of humeri and femora, the standard procedures for taking the measurements minimize the likelihood for variation. That is, if the bone is moved back and forth between the fixed and moveable ends of the osteometric board until the true maximum length is determined, there should be no ambiguity as to the accuracy of the measurement. The same statement can also be made about the biepicondylar widths of the humerus and femur. For the purposes of this study, each paired measurement is coded as symmetrical if the magnitude of difference between the dimension on the left bone and the right bone was less than one millimeter. Differences greater than or equal to one millimeter are then coded left-dominant or right-dominant, depending on which side is larger.

Nonetheless, it is worthwhile to assess how the distribution patterns of asymmetry direction change if a two millimeter threshold is employed in place of a one millimeter threshold. For this reason, patterns of asymmetry direction are compared for the lengths of the humerus and femur as reported using a two-millimeter threshold as well as a one-millimeter threshold. The two-millimeter threshold is arguably a more valid indicator of true asymmetry by mitigating the effects of measurement error.

CALCULATING ASYMMETRY MAGNITUDE

Once the distinction between "symmetry" and "asymmetry" is made, calculating the direction of asymmetry is a straightforward process. In contrast to the ease of determining the direction of asymmetry in paired linear dimensions, there are several different ways to report the magnitude of that asymmetry. One way is to simply calculate the difference in the corresponding measurements on the right and left sides. That is, if a right femur were 480 mm in length and the left were 482 mm long, the magnitude of asymmetry is reported as 2 mm. If the right side were shorter than the left, the result would still be reported as 2 mm.

Some researchers attempt to include both magnitude and direction in their calculations, typically by applying subtracting the left-side measurement from the right-side measurement and reporting a <u>signed</u> magnitude value. Using this strategy, the two femora pairs described above would be reported as having asymmetry magnitude of 2 mm and -2 mm, respectively. Whether or not the difference is reported as signed or unsigned will greatly affect the summary statistics derived for a population. For this reason, summary statistics and frequency distributions based on both signed and unsigned asymmetry values are reported for each measurement for each subpopulation.

Another consideration further complicates the calculation of asymmetry. It is plausible that the magnitude of asymmetry is affected by the size of the character being measured. For example, asymmetry of 2 mm between paired femoral heads is a greater proportion of difference that between the lengths of paired femora. Table 10 describes this difference using mock data, showing that in the case of the head diameters the variation represents a difference of five percent. In assessing lengths, however, the same two millimeters represents a difference of only one-half percent. It is possible that the magnitude of asymmetry is correlated with the size of the character being measured. If this were the case then it is valuable to report the asymmetry as a percentage of the total character size.

Table 10 Effect of Character Size on Asymmetry Magnitude

	Right (mm)	Left (mm)	Difference (mm)	Difference (%)
Femur Head	42	40	2	5%
Femur Length	402	400	2	.5%

There is yet another potential source of inconsistency between reported studies, even when magnitude of asymmetry is scaled on character size. There are several different ways to calculate the size of a characteristic in paired bones.

$$Asymmetry = \left(\frac{(Right - Left)}{Right}\right)(100) \tag{5}$$

One way is to choose one or the other side arbitrarily as the character size (Equation 5). Fresia et al. (1990) chose this technique, which results in a negative value if the left-sided element is the larger of the paired characteristics.

Another strategy is to scale the asymmetry against the smaller of the two side measurements, as indicated in Equation 6. Trinkaus et al (1994) employed this formula, which maximizes the perceived level of asymmetry in a population.

It also results in no negative values, which makes it more amenable to statistical

$$Asymmetry = \left(\frac{(Maximum - Minimum)}{Minimum} \right) (100) \tag{6}$$

analysis. However, the direction of the asymmetry is not available from the calculation.

Palmer and Strobeck (1986) list a number of ways that researchers have calculated asymmetry patterns in assessing biological asymmetry (in their case, fluctuating asymmetry). Both signed and unsigned calculations figure prominently in their discussion. In this study asymmetry is reported both in terms of millimeters difference (both signed and unsigned) and as a percentage of mean character size (again both signed and unsigned).

In short, asymmetry magnitude is calculated in four different ways for each individual, and summary statistics are reported for each. In addition, each subpopulation is ordinally ranked with respect to mean asymmetry values of each paired measurement, based on each of these four calculation strategies:

$$Signed\ Value = (Right - Left) \tag{7}$$

$$Unsigned\ Value = |Right - Left| \tag{8}$$

$$\textit{Signed Percentage} = \frac{(\textit{Right} - \textit{Left})}{\left(\frac{\textit{Right} + \textit{Left}}{2}\right)} \tag{9}$$

$$\textit{Unsigned Percentage} = \frac{|\textit{Right} - \textit{Left}|}{\left(\frac{\textit{Right} + \textit{Left}}{2}\right)} \tag{10}$$

ASSESSING CROSS SYMMETRY

Cross symmetry refers to the phenomenon of reversed length dominance between a component of the upper and lower limb—for example, a pattern wherein the right humerus is longer than the left, while the left femur is longer than the right. For a substantial subset of the core and comparative populations, preservation is sufficient to allow length measurements to be taken on both humeri and both femora. In many cases, it is also possible to determine all six paired measurements from the skeletal material available. Having all these observations together permits an assessment of cross symmetry in the postcranial skeleton.

TESTING THE SIGNIFICANCE OF ASYMMETRY

The most challenging problem in this analysis is to determine how to indicate the level of significance for the asymmetry that is observed. When sample sizes are small, as they commonly are in skeletal biology research, a relatively large amount of variation needs to be present for the difference to be regarded as statistically significant. In the past most authors have avoided these methodological problems by primarily describing the patterns that they have observed, and providing a series of summary statistics consisting solely of means, standard deviation, and/or standard error (cf. Münter 1936; Schultz 1937).

In inferential statistics a fundamental distinction is made among nominal, ordinal, interval, and ratio data. The nature of bilateral asymmetry is such that the different aspects of it are best assessed in terms of each of these scales of data. For example, nominal data is that which falls into discrete categories, as illustrated by the direction of asymmetry. In terms of side dominance, paired bones are either right-dominant, left-dominant, or symmetrical. These categories are arbitrarily constructed, but a given observation in a given individual can only fit into one of the categories. As such, the appropriate test statistic for determining the statistical significance of differences between groups is based on the chi-square (χ^2) distribution.

A defining characteristic of nominal data is that the categories have no hierarchical ranking, but the magnitude of asymmetry can be ranked. The magnitude of asymmetry can be viewed as an interval variable as well, to which standard parametric analyses can be applied. A significant difficulty arises when one attempts to assess both the direction and magnitude of asymmetry in a single statistical framework. Those researchers who did employ inferential statistics (Falk et al. 1988) used paired *t*-tests to compare the size of paired skeletal elements.

Any attempts to assess simply the direction of asymmetry as a nominal variable suffer from problems as well. Researchers who have examined direction of asymmetry in limb bones (Latimer and Lowrance 1965, for example) have avoided statistical problems by relying solely on describing the asymmetry patterns they observed. Their strategy of characterizing asymmetry as left-dominant or right-dominant can lend itself to chi-square analysis.

The most frustrating issue is that there is no well-reported statistic that can represent both the direction and the magnitude of skeletal asymmetries. As will be seen in the following chapter, reporting asymmetry in terms of unsigned magnitude values alone provides a very different picture than when signed values are used. For example, if the study populations are ordinally ranked from the most symmetrical to the least symmetrical on the basis of signed measurements there is no guarantee that the same ordinal ranking will persist with unsigned measurements. The implications of this problem are discussed more fully in Chapter 6.

For each of the measurements in each of the populations, asymmetry direction is partitioned into one of three categories: left-dominant, symmetrical, or right dominant. For the head diameters and biepicondylar widths a one-millimeter threshold distinguishes between the dominant and symmetrical categories. For the bone lengths both a one-millimeter and a two-millimeter threshold is employed to categorize asymmetry direction. Each of the study subpopulations is compared with the others to determine the probability that differences in asymmetry direction findings could be due to chance.

To maintain consistency with reports in the literature that treat asymmetry as if it met the criteria for parametric assessment, the unsigned magnitude values are subjected to parametric inferential statistical analysis. Summary statistics are reported for all the study subsamples following the four conventions listed in the previous section, and the populations are ordinally ranked.

The Mann-Whitney *U* Test for Statistical Significance

Trinkaus et al (1994) employed the Mann-Whitney *U* statistic to test the significance of differences in asymmetry patterns within a population. The Mann-Whitney *U* was designed to test ordinally ranked data from two independent samples to determine the probability that they are drawn from the same population (Mann and Whitney 1947). It is a particularly useful tool for assessing bilateral asymmetry since it does not rely on assumptions that underlie parametric statistical analysis. Specifically, *U*-based statistics do not require that the variable under study follow a statistically normal distribution pattern.

Table 11 Sample Data for a Mann-Whitney *U* Calculation

Humerus Length (Right - Left)							
Sample 1	0	2	2	-1	3	-2	1
Sample 2	0	0	2	4	-1	3	

The Mann-Whitney *U* tests the probability that two unmatched and ordinally ranked samples are drawn from a single population. The *U* is computed by pooling the scores of the two samples, assigning ranks to each score, and then summing the rank values for each group individually. The procedure is somewhat time-consuming, particularly with large samples, and it is worthwhile to lay out the exact procedure by which the *U* is calculated. Table 11 lists asymmetry values for several individuals from two samples. Observations with a negative value reflect left-dominance, while those with a positive value are right dominant.

Table 12 Sample Data Placed into Ordinal Ranks

Sample 1	Ranks	Sample 2	Ranks
-2	1	-1	2.5
-1	2.5	0	5
0	5	0	5
1	7	2	9
2	9	3	11.5
2	9	4	13
3	11.5		

Table 12 shows the sample data ranked ordinally for the two samples. Because the smallest observed value is "-2", it is given the lowest rank. There are two observations at the next level ("-1"), so their ranks are averaged; rank 2 and rank 3 become a shared rank 2.5. Three values of "0" mean that they share the average ranking of 4, 5, and 6--that is, 5. The same strategy is employed to determine the ranks of all observations in both samples.

The Mann-Whitney U is the smaller of the two values derived from the following two equations:

$$U = n_1 n_2 + \frac{n_1 (n_1 + 1)}{2} - R_1 \tag{11}$$

$$U = n_1 n_2 + \frac{n_2 (n_2 + 1)}{2} - R_2 \tag{12}$$

In these equations, n_1 is the number observations in the smaller of the two samples, and n_2 is the number of observations in the larger sample. R_1 is the sum of the ranks for the smaller sample, and R_2 is the sum of the ranks in the larger sample.

$$U = (6)(7) + \frac{(6)(6+1)}{2} - 46 = 17 \tag{13}$$

Using the sample data above, $n_1 = 6$ and $n_2 = 7$; $R_1 = 46$ and $R_2 = 45$. Placing the values into the formula, a U of 17 is calculated. For values of $n_2 \leq 20$, consultation of a Mann-Whitney table is required to determine the probability associated with the test.[17] In this case, the table gives a probability of .314 when $n_1 = 6$, $n_2 = 7$, and $U = 17$. Therefore, the null hypothesis that both samples were drawn from the same population cannot be rejected. To reach an a priori rejection value of $p < .05$ with samples of this size would require a calculated U of 8.

$$z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}} \tag{14}$$

A powerful characteristic of the Mann-Whitney U test is that when $n_2 > 20$ it is possible to derive a z score from U, using the formula presented in Equation 14. From z it is easily possible to determine the statistical probability p that the two samples were drawn from a single population.

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[17]The original tables are found in Mann and Whitney (1947), and have been reproduced in textbooks of nonparametric statistics such as Siegel (1956) and Sprent (1989).

$$z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\left(\frac{n_1 n_2}{N(N-1)}\right)\left(\frac{N^3 - N}{12} - \Sigma T\right)}} \tag{15}$$

$$\Sigma T = \frac{2^3-2}{12} + \frac{2^3-2}{12} + \frac{3^3-3}{12} + \frac{3^3-3}{12} = \frac{1}{2} + \frac{1}{2} + 2 + 2 = 5 \tag{16}$$

The presence of ties (i.e., multiple observations of the same value) does have a slight effect on the value of z derived from this equation. The length of the ties is the characteristic that modifies the z score, by changing the variability in the set of ranks, and hence the standard deviation of the sampling distribution of U. Siegel (1956:124-5) offers a correction for ties based on the formula in Equation 15. In this equation N equals the sum of n_1 and n_2. The length of each tie is t, and $\sum T = \sum_{1}^{x} \frac{t_x^3 - t_x}{12}$. For example, the sample data from the Table above displays two ties of length 2 and two ties of length 3.[18] Equation 16 shows how this translates into a $\sum T$ of 5.

Two additional points about the correction of ties in the Mann-Whitney statistic merit note. First, the correction has the effect of increasing the z score slightly, which will in turn cause a small reduction in the value of p. In other words, not correcting for ties leads to a slightly more conservative test. Secondly, a long run of ties contributes significantly more to the value of $\sum T$ than would a shorter run of ties. For example, a t of

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[18]The correction for ties applies only in the case where a z score can be derived from U— that is, where $n_2 > 20$. The sample data from the Table does not contain an adequate number of observations for the correction formula to be applied. In this case, the sample Table data is applied for convenience simply to demonstrate the calculation of $\sum T$.

6 results in a t of 17.5, and a t of 12 results in a t of 143.833. Emphasizing these two points, Siegel (1956:126) recommends that "one should correct for ties only if the proportion of ties is quite large, if some of the t's are large, or if the p which is obtained without the correction is very close to one's previously set value of α." The report of results in Chapter 5 presents a correction for ties for all comparisons which display an uncorrected $p < .10$; the corrected z and p values are listed in parentheses below the uncorrected values..

The Mann-Whitney U is a median-based statistic. In addition to not assuming an underlying normal distribution pattern, it also minimizes the influence of extreme outliers in the sample distribution. If, for example, the largest asymmetry value in Sample 2 from the Table were 6, rather than 4, it would still retain the same rank value. In a parametric test, such an outlier would have a greater impact on the calculated relationship between the two samples. This is a noteworthy consideration in discussions of asymmetry, since in a given data set there is a possibility for a outlier demonstrating an unusually large magnitude of asymmetry. When there is no evidence of measurement error, inaccurate pairing of the bones, or pathology, it would be unreasonable to remove the outlier from the study sample. At the same time, if that outlier were assessed in terms of its magnitude, rather than its ordinal ranking, it might lead to a spurious representation of the population mean.

HYPOTHESIS TESTING

The hypothetical questions raised at the conclusion of Chapter 2 are assessed first by tests that compare the two Georgian populations with each other, then pool the

Georgians to make a comparison with the Forensic sample. In each case the pertinent testing statistic determines the probability that the two samples being compared are drawn from a single statistical population. Each of the asymmetry hypotheses is tested at three levels. For the direction of asymmetry, χ^2 tests are the basis for testing statistical significance of the differences. For both signed and unsigned magnitude values, the Mann-Whitney *U* statistic is employed. The a priori significance level (α) is set at .05 for all the assessments, and other more conservative levels of *p* are identified below as appropriate. The .05 alpha value is chosen to maintain consistency with the literature; none of the asymmetry studies in the existing literature which employ significance levels use values which are less conservative.

The specific hypothetical testing strategies are as follows:

(1) That the Georgian skeletal series are drawn from a common population that is significantly different from the Forensic series in terms of the dimensions of the long bone. Before assessing differences in asymmetry patterns between the skeletal series it is first necessary to assess how the series differ in terms of the magnitude of the dimensions of the bones themselves. This hypothesis would be supported if the two series of Georgians display statistically similar distribution patterns in long bone dimensions which differ significantly from those of the Forensic series. This means that comparisons of bone dimensions between the two series of Georgian males would not reject the null hypothesis that they are drawn from the same statistical population, and that comparisons of bone dimensions between the pooled Georgian males and the Forensic males would reject the null hypothesis that they are drawn from the same statistical population. Likewise, comparisons of bone dimensions between the two series of Georgian females

would not reject the null hypothesis that they are drawn from the same population, and that comparisons of bone dimensions between the pooled Georgian females and the Forensic females would reject the null hypothesis that they are drawn from the same population.

(2) That an individual's sex is a primary determinant of long bone length asymmetry patterns. This hypothesis would be supported if the two Georgian male populations display a similar pattern of asymmetry which is statistically consistent with the Forensic males pattern, and if the Georgian females display asymmetry patterns which are consistent with the Forensic females. This means that comparisons of asymmetry direction and magnitude between the sexes in each of the three populations (St. Bride's, Spitalfields, and Forensic Data Bank) would reject the null hypothesis that they are drawn from the same statistical population; and comparisons of asymmetry direction and magnitude between the two series of Georgian males and between the two series of Georgian females would not reject the null hypothesis that they are drawn from the same statistical population.

(3) That setting in time and space acts as a primary determinant of long bone length asymmetry patterns. This hypothesis would be supported if the two series of Georgians display a statistically similar pattern of asymmetry which differ significantly from the Forensic series. To avoid confusion with possible sex-related factors the two sexes are tested separately. This means that comparisons of asymmetry direction and magnitude between the two series of Georgian males would not reject the null hypothesis that they are drawn from the same statistical population, and that comparisons of asymmetry direction and magnitude between the pooled Georgian males and the Forensic

males would reject the null hypothesis that they are drawn from the same statistical population. Likewise, comparisons of asymmetry direction and magnitude between the two series of Georgian females would not reject the null hypothesis that they are drawn from the same statistical population, and that comparisons of asymmetry direction and magnitude between the pooled Georgian females and the Forensic females would reject the null hypothesis that they are drawn from the same statistical population.

(4) That physical activity is a primary determinant of long bone asymmetry. If this is the case then the direction of asymmetry in biepicondylar widths (which are sites of tendon and ligament attachments) within individuals should correspond to direction of asymmetry in the corresponding bone lengths. In statistical terms this means that in any given subsample the results of χ^2 analysis comparing proportions of right- and left-dominance in biepicondylar width with direction of dominance in bone length would not reject the null hypothesis that they are drawn from a common statistical population. This hypothesis is based on France's (1988) assertion that the morphology of muscle insertions on bones are associated with physical activity levels.

SUMMARY

In sum, six paired long bone measurements are to be assessed for the two skeletal samples representing Georgian-era crypt populations from London--St. Bride's and Spitalfields. The measurements are analogous components of the humerus and femur: maximum length, head diameter, and biepicondylar width. The statistical significance of the population differences are assessed in four ways: (a) *z* test for comparing population means of the long bone dimensions, or a *t* test if the two samples being compared do not each meet the minimum for sample size (n≥30); (b) χ^2 test for comparing patterns of asymmetry direction; (c) Mann-Whitney *U* test for comparing the signed and unsigned magnitude of asymmetry; and (d) binomial test for comparing asymmetry direction patterns between measurements within bones, and for crossed symmetry between humerus and femur length.

The two Georgian series are dealt with both as individual populations and as a common population. When pooled, the Georgians are contrasted with individuals from the 20th century United States, based on measurements derived from the Forensic Data Bank at the University of Tennessee. For each individual measurement, comparisons are made at three levels. First, the males and females of each series are compared. Secondly, the males of the two Georgian series are compared, and females of the two Georgian series are compared. Thirdly, the pooled Georgian males are compared with the Forensic males, and the pooled Georgian females are compared with the Forensic females.

CHAPTER 5—RESULTS

The overall strategy of this research project is unique in two respects. First, it addresses both the magnitude and direction of asymmetry of each of the six measurements in detail. Secondly, it investigates relationships among asymmetry patterns at the population level both within individual bone pairs and between the humerus and femur. Accordingly, this chapter is divided into several sections. The first section describes how the individual linear dimensions are distributed among the study subgroups. The second section focuses specifically on the direction of asymmetry for each measurement among the groups. The third section presents the patterns of signed and unsigned asymmetry magnitude for each measurement among the subgroups. The fourth and fifth sections evaluate the patterns of asymmetry within the paired humeri and the paired femora of each group, respectively, and the sixth section addresses the issue of cross symmetry in the maximum length of the humerus and femur. The final section summarizes the results in terms of the hypotheses laid out in the previous chapter.

Throughout this chapter a series of Tables present summary statistics for the study subgroups, partitioned by sex. In addition, a series of Figures display in a graphic format the distribution patterns for each of the measurements. In most cases, the vertical axes of the graphs are scaled to represent the percentage of each subgroup represented at each interval, rather than the raw numbers of individuals represented. Because the subgroups vary substantially in size, this strategy for illustrating findings facilitates the reader's ability to make comparisons of patterns among them. Likewise, all Figures associated with a given measurement employ a consistent scale along the horizontal axis.

LINEAR DIMENSIONS DISTRIBUTION PATTERNS

Preliminary to reporting patterns of asymmetry patterns in the bones it is necessary to describe the distribution patterns of the measurements themselves. This comparison gives some indication of how the Georgian groups compare with each other, and how they contrast with the Forensic Data Bank individuals.

Humerus Length—HL

Summary statistics for each of the four Georgian subgroups are presented in Table 13, and the distribution patterns themselves are shown in Figures 2 and 3 The two Georgian male samples show very little difference in mean humerus length but the females display a statistically significant mean difference of 4.9 mm, with the Spitalfields females larger ($z = 1.710, p < .05$).

Table 13 Paired Georgian Humerus Length Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	321.3	293.9	320.9	289.0
SE	2.92	2.24	2.75	1.76
SD	18.89	16.34	15.06	9.94
.95 Confidence	5.71	4.40	5.39	3.45
N	42	53	30	32

As would be expected, the differences between the sexes in the two Georgian samples are highly statistically significant (St. Bride's $z = 9.750$, Spitalfields $z = 7.442$).

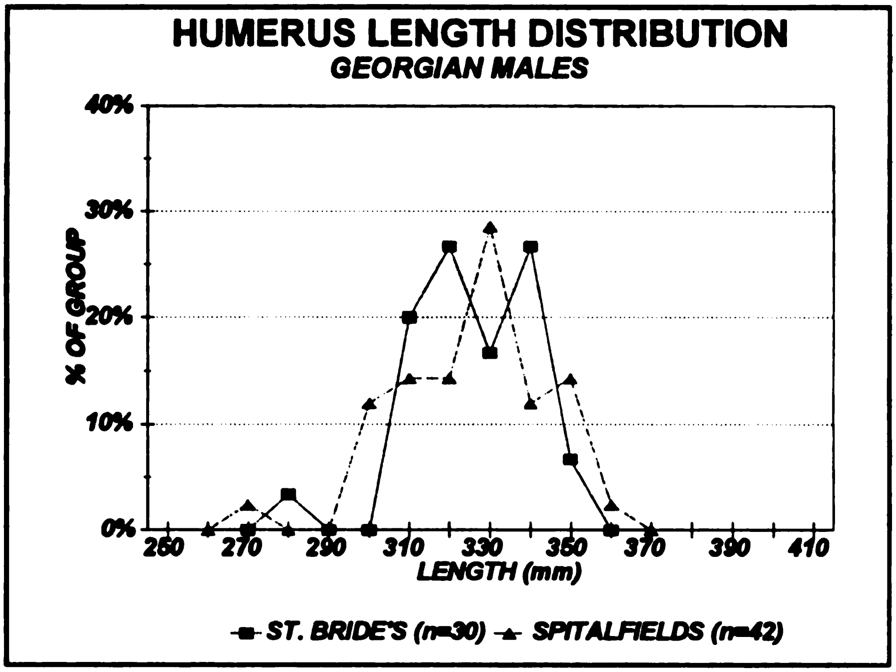

Figure 2 Humerus Length Distribution -- Georgian Males

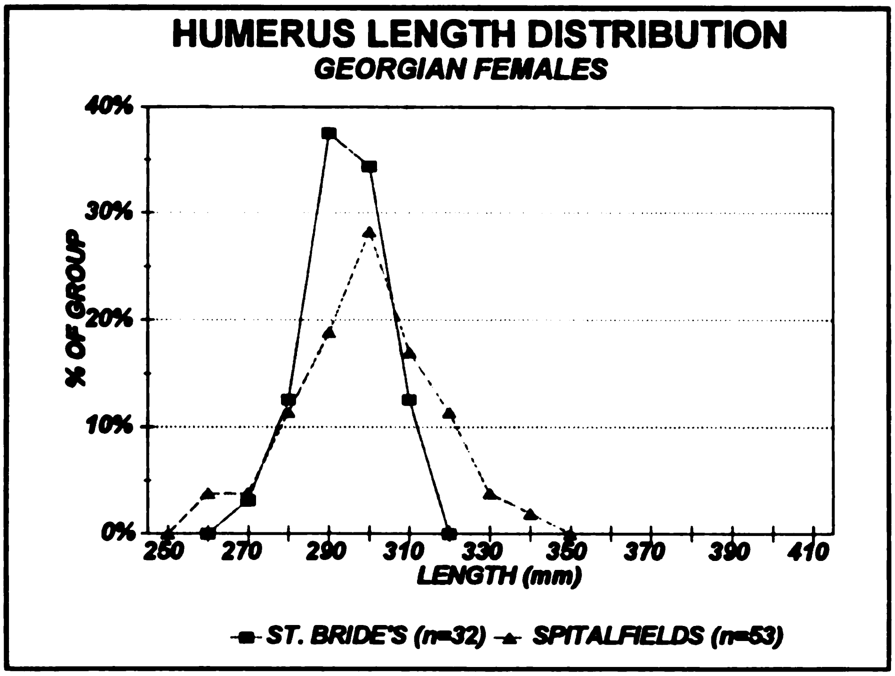

Figure 3 Humerus Length Distribution -- Georgian Females

Table 14 Intact Georgian Humerus Length Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	322.8	293.1	320.6	289.9
SE	2.96	2.46	2.94	1.88
SD	17.77	16.86	15.28	8.83
.95 Confidence	5.81	4.82	5.76	3.69
N	36	47	27	22

Table 14 partitions intact[19] humerus length summary statistics by sex between the Georgian groups. The reduction in the study sample size in the intact groups is associated with a slight change in summary statistics when compared with the paired bones. Nonetheless, the Spitalfields and St. Bride's males are very similar to each other; likewise, the females of the intact group present the same general pattern as they do in paired humeri.

Table 15 pools the Georgian males and females for comparison of the paired and intact samples. The pooled groups display very similar summary statistics, which suggests that there is little difference in the character of the more well preserved intact long bones when compared with the less well preserved paired bones. The mean difference in humerus lengths between the paired humeri samples and the intact humeri

[19]The intact sample is the subset of the paired sample for which head diameter and biepicondylar width were also observed.

Table 15 Pooled Georgian Humerus Length Summary Statistics

	Paired ♂	Paired ♀	Intact ♂	Intact ♀
Mean	321.1	292.1	321.8	292.1
SE	2.04	1.56	2.10	1.78
SD	17.29	14.40	16.66	14.79
.95 Confidence	3.99	3.06	4.11	3.49
N	72	85	63	69

samples is negligible—well within the standard error of each sample.

Among the Georgian males, a reduction in sample size from 72 to 63 is associated with only a 0.7 mm difference in mean humerus length. For the females, the sample is reduced from 85 to 69, with virtually no change in mean humerus length. This is a noteworthy finding, for it suggests that bones are not likely to be differentially preserved on the basis of their size. It also argues against the assumption that larger and more robust bones would be less likely to suffer from the effects of poor preservation than smaller bones. If that were truly the case, then the intact sample would show a larger mean length value than the paired sample.

Table 16 presents a comparable picture of the summary statistics of humerus length for the paired and the intact humeri of the Forensic Data Bank. The results are consistent with those of the Georgians, in that the difference in mean humerus length between the paired and intact samples is negligible.

Table 16 Forensic Data Bank Humerus Length Summary Statistics

	Paired ♂	Paired ♀	Intact ♂	Intact ♀
Mean	334.5	306.7	334.2	308.2
SE	1.97	1.80	2.05	1.77
SD	18.20	14.37	18.35	13.44
.95 Confidence	3.87	3.52	4.02	3.46
N	85	64	80	58

In Figure 4 humerus length distributions of the pooled Georgian males are displayed against the Forensic Data Bank males; Figure 5 does the same for the females. The differences between the 18th and 20th century samples are striking for both sexes. The mean male humerus length for the Forensic Data Bank is nearly 13 mm greater that for the Georgians ($z = 4.73$). Likewise, the Forensic Data Bank females show a mean humerus length approximately 15 mm greater than the Georgians ($z = 6.13$).

The difference between the males and females of the Forensic sample parallels that of the two Georgian groups, in that the males display a significantly larger mean humerus length ($z = 10.44$). It is not surprising that the males of each of the three study samples show a substantially larger mean humerus length than their female counterparts. It is noteworthy, however, that the male-female difference in means for the Forensic Data Bank sample (27.8 mm) is slightly smaller than for the pooled Georgians (29.0 mm), even though the Georgian humeri are smaller in length overall than the Forensic Data Bank humeri.

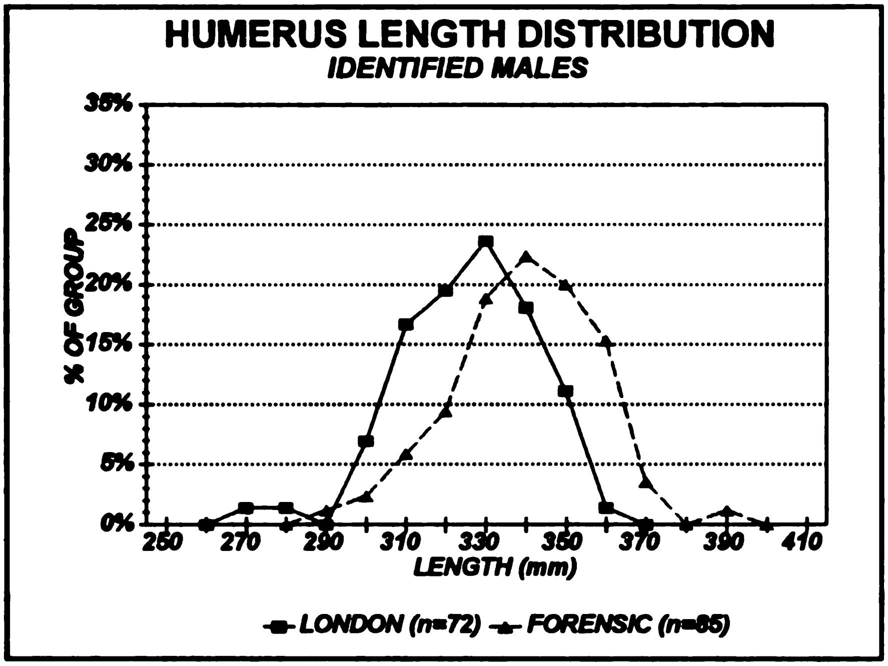

Figure 4 Humerus Length Distribution — Identified Males

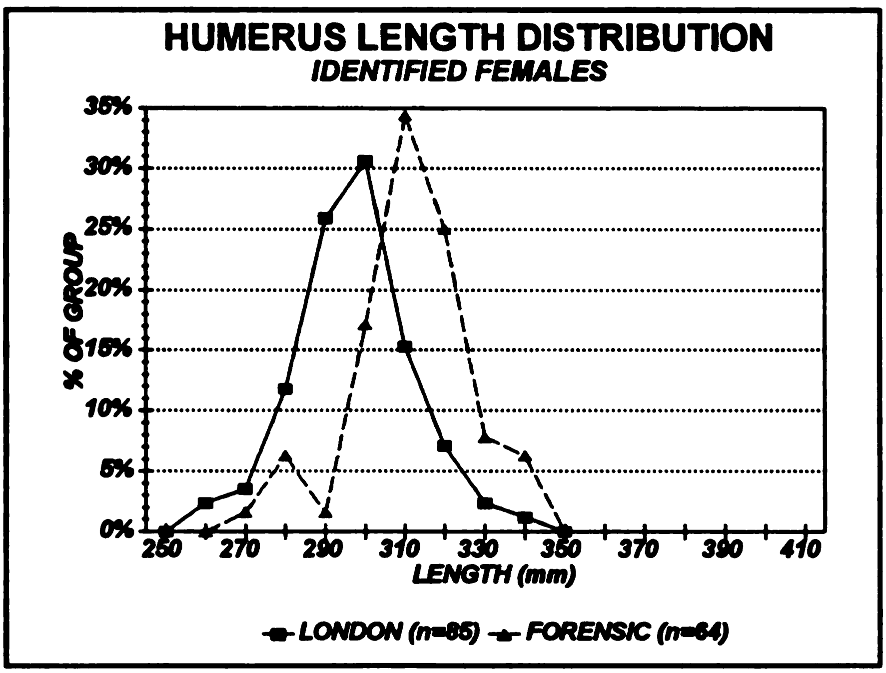

Figure 5 Humerus Length Distribution — Identified Females

Humerus Head Diameter—HH

The diameter of the humerus head typically is employed by osteologists as a tool for sexing the humerus. As expected, in both Georgian groups the differences between the male and female means are statistically significant (St. Bride's: $t = 10.47$, $df = 43$, $p < .0001$; Spitalfields: $t = 12.06$, $df = 70$, $p < .0001$). The summary statistics for vertical head diameters in the Georgian groups are listed in Table 17.

Table 17 Georgian Humerus Head Diameter Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	46.8	40.9	46.9	41.0
SE	0.39	0.30	0.47	0.31
SD	2.35	2.07	2.47	1.43
.95 Confidence	0.77	0.59	0.93	0.60
N	36	47	27	22

In the case of both the males and females, the mean head diameter is only slightly larger (0.1 mm) in the St. Bride's humeri than in their Spitalfields counterparts, and this is not statistically significant for either the males ($t = 0.061$, $df = 55$, $p = 0.95$) or females ($t = .197$, $df = 57$, $p = .84$). For the Georgians the male and female curves intersect between 43 and 44 mm (Figures 7 and 8). In contrast, the humerus head distribution curves for the Forensic Data Bank sample intersect between 46 and 47 mm. Just as there is a significant difference between the Georgian males and females, the mean head diameter of the Forensic males and females is also significantly different ($z = 16.18$).

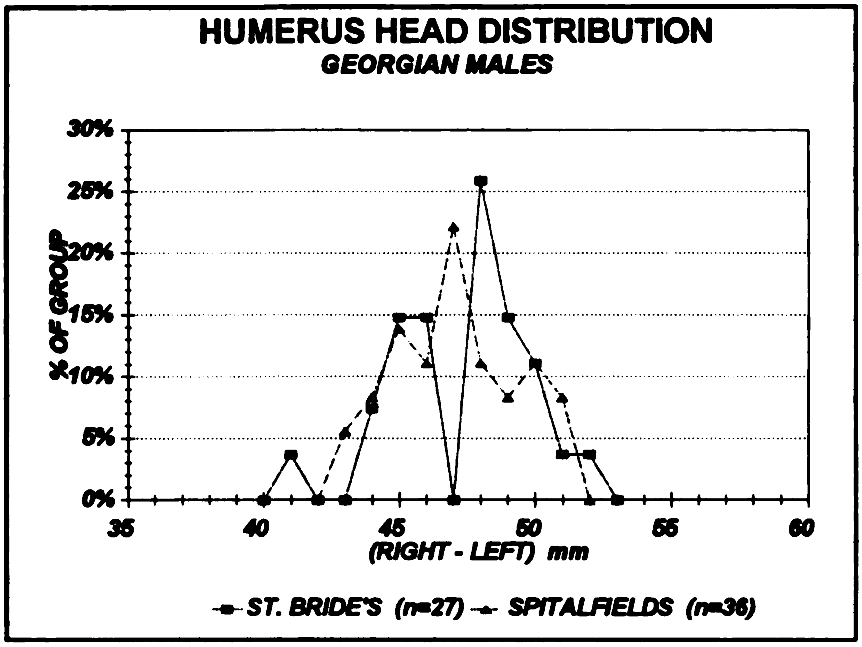

Figure 6 Humerus Head Distribution — Georgian Males

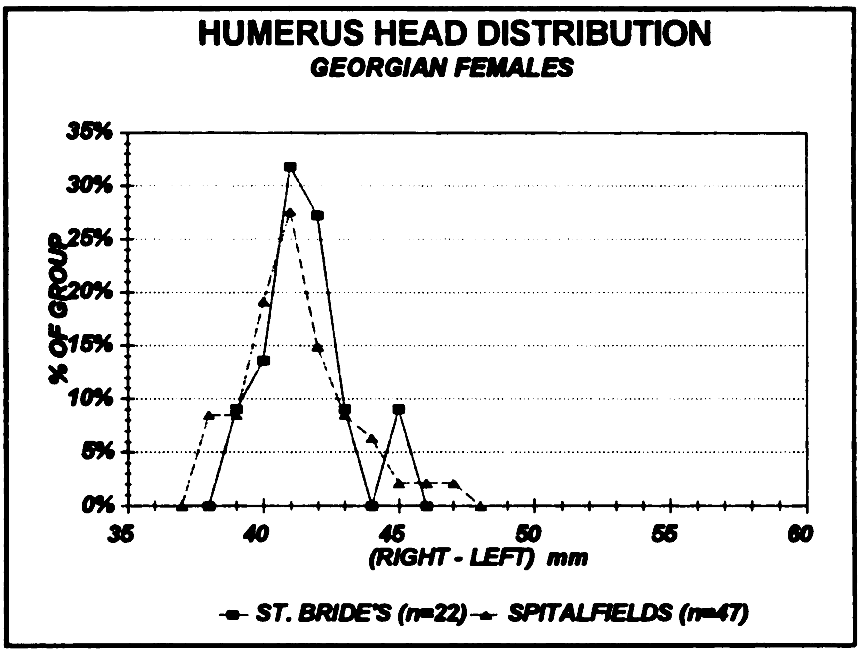

Figure 7 Humerus Head Distribution — Georgian Females

Summary statistics for the pooled Georgian males and females are compared with those of the Forensic Data Bank in Table 18. The average head diameter for Forensic Data Bank males is a statistically significant 2.2 mm larger than that of the pooled Georgian males ($z = 5.51$). For the females the mean difference in humerus head diameter is 1.7 mm, which is also significant ($z = 4.57$). The distribution patterns of male head diameter between the Forensic Data Bank and the pooled Georgians are offset by approximately two millimeters (Figure 8). For the Georgian females (Figure 9) the range of variation is quite narrow, with over fifty percent maintaining a diameter between 39 and 41 mm.

Table 18 Humerus Head Diameter Summary Statistics

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	46.9	40.9	49.1	42.6
SE	0.30	0.23	0.29	0.29
SD	2.38	1.88	2.57	2.18
.95 Confidence	0.59	0.44	0.56	0.56
N	63	69	80	58

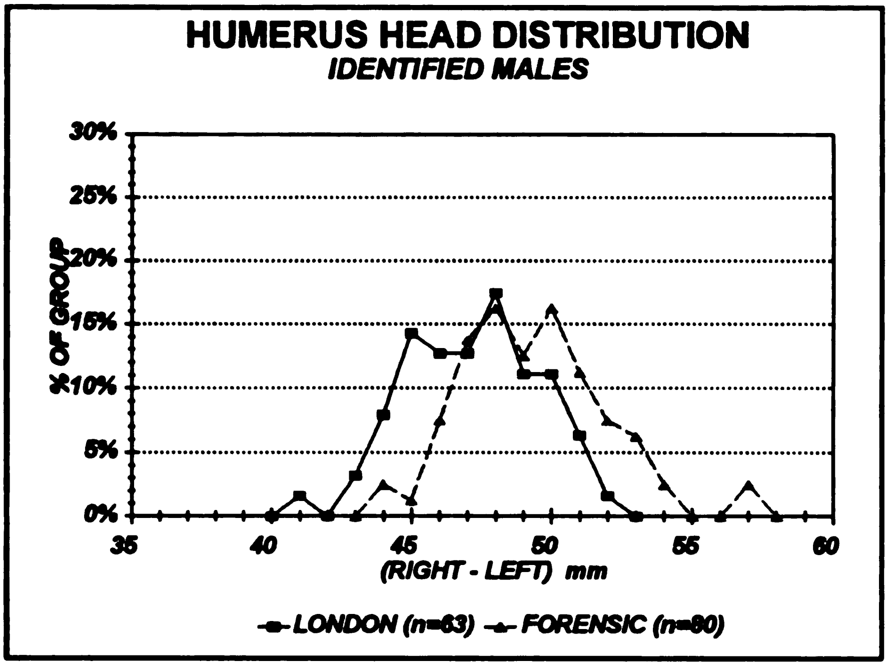

Figure 8 Humerus Head Distribution — Identified Males

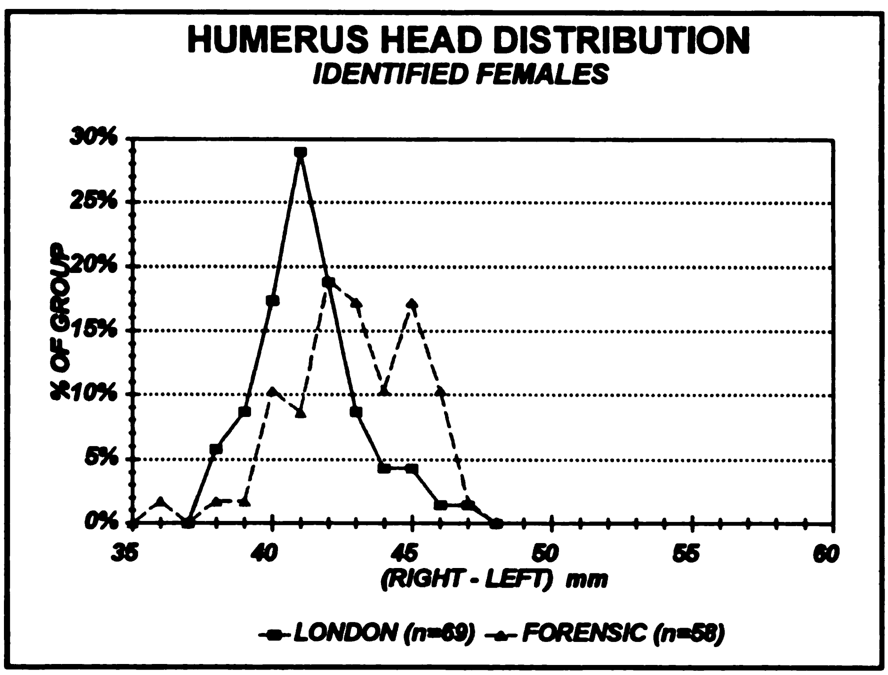

Figure 9 Humerus Head Distribution — Identified Females

Humerus Biepicondylar Width—HB

The biepicondylar width of the humerus has also been identified as a useful univariate characteristic for distinguishing between the sexes. Unlike the diameter of the humerus head, however, biepicondylar width is subject to modification in size and shape associated with the role of the epicondyles as points of attachment for muscles that flex the wrist and pronate the forearm. For this reason, it is expected that this measurement would manifest a greater range of variation within a sample.

Table 19 Georgian Humerus Biepicondylar Width Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	61.9	54.3	61.8	53.7
SE	0.50	0.48	0.63	0.52
SD	3.00	3.30	3.28	2.44
.95 Confidence	0.98	0.94	1.24	1.02
N	36	47	27	22

Statistics for humerus biepicondylar width in the Georgian groups are summarized in Table 19, and the distributions are graphically represented in Figures 10 and 11. In contrast with the humerus head diameter, the mean values of biepicondylar width are slightly higher in the Spitalfields sample than in their St. Bride's counterparts. In the case of the males, the difference of 0.1 mm is negligible ($t = .167$, $df = 53$, $p = .87$), as is the difference of 0.6 mm between the Georgian females ($t = .878$, $df = 54$, $p = .38$).

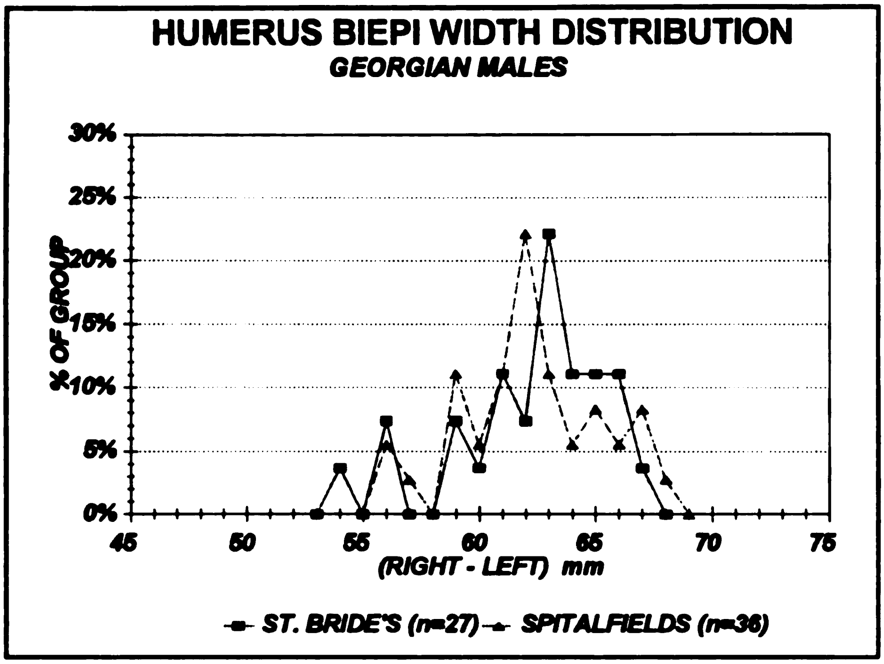

Figure 10 Humerus Biepi Distribution — Georgian Males

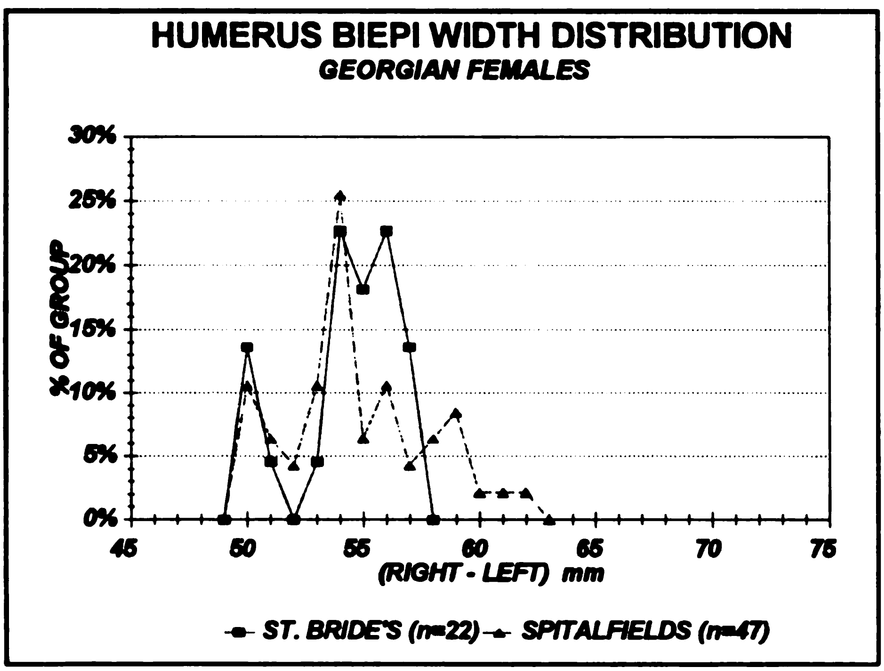

Figure 11 Humerus Biepi Distribution — Georgian Females

The differences between the sexes within the two Georgian groups are highly statistically significant, however (St. Bride's $t = 9.89$, $df = 47$, $p < .0001$; Spitalfields $t = 10.96$, $df = 79$, $p < .0001$). The difference between the sexes is also significant within the Forensic sample ($z = 18.66$).

Biepicondylar width statistics for the pooled Georgian males and females are shown in Table 20, as well as for the Forensic Data Bank males and females. The Forensic sample is relatively larger for both sexes, and the difference in means between the Georgians and the twentieth-century sample is statistically significant. Among the

Table 20 Humerus Biepicondylar Width Summary Statistics

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	61.9	54.1	64.8	55.7
SE	0.39	0.37	0.36	0.33
SD	3.10	3.04	3.20	2.52
.95 Confidence	0.77	0.72	0.70	0.65
N	63	69	80	58

males, the difference in the mean biepicondylar width is 2.9 mm ($z = 5.51$); among the females the difference between the means is 1.6 ($z = 3.15$, $p < .001$). These differences in distribution pattern are evident in Figures 12 and 13, as well. An intriguing similarity between the Georgian females is apparent in both the distribution polygons for humerus head diameter and biepicondylar width. That is the high unimodal peak of the distribution curve, which appears much less prominent in the Georgian males, the Forensic Data Bank males, and the Forensic Data Bank females.

In the St. Bride's sample, no female shows a width larger than 57 mm, although a few of the males have smaller biepicondylar width than that. There is slightly more overlap within the Spitalfields sample, with several of the females displaying a biepicondylar width greater than 57 mm. The distribution patterns of the Forensic Data Bank sample show a comparable pattern of overlap, but in this case the male and female distributions intersect at a value of approximately 60 mm.

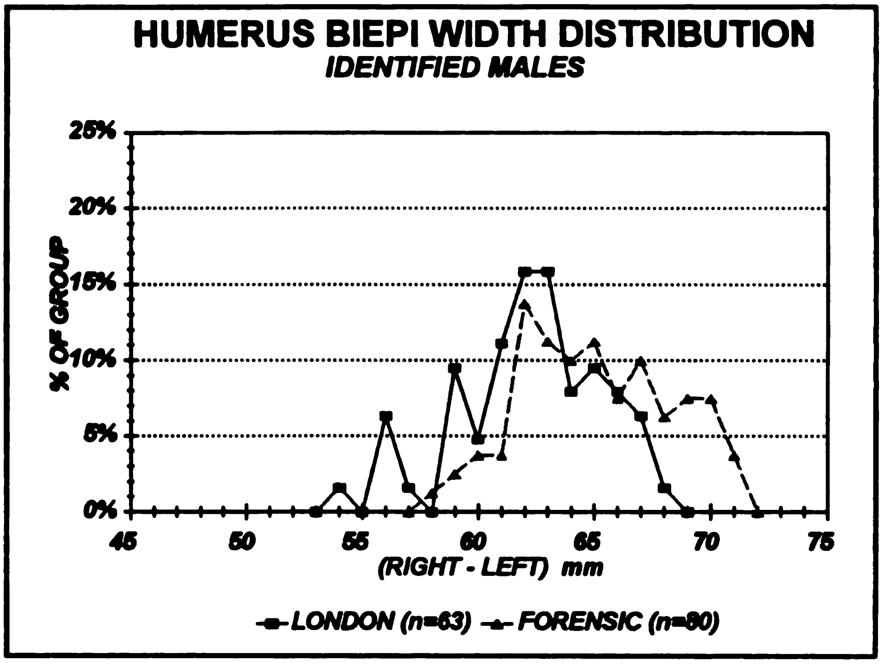

Figure 12 Humerus Biepi Distribution — Identified Males

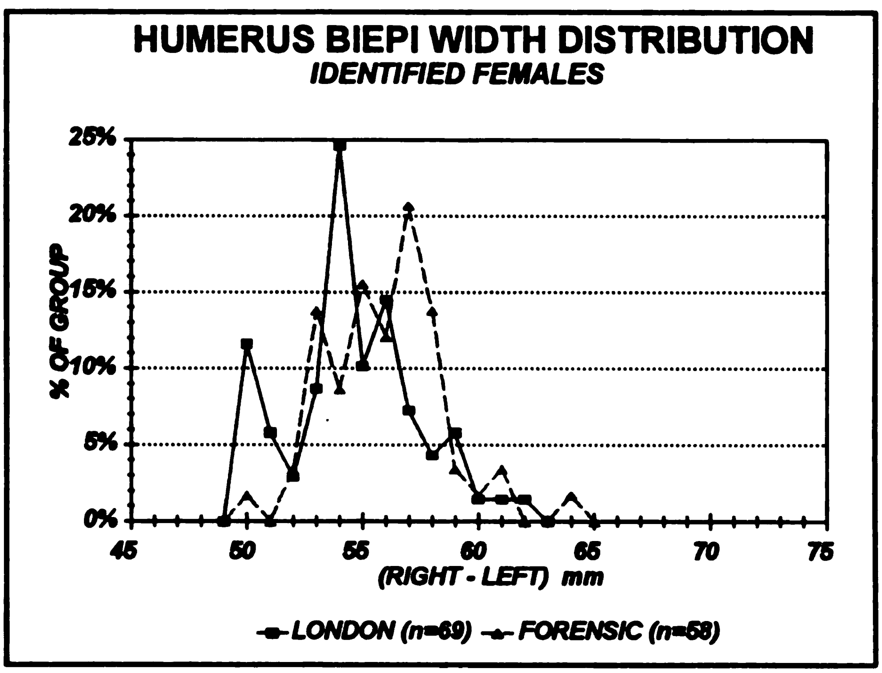

Figure 13 Humerus Biepi Distribution — Identified Females

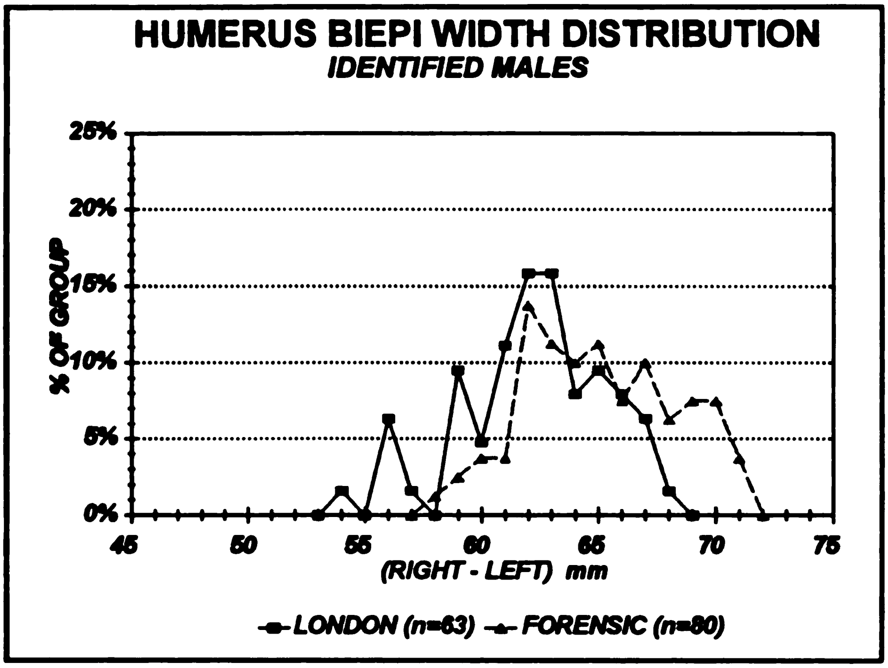

Figure 12 Humerus Biepi Distribution — Identified Males

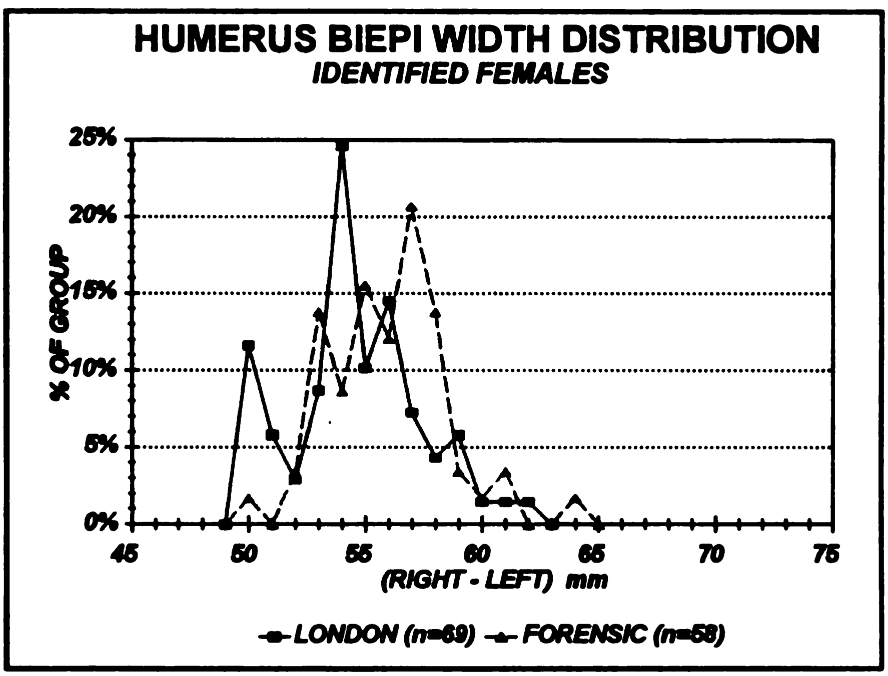

Figure 13 Humerus Biepi Distribution — Identified Females

Femur Length—FL

As was the case for the humerus, femur length assessments in this study reflect two series. The larger paired sample includes those femora for which maximum length measurements are available. The subset of that series for which biepicondylar width and head diameter measurements were also available is referred to as the intact sample.

Table 21 Paired Georgian Femur Length Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	447.1	408.7	455.3	412.1
SE	5.77	3.92	5.05	3.41
SD	24.49	22.54	30.30	20.16
.95 Confidence	11.31	7.69	9.90	6.68
N	18	33	36	35

Summary statistics for the maximum lengths of paired femora in the Georgian samples are listed in Table 21. On the basis of the total range of paired femora for which paired maximum lengths are available, the St. Bride's males (Figure 14) and females (Figure 15) appear to be somewhat larger than their Spitalfields counterparts, but the differences are not statistically significant (males $t = 1.07$, females $z = .646$). The differences between the sexes are substantially different, as expected (Spitalfields $t = 5.50$, $df = 33$, $p < .0001$; St. Bride's $t = 7.10$, $df = 61$, $p < .0001$).

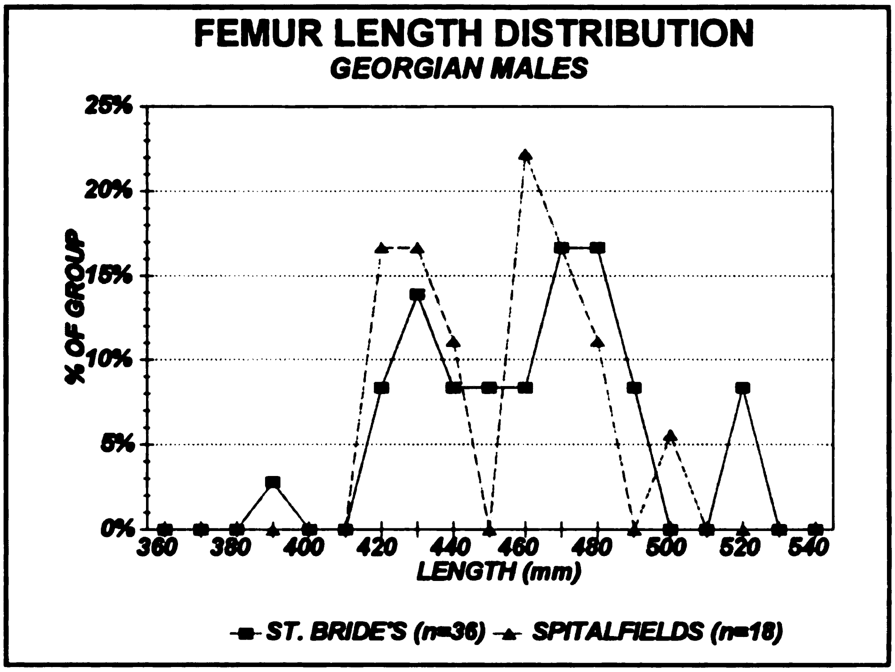

Figure 14 Femur Length Distribution — Georgian Males

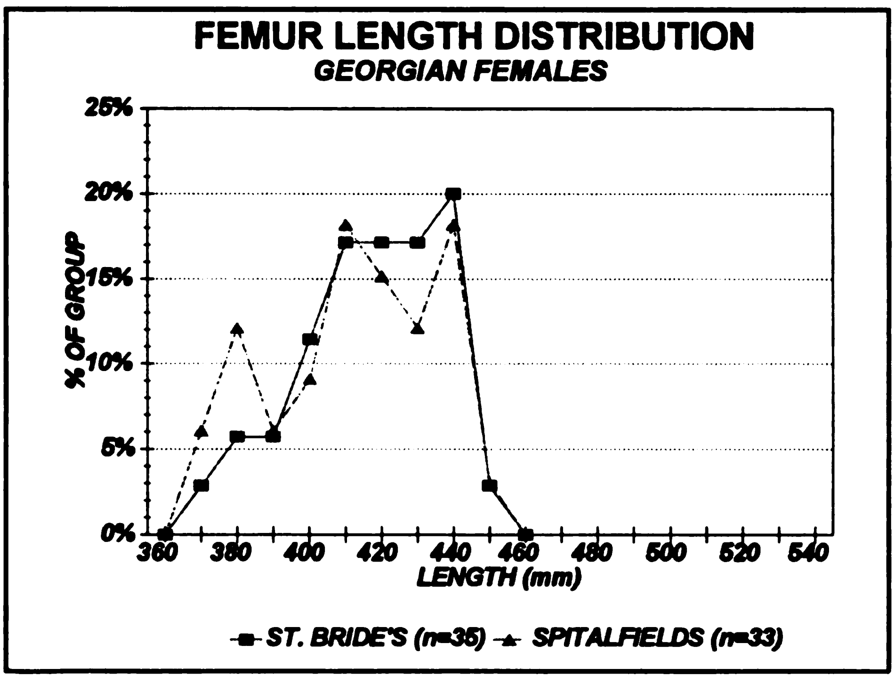

Figure 15 Femur Length Distribution — Georgian Females

Table 22 Intact Georgian Femur Length Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	446.7	411.9	447.8	410.9
SE	6.11	3.97	6.07	4.20
SD	25.18	20.63	29.75	18.29
.95 Confidence	11.97	7.76	11.90	8.22
N	17	27	24	19

As is the case with the humeri, a subset of intact femora was extracted from the paired femora data set. Table 22 partitions the intact femur length summary statistics between the Georgian samples. A comparison with the Figures for the paired femora shows a greater difference in two of the subgroups than was the case with the humeri. The Spitalfields females show a difference in mean femur length between the paired and intact samples of 3.2 mm. Although this is within the standard error of the mean calculated for the samples, it is twice the difference for either the St. Bride's females or the Spitalfields males. More remarkable is the difference of 7.5 mm between the mean length of paired and intact femora of the St. Bride's males. This figure is well in excess of the standard error of the mean that was calculated for either of the samples.

When the Georgian males and females are pooled for comparison of the paired and intact samples, the pattern is still evident (Table 23). It is notable that, for the males, the intact femora show a smaller mean length than the paired femora. This is the opposite of what one might expect if the expectation is that larger bones are more likely to survive intact than smaller bones. The pattern is reversed for the females, but the magnitude of difference in mean femur lengths is quite small in contrast with that of the males.

Table 23 Georgian Femur Length Summary Statistics

	Paired ♂	Paired ♀	Intact ♂	Intact ♀
Mean	452.6	410.5	447.4	411.5
SE	3.88	2.58	4.31	2.87
SD	28.53	21.25	27.62	19.5
.95 Confidence	7.61	5.05	8.45	5.63
N	54	68	41	46

Summary statistics of femur length for the paired and intact femora of the Forensic Data Bank sample are listed in Table 24. Unlike the Georgians, the Forensic Data Bank samples show consistency between mean femur lengths in the paired and intact samples. When the Georgian males are pooled, they display a significantly smaller femur length than the Forensic Data Bank males ($z = 4.61$)(Figure 16).

There is also a distinct pattern of bimodality in the femur length distributions of the Georgian males which is not evident in the Forensic sample. That is, there are two distinct and roughly equivalent peaks separated by at least two measurement intervals; this suggests that the apparent pattern reflects an underlying bimodal distribution and is not simply an artifact of how observations are placed into interval categories. The

Table 24 Forensic Data Bank Femur Length Summary Statistics

	Paired ♂	**Paired ♀**	**Intact ♂**	**Intact ♀**
Mean	473.9	437.5	473.9	437.6
SE	2.50	2.59	2.76	2.67
SD	24.09	20.85	25.00	20.35
.95 Confidence	4.90	5.07	5.41	5.24
N	93	65	82	58

difference in lengths between the 18th and 20th century samples are also evident for the females (Figure 17), but the distribution patterns for the two groups are clearly unimodal.

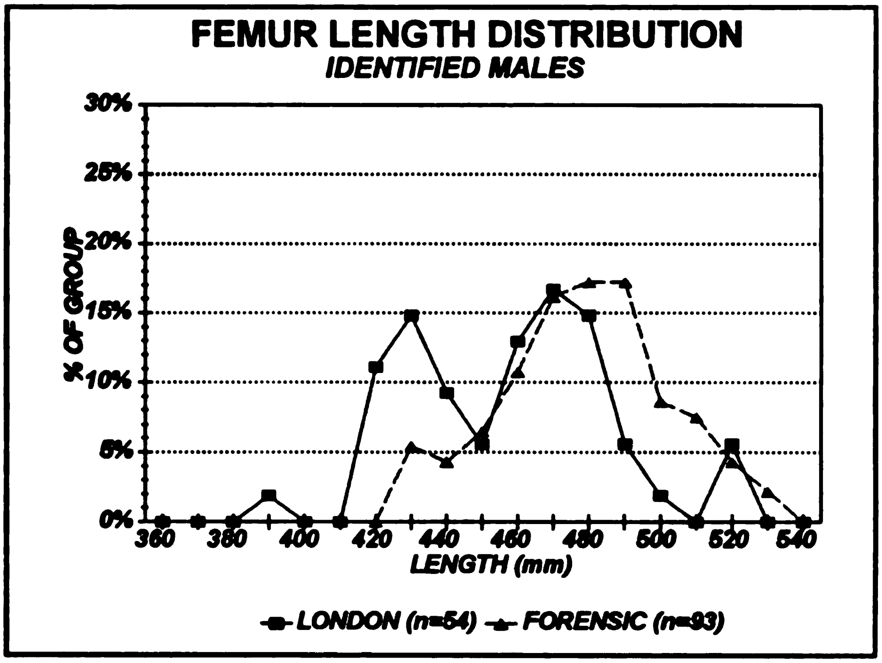

Figure 16 Femur Length Distribution — Identified Maloes

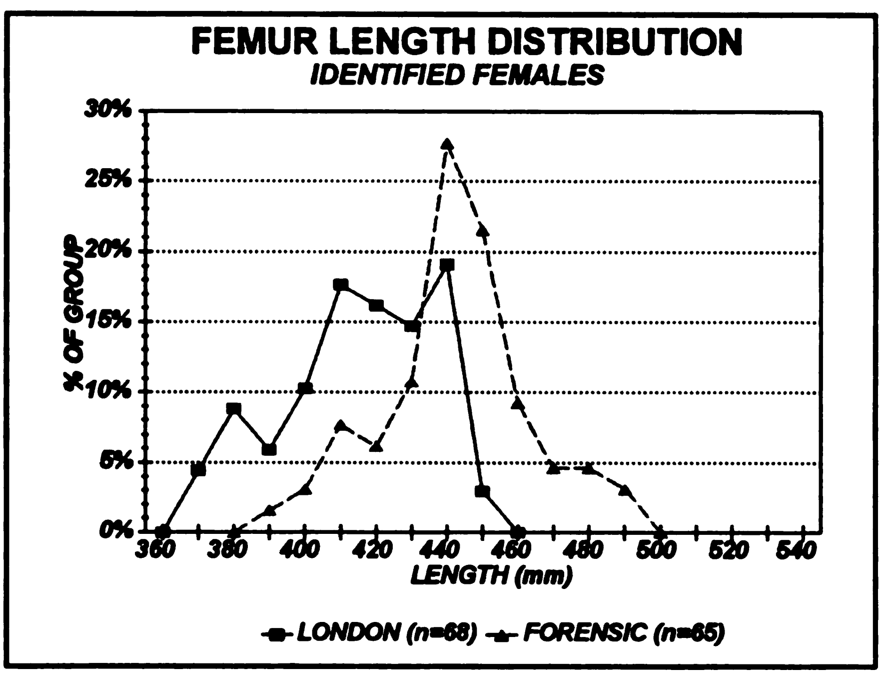

Figure 17 Femur Length Distribution — Identified Females

Femur Head Diameter—FH

Table 25 Georgian Femur Head Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	48.0	41.8	46.8	41.5
SE	0.74	0.51	0.58	0.52
SD	3.06	2.67	2.84	2.29
.95 Confidence	1.46	1.01	1.14	1.03
N	17	27	24	19

It is interesting to note that while the St. Bride's males and females presented a larger mean femur length than their counterparts from Spitalfields, the pattern is reversed for the diameter of the femoral head (Table 25). The differences, however, are not statistically significant (males $t = 1.31$, $df = 33$, $p = .198$; females $t = .377$, $df = 42$, $p = .708$). When the differences are presented graphically, the males from Spitalfields display a modal value (50 mm) which is three millimeters greater than that of the St. Bride's males (47 mm) (Figure 18). In contrast, the St. Bride's females display a mode (44 mm) which is only one millimeter greater than their Spitalfields counterparts (Figure 19).

There are, however, statistically significant differences between the sexes in all three of the study samples. This is not surprising, given the popularity of femoral head diameter as a univariate technique for determining sex from skeletal material (Spitalfields $t = 6.90$, $df = 31$, $p < .0001$; St. Bride's $t = 6.74$, $df = 41$, $p < .0001$; Forensic $z = 17.30$).

Table 26 Femur Head Diameter Summary Statistics

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	47.3	41.7	48.9	42.5
SE	0.46	0.37	0.28	0.25
SD	2.96	2.50	2.52	1.91
.95 Confidence	0.91	0.72	0.55	0.49
N	41	46	82	58

When the pooled Georgian males and females are compared with the modern sample of the Forensic Data Bank, there are marked differences in mean femur head diameter (Table 26). The average head diameter for the Georgian males is a statistically significant 1.5 mm less than that of the Forensic Data Bank ($z = 3.015, p < .005$); the difference between the Georgian and Forensic females is less than one millimeter, but still significant ($z = 1.740, p < .05$). The apparent bimodal distribution that was present in the Georgian males femur length distributions also appears in their femur head distribution, again in contrast with the Forensic sample (Figure 20). For the females, the distribution patterns of the Georgians and the modern group are similar (Figure 21).

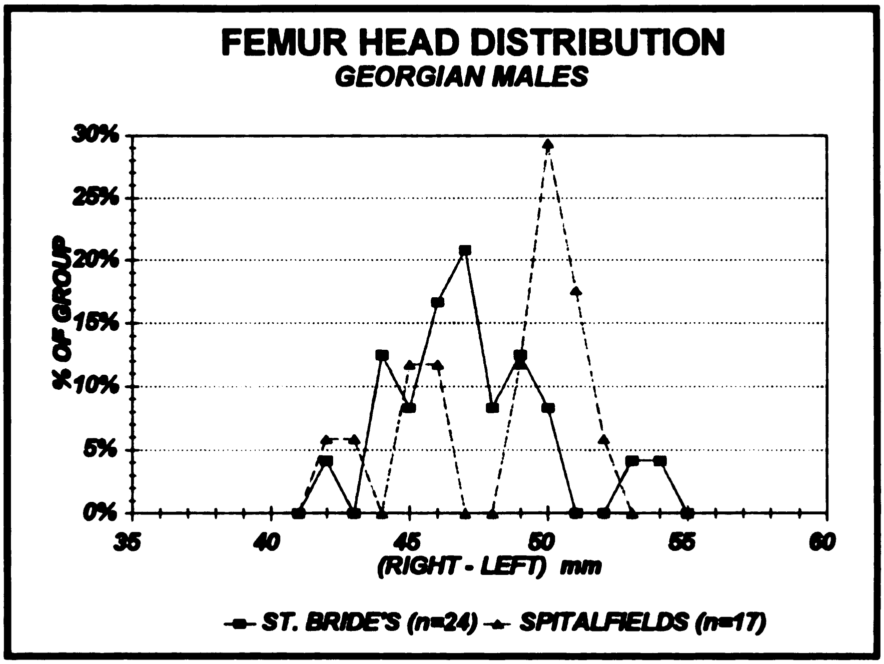

Figure 18 Femur Head Distribution — Georgian Males

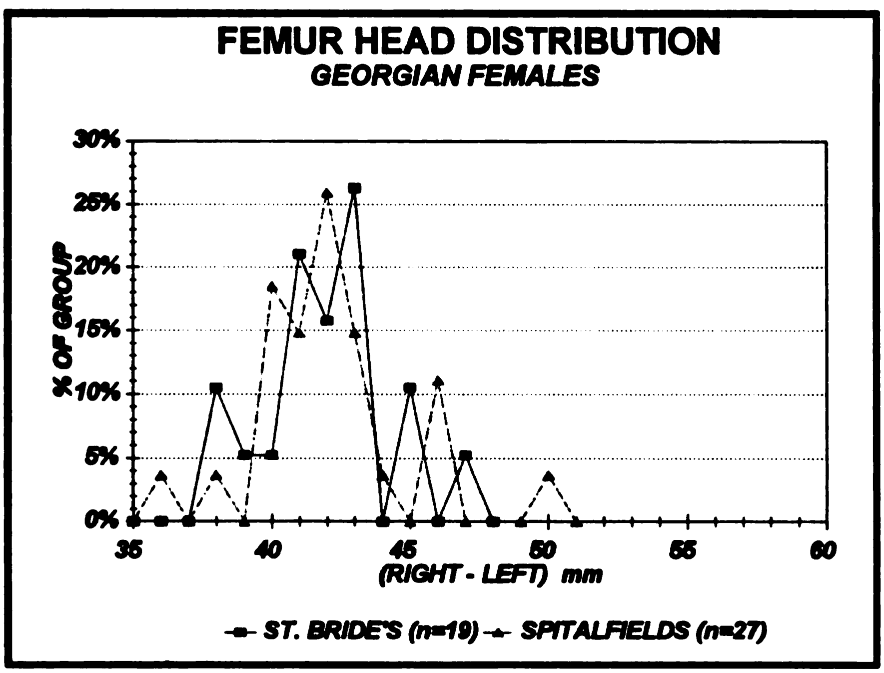

Figure 19 Femur Head Distribution — Georgian Females

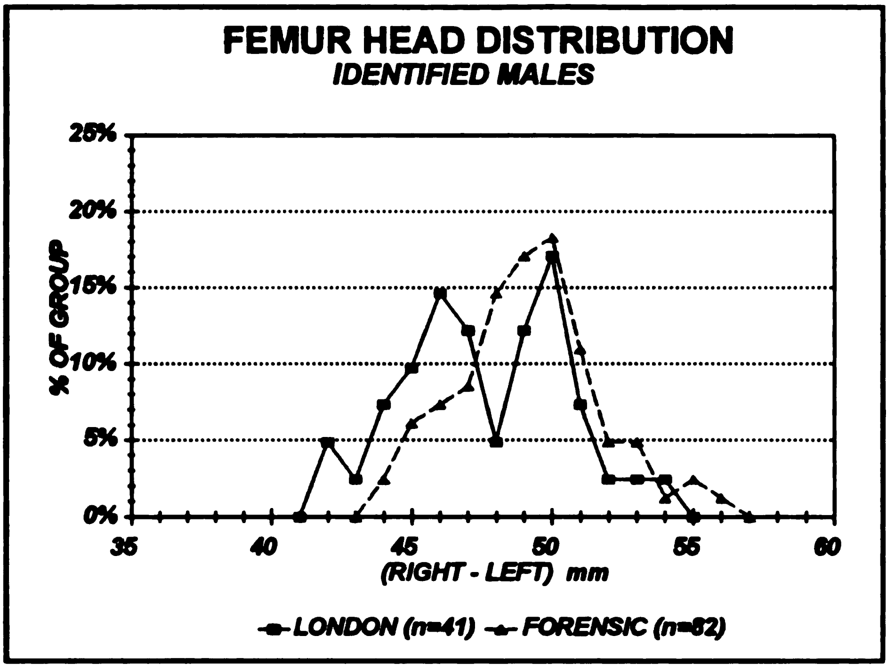

Figure 20 Femur Head Distribution — Identified Males

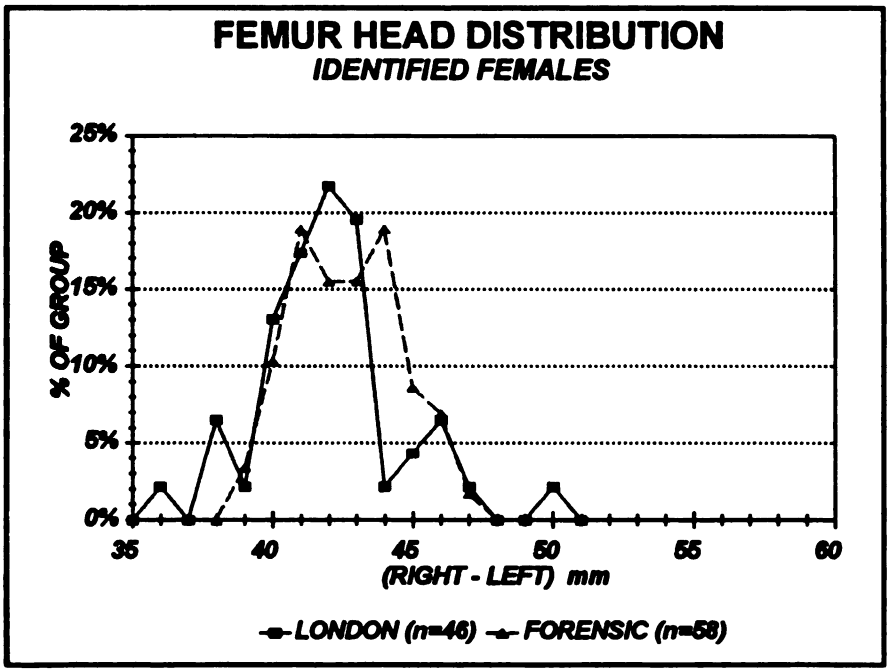

Figure 21 Femur Head Distribution — Identified Females

Femur Biepicondylar Width—FB

Because the epicondyles of the femur are the sites of attachment for ligaments rather than tendons, they are less likely to display osteophytic projections that would corrupt measurements. However, in the Georgian skeletal collections a large number of individuals suffered from disintegration of the distal ends of the femur that rendered them unsuitable for measurement. This contributed to a profound reduction in the number of intact paired femora available for observation.

Table 27 Georgian Femur Biepicondylar Width Summary Statistics

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	80.9	72.5	80.8	73.2
SE	0.84	0.75	0.98	0.77
SD	3.47	3.90	4.78	3.35
.95 Confidence	1.65	1.47	1.91	1.51
N	17	27	24	19

Unlike the case with femoral head diameter, the biepicondylar width of the femur differs very little between the males of St. Bride's and Spitalfields (Table 27). When the distributions are presented graphically, the shapes of the patterns differ significantly from the relatively unimodal (or bimodal) distributions of the bone length and head diameter. Particularly in the case of the males, there is a broad pattern of variation in biepicondylar width (Figure 22). In contrast, the females display patterns of bimodality (Figure 23).

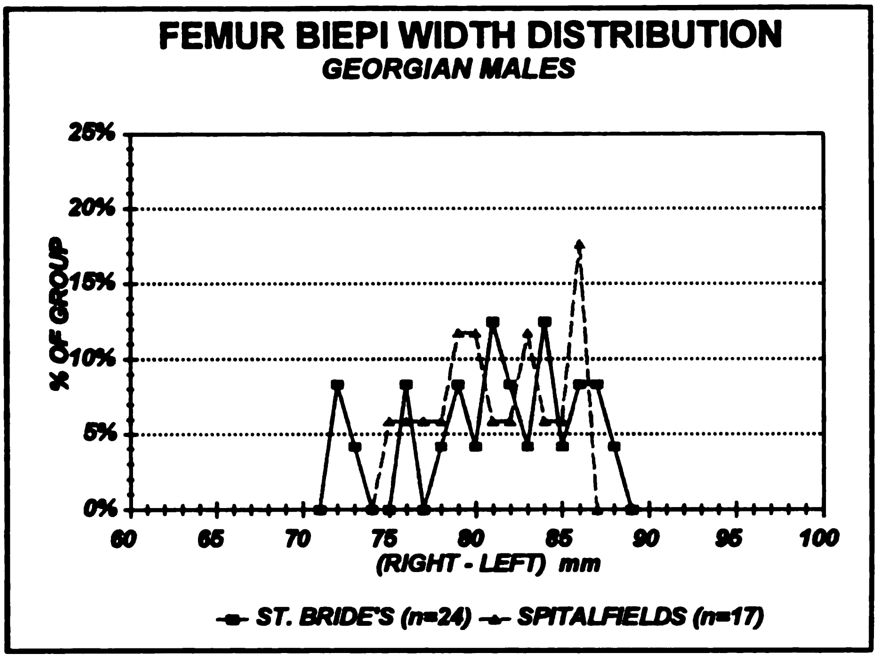

Figure 22 Femur Biepi Width Distribution -- Georgian Males

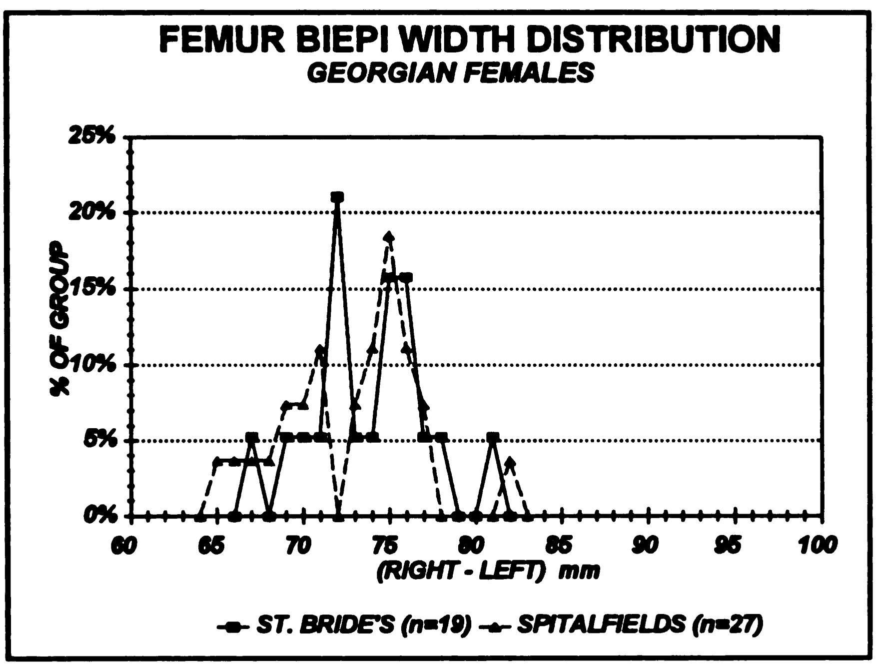

Figure 23 Femur Biepi Width Distribution -- Georgian Females

As was the case for the diameter of the femoral head, biepicondylar widths manifest a statistically significant difference between the sexes in each of the study samples (Spitalfields $t = 7.45$, $df = 37$, $p < .0001$; St. Bride's $t = 6.08$, $df = 40$, $p < .0001$; Forensic $z = 15.79$).

Table 28 Femur Biepicondylar Width Summary Statistics

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	80.8	72.8	85.7	75.0
SE	0.66	0.54	0.51	0.45
SD	4.24	3.66	4.60	3.39
.95 Confidence	1.30	1.06	1.00	0.87
N	41	46	82	58

Although the males of the two Georgian groups are very similar with respect to their mean biepicondylar widths, Table 28 and Figure 24 show that when they are pooled they contrast markedly with the males in the Forensic Data Bank sample. The difference is statistically significant ($z = 5.83$). The same is true for the females (Figure25) ($z = 3.198$, $p < .001$).

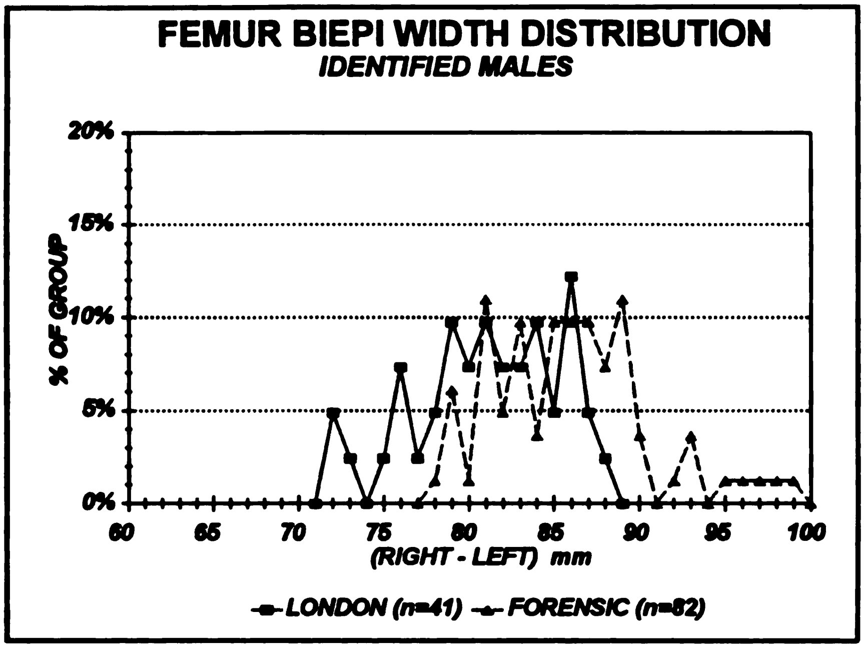

Figure 24 Femur Biepi Width Distribution -- Identified Males

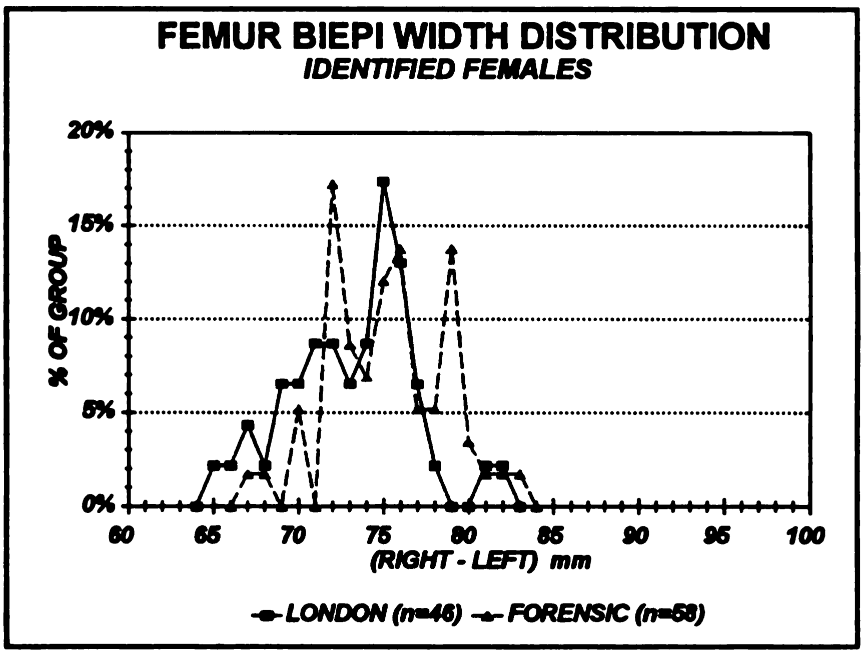

Figure 25 Femur Biepi Width Distribution -- Identified Females

Summary

The distribution patterns for each of the six individual measurements indicate that there is a very clear difference in means between the sexes of all three groups. However, the St. Bride's males and females display a notably greater mean femur length than their Spitalfields counterparts, although the male/female distinction was still clearly evident between the samples. For all six of the measurements, the pooled Georgians differ considerably from the Forensic Data Bank figures, with the latter individuals considerably larger. Again the magnitude of the differences appear to be fairly consistent among the males and among the females.

For both the humeri and femora, the more well-preserved intact Georgian samples did not show a greater mean length than the less well preserved paired samples. In the humeri the difference between the two samples was negligible, and for the femora the

Table 29 Summary: Differences in Humerus Size Distribution Patterns

	Maximum Length		**Vertical Head Diameter**		**Biepicondylar Width**	
	z	*p*	*z/t**	*p*	*z/t**	*p*
Georgian ♂	.109	—	.061	—	.167	—
Georgian ♀	1.71	<.05	.197*	—	.878*	—
Spitalfields ♂ / ♀	7.44	<.0001	12.1*	<.0001	11.0*	<.0001
St. Bride's ♂ / ♀	9.75	<.0001	10.5*	<.0001	9.89*	<.0001
Forensic ♂ / ♀	10.4	<.0001	16.2	<.0001	18.7	<.0001
Georgian / Forensic ♂	4.73	<.0001	5.51	<.0001	5.51	<.0001
Georgian / Forensic ♀	6.13	<.0001	4.57	<.0001	3.15	<.001

paired samples were slightly longer. This is not consistent with the idea that larger (and supposedly more robust) bones are better preserved than smaller bones.

Table 30 Summary: Differences in Femur Size Distribution Patterns

	Maximum Length		**Head Diameter**		**Biepicondylar Width**	
	*z/t**	*p*	*z/t**	*p*	*z/t**	*p*
Georgian ♂	1.07*	—	1.31*	—	.080*	—
Georgian ♀	.646	—	.377*	—	.695*	—
Spitalfields ♂ / ♀	5.50*	<.0001	6.90*	<.0001	7.45*	<.0001
St. Bride's ♂ / ♀	7.10	<.0001	6.74*	<.0001	6.08*	<.0001
Forensic ♂ / ♀	10.1	<.0001	17.3	<.0001	15.8	<.0001
Georgian / Forensic ♂	4.61	<.0001	3.02	<.005	5.83	<.0001
Georgian / Forensic ♀	7.41	<.0001	1.74	<.05	3.20	<.001

ASYMMETRY DIRECTION

Results of assessments of asymmetry direction are summarized in a series of Tables in this section. Each Table partitions asymmetry into one of three nominal categories: left-dominant (represented by "L" in the Table), symmetrical (represented by "O" in the Table), and right-dominant (represented by "R" in the Table). Following the same presentation strategy as the previous section, the four Georgian subgroups are listed in one Table, followed by a listing of the pooled Georgians in contrast with the Forensic data. The chi-square (χ^2) statistic is used to test the statistical probability of independence of the subgroups.

Humerus Length—HL

Direction of humerus length was assessed on the basis of two thresholds of difference. In the first case, paired bones were considered symmetrical if the magnitude of their differences was coded as less than one millimeter. In the second case, they were considered symmetrical if the difference in magnitude was coded as less than two millimeters.

Figures 26 through 33 display the effects of shifting the threshold for symmetry in the study samples. In each Figure, the X-axis represents the assessment of asymmetry: left-dominant (L), symmetrical (O), or right-dominant (R). Two series are plotted; the solid series represents the number of individuals who display each dominance pattern with a one-millimeter threshold, and the hashed series represents the number who manifest the pattern with a two-millimeter threshold.

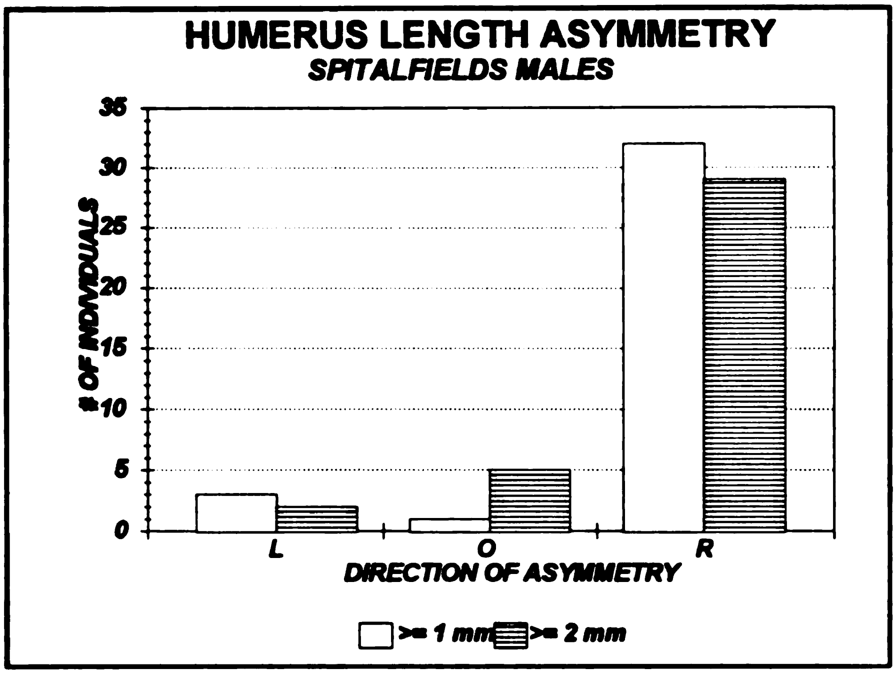

Figure 26 Humerus Asymmetry Direction -- Spitalfields Males

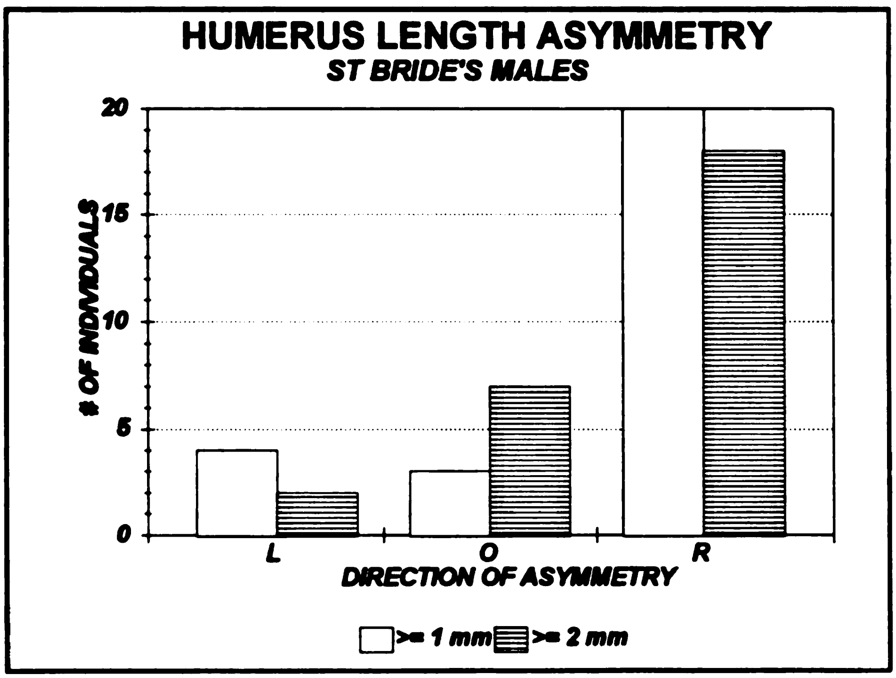

Figure 27 Humerus Asymmetry Direction -- St. Bride's Males

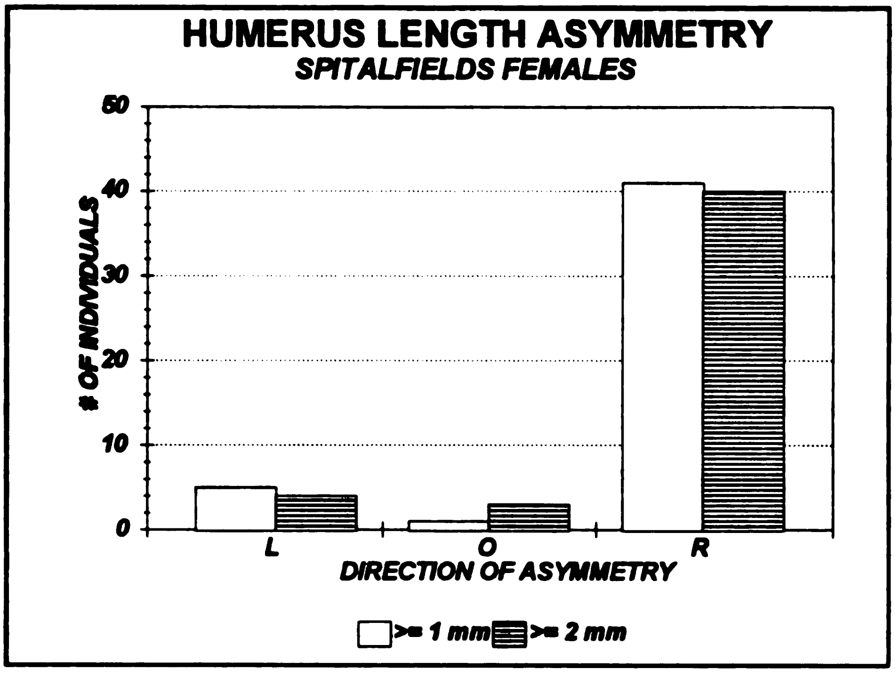

Figure 28 Humerus Asymmetry Direction -- Spitalfields Females

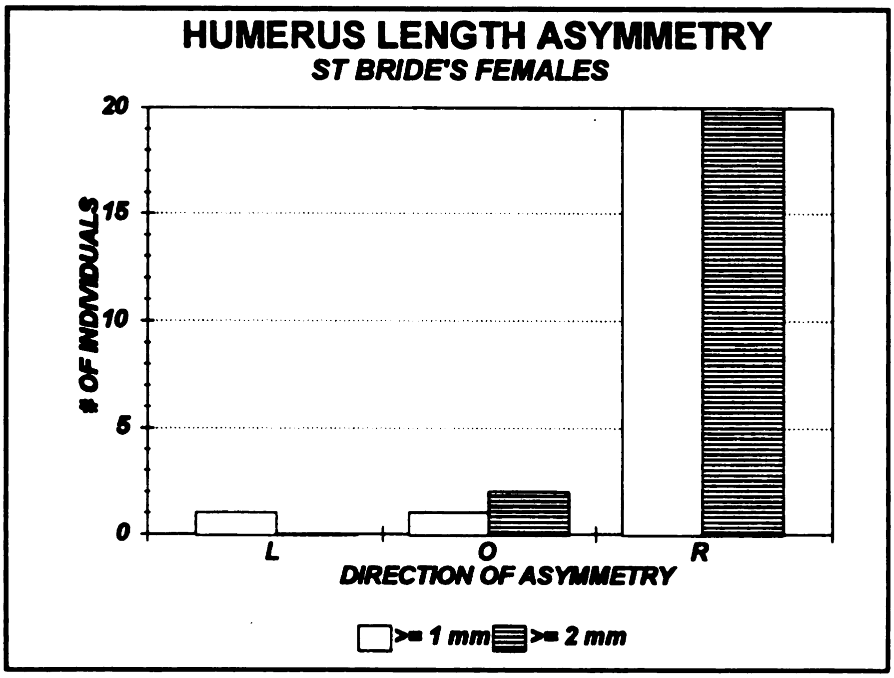

Figure 29 Humerus Asymmetry Direction -- St. Bride's Females

In all cases, a number of individuals shift from the left-dominant and right-dominant categories to the symmetrical category in the second series. The extent of the shift varies, however, depending on the magnitude of asymmetry in the series.

Figures 26 and 27 contrast the relationship between the two thresholds for Georgian males. One of the Spitalfields males shifts from left-dominant to symmetrical, and three shift from right-dominant to symmetrical. In the St. Bride's males, two left-dominants shift to the center, and two right-dominants shift to the center. The pattern is even more pronounced among the Georgian females. Of the 47 Spitalfields females, only one right-dominant and one left-dominant pair are shifted to the symmetrical category (Figure 28). Of the 22 St. Bride's females, only the single left-dominant pair is absorbed with the increased threshold (Figure 29).

Because the Georgian males are similar in their asymmetry patterns, when they are pooled their patterns do not appear to vary greatly (Figure 30); the same is true for the females (Figure 31). However, the Georgians contrast markedly with their counterparts from the Forensic sample. Among the Forensic males, nine make the shift from left-dominant and nine make the shift from right-dominant to symmetrical (Figure 32). Among the females, three shift from left-dominant to symmetrical, and five shift from right-dominant to symmetrical (Figure 33).

Table 31 contrasts the four Georgian subgroups under the one-millimeter threshold. The overall right-dominance in humerus length is striking, particularly in the females. The St. Bride's males are the only one of the subgroups with less than 75% of the individuals right-dominant in humerus length. There are no statistically significant differences in asymmetry direction among any of the Georgian subsamples.

Table 31 Georgian Humerus Length Asymmetry Direction (≥ 1 mm)

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	3	8.3%	5	10.6%	4	14.8%	1	4.5%
O	1	2.8%	1	2.1%	3	11.1%	1	4.5%
R	32	88.9%	41	87.2%	20	74.1%	20	91.0%
T	36		47		27		22	

Table 32 Combined Humerus Length Asymmetry Direction (≥ 1 mm)

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	7	11.1%	6	8.7%	29	36.3%	11	19.0%
O	4	6.3%	2	2.9%	12	15.0%	9	15.5%
R	52	82.5%	61	88.4%	39	48.8%	38	65.5%
T	63		69		80		58	

When the Georgian samples are pooled and compared with the figures from the Forensic Data Bank, a significant contrast becomes apparent: the latter individuals are less side-dominant (Table 32). Fewer than 50% of the males from the Forensic Data Bank sample are right-dominant, and only 65.5% of the females are right-dominant. Likewise, the percentage of left-dominant individuals in the Forensic Data Bank samples are substantially higher than is the case with the Georgians. The differences between the Georgian and Forensic males are statistically significant ($\chi^2 = 17.53$, p <0.001); the same is true for the relationship between the Georgian and Forensic females ($\chi^2 = 10.39$, $p < .01$).

Table 33 Georgian Humerus Length Asymmetry Direction (≥ 2 mm)

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	2	5.6%	4	8.5%	2	7.4%	0	0.0%
O	5	13.9%	3	6.4%	7	25.9%	2	9.0%
R	29	80.6%	40	85.1%	18	66.7%	20	91.0%
T	36		47		27		22	

The revised figures for the Georgian samples under the two-millimeter threshold are found in Table 33. As expected, with the larger threshold there is a net shift in the number of individuals who are asymmetrical into the symmetrical category. Reduction in the apparent right-dominance is slight; in all but the St. Bride's males more than 80% of the individuals still show right-dominance with the higher threshold. Under the revised threshold there is still no statistically significant difference in humerus length asymmetry direction between any of the Georgian subgroups.

When the pooled Georgians are compared with the Forensic Data Bank individuals under the more revised threshold, the strong contrasts between the two groups persist (Table 34). Although there is still a net right-dominance pattern in all of the subgroups, the Forensic Data Bank males in particular display relatively little side-dominance in asymmetry direction.

Table 34 Combined Humerus Length Asymmetry Direction (≥ 2 mm)

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	4	6.3%	4	5.8%	20	25.0%	8	13.8%
O	12	19.0%	5	7.2%	30	37.5%	17	29.3%
R	47	74.6%	60	87.0%	30	37.5%	33	56.9%
T	63		69		80		58	

Because there is relatively less directionality in the Forensic sample, increasing the symmetry threshold to two millimeters has an effect of increasing the χ^2 values when they are compared with the Georgians; there is a concomitant increase in the calculated probability that the two samples are independent. Using the figures in Table 35 the χ^2 for Georgian and Forensic males is increased to 20.40 ($p < .0001$); for the females the χ^2 is increased to 14.88 ($p < .001$). The implications of a shift in direction-of-asymmetry patterns are discussed more fully in Chapter 6.

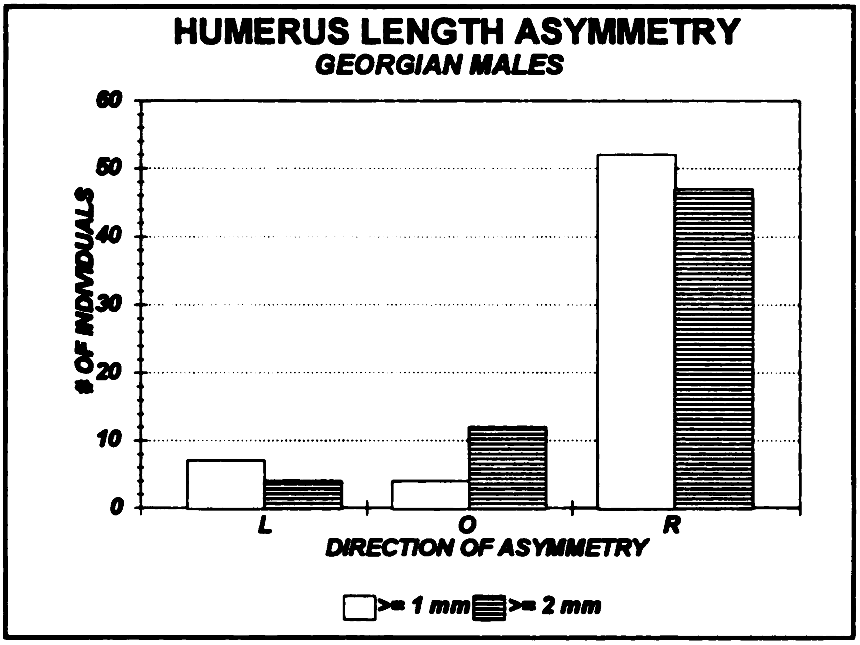

Figure 30 Humerus Asymmetry Direction -- Georgian Males

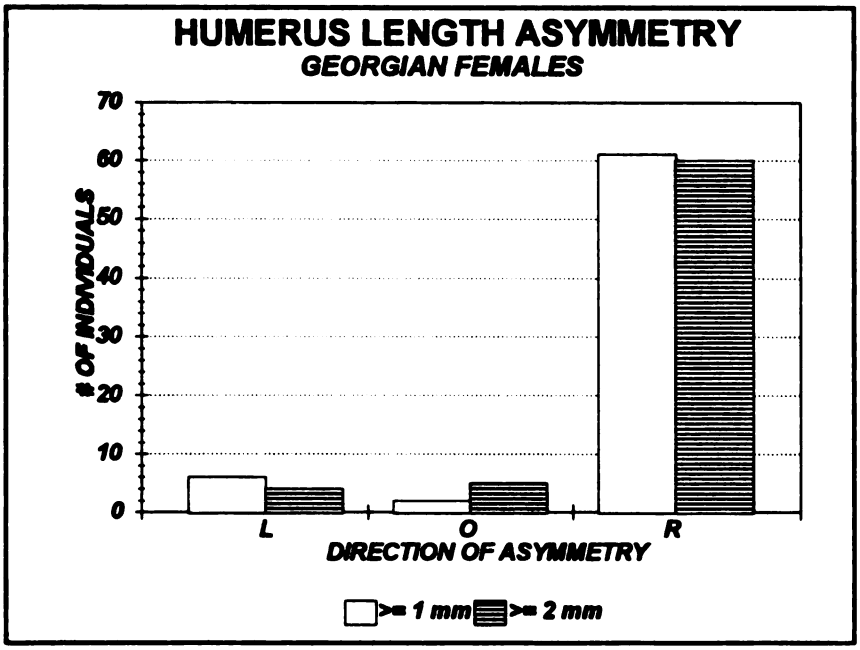

Figure 31 Humerus Asymmetry Direction -- Georgian Females

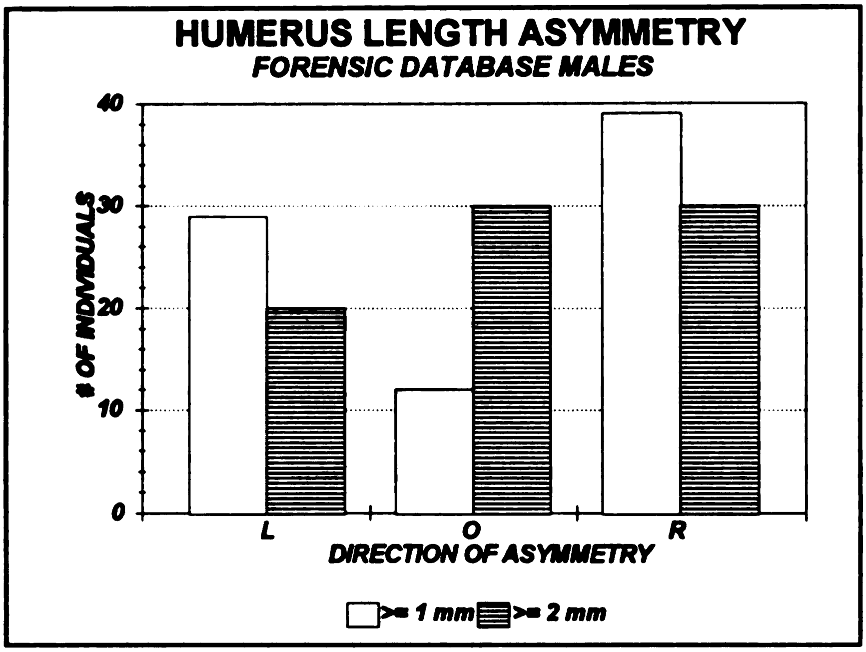

Figure 32 Humerus Asymmetry Direction -- Forensic Males

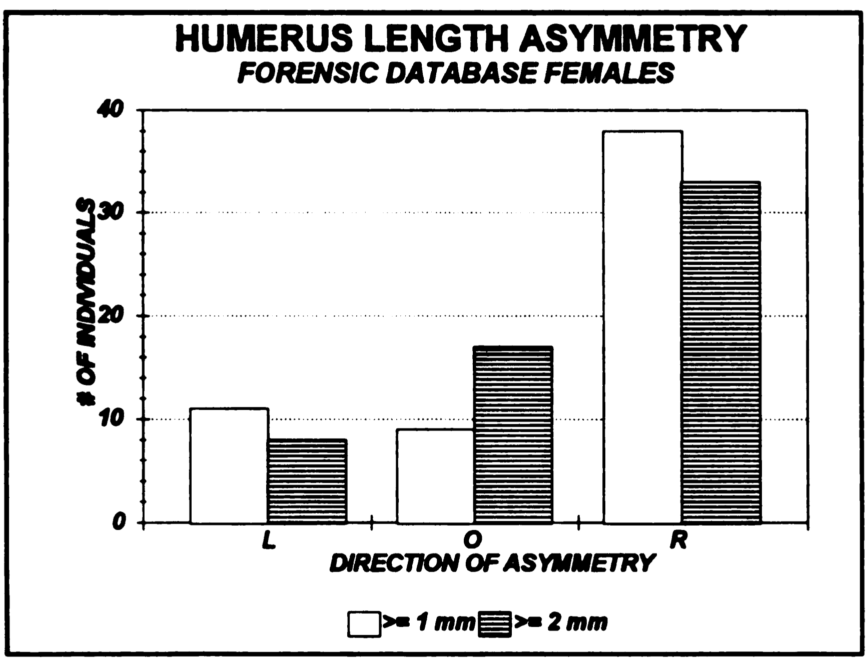

Figure 33 Humerus Asymmetry Direction -- Forensic Females

Humerus Head Diameter—HH

Because the head of the humerus is relatively small in size, a one-millimeter difference in size between paired heads represents a fairly large amount of asymmetry. Therefore, in contrast with humerus length it would be expected that more individuals in each of the study samples would fall into the symmetrical category. The striking pattern for the Georgians is that the differences appear to be greater between the groups, rather than between the sexes. That is, head diameter is more symmetrical among the St. Bride's sample than the Spitalfields sample. For the females the difference in pattern is statistically significant ($\chi^2 = 7.026$, $p < .05$).

Table 35 Georgian Humerus Head Asymmetry Direction

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	5	13.9%	5	10.6%	2	7.4%	3	13.6%
O	16	44.4%	23	48.9%	18	66.7%	17	77.3%
R	15	41.7%	19	40.4%	7	25.9%	2	9.1%
T	36		47		27		22	

When the Georgian males and females are pooled, they appear to display similar patterns in direction of head diameter asymmetry. Just as there is little gender-related difference in humerus head diameter among the pooled Georgians, there is also little difference between the males and the females of the Forensic Data Bank sample (Table 36). Again, the trend suggests that population rather than sex trend appears when the Georgians are compared with the Forensic sample, but none of the differences are statistically significant. Specifically, the latter group displays double the prevalence of

Table 36 Combined Humerus Head Asymmetry Direction

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	7	11.1%	8	11.6%	18	22.5%	14	24.1%
O	34	54.0%	40	58.0%	35	43.8%	28	48.3%
R	22	34.9%	21	30.4%	27	33.8%	16	27.6%
T	63		69		80		58	

left-dominance than the former. This finding is consistent with the asymmetry patterns which appeared in the length of the humeri. The contrast in these patterns point to the one of the conundrums of asymmetry assessment. In the sense that a larger percentage of the Georgians fall into the symmetrical category, it can be asserted that they are more symmetrical than the modern sample. However, because the extent of directionality in asymmetry patterns is so much greater for the Georgians, it can also be said that the Forensic Data Bank sample appears more symmetrical than the Georgians.

Humerus Biepicondylar Width—HB

As is the case with head diameter, biepicondylar width of the humerus displays a compelling population-related pattern among the Georgians (Table 37). The males and females of the St. Bride's display a similar pattern of variation in asymmetry direction, with nearly 50% of the group showing a symmetrical pattern. In contrast, the Spitalfields males and females display greater levels of asymmetry. (The differences are not quite statistically significant at the $p < .05$ level. For the males, $\chi^2 = 5.89, p \approx .0526$; for the females $\chi^2 = 4.70, p \approx .0952$.)

Table 37 Georgian Humerus Biepicondylar Width Asymmetry Direction

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	9	25.0%	11	23.4%	4	14.8%	3	13.6%
O	7	19.4%	13	27.7%	13	48.1%	12	54.5%
R	20	55.6%	23	48.9%	10	37.0%	7	31.8%
T	36		47		27		22	

When the Georgian males and Georgian females are pooled, they appear to display comparable patterns of asymmetry (Table 38). However, in this case the Georgian and modern Forensic samples are very similar in asymmetry direction patterns, with no differences approaching statistical significance. This is a notable contrast with the pattern for either humerus length or head diameter.

Table 38 Humerus Biepicondylar Width Asymmetry Direction

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	13	20.6%	14	20.3%	21	26.3%	8	13.8%
O	20	31.7%	25	36.2%	23	28.8%	17	29.3%
R	30	47.6%	30	43.5%	36	45.0%	33	56.9%
T	63		69		80		58	

Femur Length—FL

As was the case with humerus length, direction of asymmetry patterns in femur lengths are assessed using both a 1 mm and a 2 mm threshold. Because the femora, in general, display a left-dominant pattern in length that is smaller in magnitude than the patterns for humeri, shifting the threshold for labeling asymmetry results in a considerable reduction in the number of individuals who are asymmetric. Table 39 describes how asymmetry direction patterns differ for the Georgian subgroups.

Table 39 Georgian Femur Length Asymmetry Direction (≥ 1 mm)

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	10	58.8%	15	55.6%	15	62.5%	6	31.6%
O	1	5.9%	4	14.8%	1	4.2%	6	31.6%
R	6	35.3%	8	29.6%	8	33.3%	7	36.8%
T	17		27		24		19	

As has been reported by other researchers, there is a general pattern of left-dominance in femur length asymmetry, but the pattern is much less one-sided than in the humerus. The St. Bride's females are the only subgroup for which there is a slight pattern of right dominance which results in a statistically significant contrast with the St. Bride's males ($\chi^2 = 7.01, p < .05$).

The pooled Georgians do not display a significantly different pattern of asymmetry direction than the Forensic sample (Table 40). The contrast between the

Table 40 Combined Femur Length Asymmetry Direction (≥ 1 mm)

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	25	61.0%	21	45.7%	43	52.4%	33	56.9%
O	2	4.9%	10	21.7%	8	9.8%	4	6.9%
R	14	34.1%	15	32.6%	31	37.8%	21	36.2%
T	41		46		82		58	

eighteenth- and twentieth- century groups that appeared so striking for the humeri does not seem to be the case when the patterns are compared for the femora.

Because the femur is substantially larger than the humerus, a one millimeter variation in length represents a smaller percentage difference, so it would not be surprising if there were a smaller proportion of symmetrical femora than humeri in any of the samples. However, this turns out not to be the case. In fact, among all the study samples more femora are symmetrical than humeri, and when the symmetry threshold is

Table 41 Georgian Femur Length Asymmetry Direction (≥ 2 mm)

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	9	52.9%	14	51.9%	14	58.3%	3	15.8%
O	3	17.6%	10	37.0%	4	16.7%	10	52.6%
R	5	29.4%	3	11.1%	6	25.0%	6	31.6%
T	17		27		24		19	

raised to two millimeters, there is a relatively large shift into the symmetrical category from both the right-dominant and left dominant sides. Table 42 shows the numbers and percentages of the Georgians who fall into each direction-of-asymmetry category with the higher asymmetry threshold.

The Spitalfields males (Figure 34) and St. Bride's males (Figure 35) display remarkably similar femur length asymmetry patterns under the two thresholds, with a shift of one or two individuals from each side to the center under the higher threshold. In the case of the Spitalfields females, five individuals shift from right-dominant to symmetrical, and one individual shifts from left-dominant to symmetrical (Figure 36). In the St. Bride's females, three left-dominants shift to symmetrical, as well as one right-dominant (Figure 37). While the Georgian females appear to display a greater magnitude of asymmetry in the humeri, the pattern is reversed in the femora. In both Georgian samples the males display greater asymmetry than the females, and in all cases the pattern is left-dominant (Figures 38 and 39).

In assessing the humeri it was apparent that shifting from a one-millimeter to a two-millimeter threshold increased the χ^2, associated with an increased statistical probability that the samples are independent. There is a comparable phenomenon in assessing relationships for femur length. The new threshold further accentuates the right-dominance pattern in St. Bride's female femora, which renders that sample significantly different from not only the St. Bride's males ($\chi^2 = 9.23$, $p < .01$), but also the Spitalfields females ($\chi^2 = 6.94$, $p < .05$).

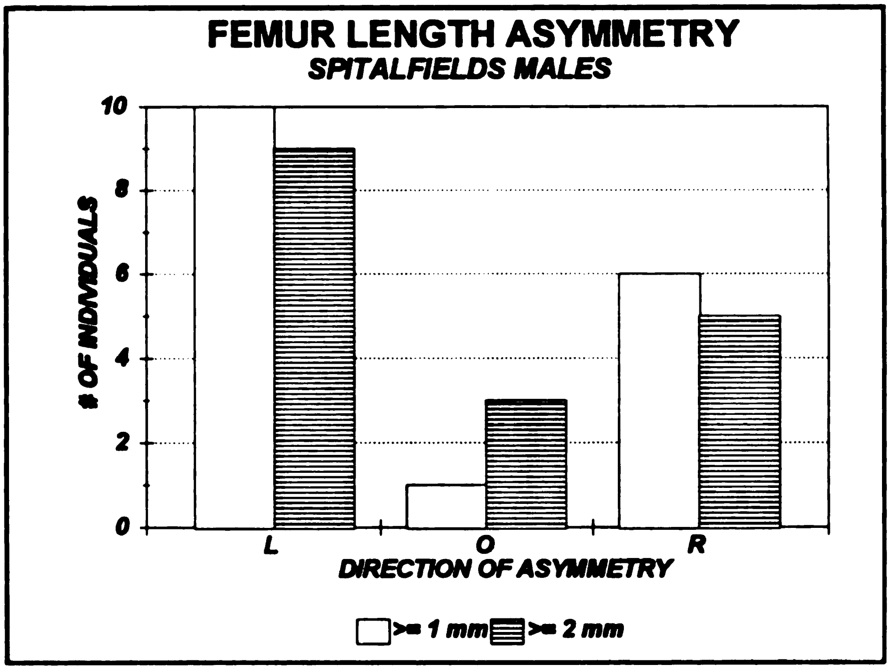

Figure 34 Femur Asymmetry Direction -- Spitalfields Males

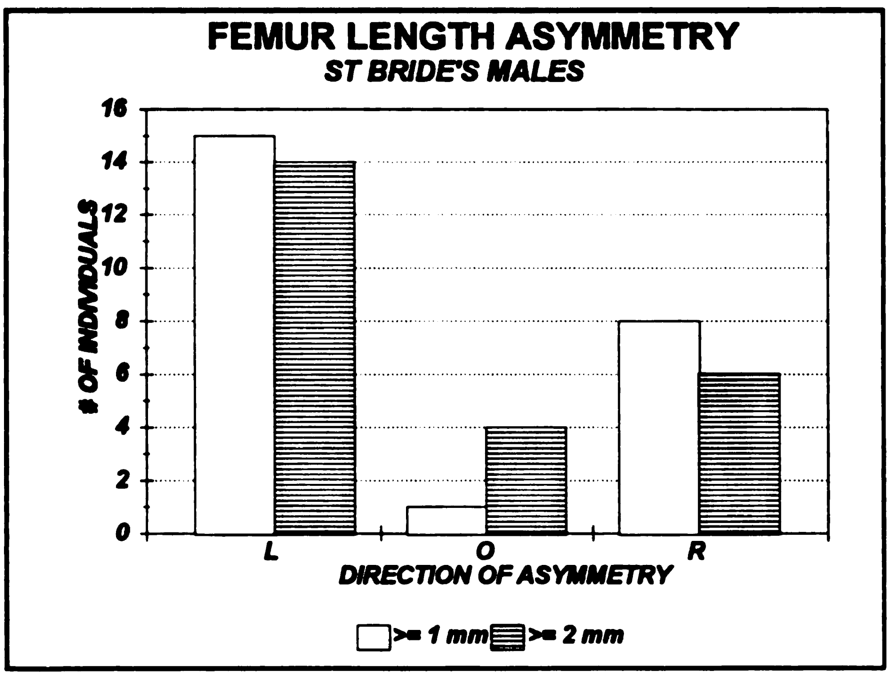

Figure 35 Femur Asymmetry Direction -- St. Bride's Males

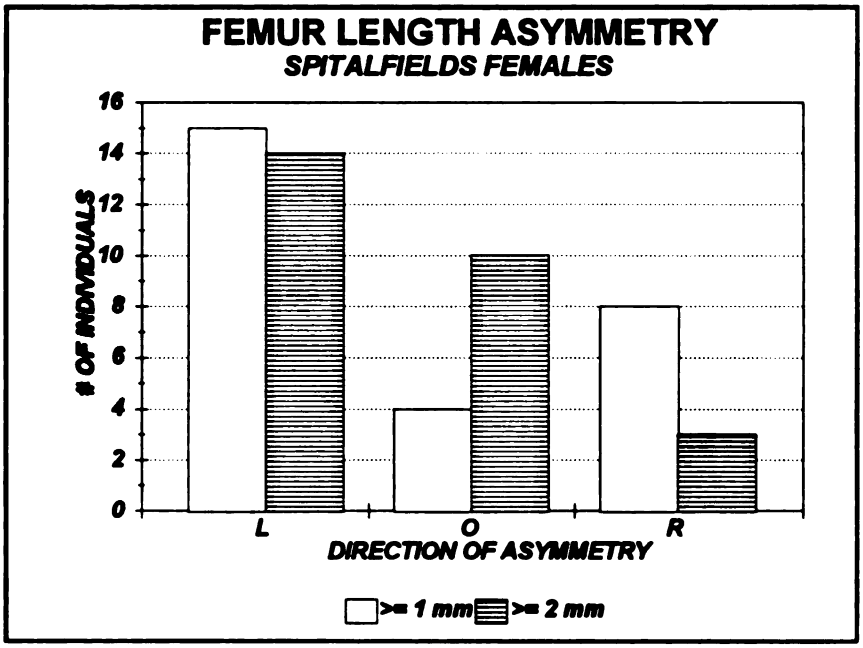

Figure 36 Femur Asymmetry Direction -- Spitalfields Females

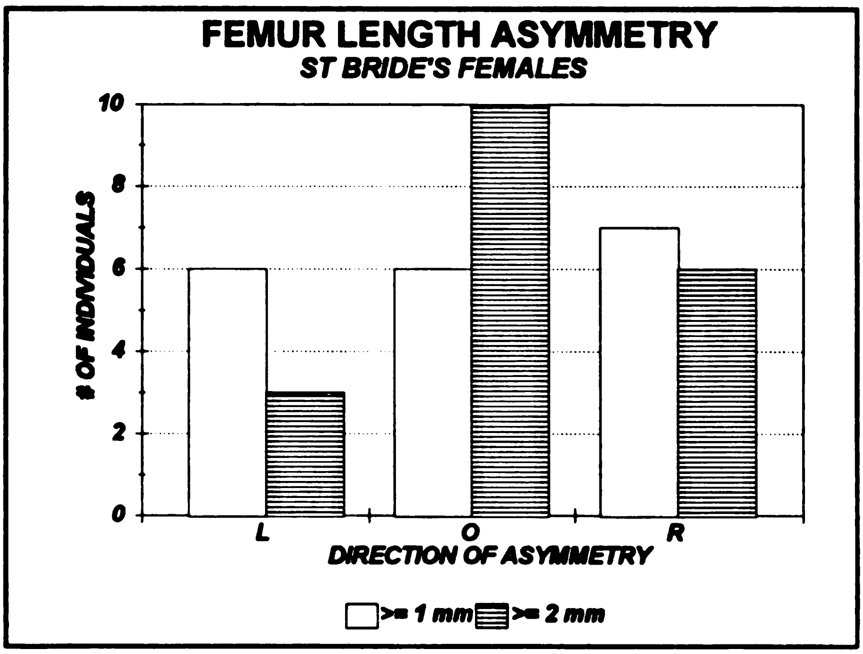

Figure 37 Femur Asymmetry Direction -- St. Bride's Females

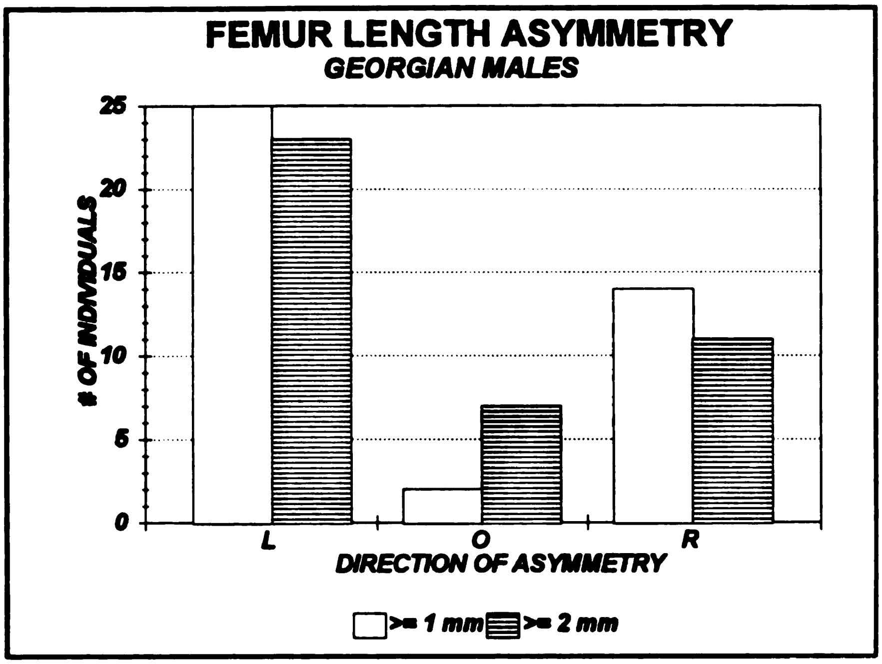

Figure 38 Femur Asymmetry Direction -- Georgian Males

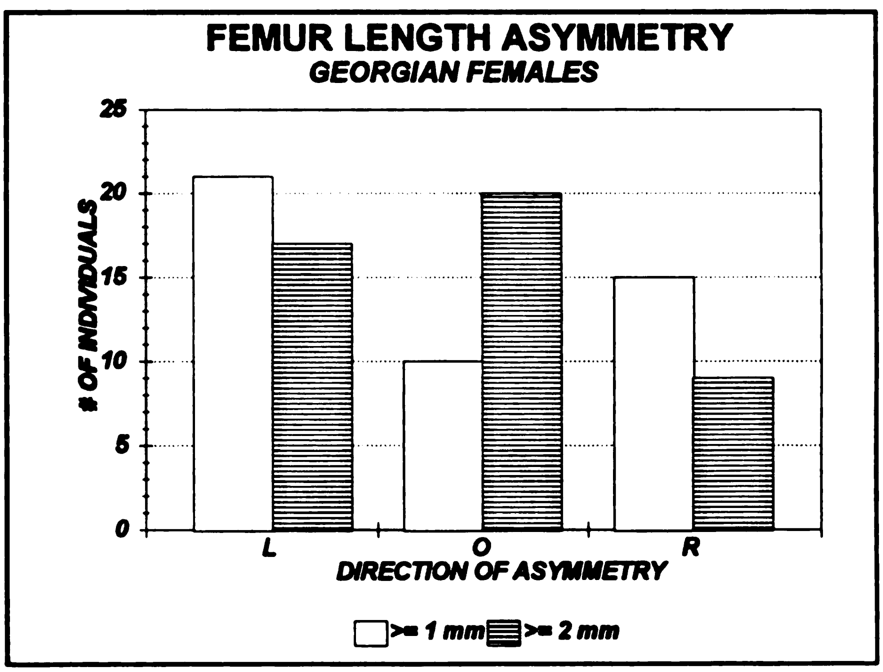

Figure 39 Femur Asymmetry Direction -- Georgian Females

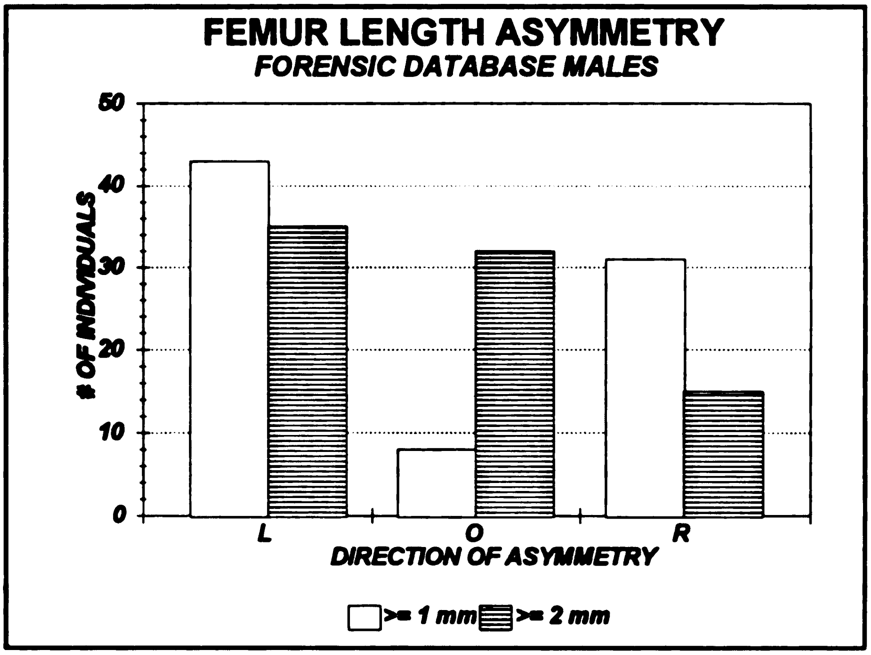

Figure 40 Femur Asymmetry Direction -- Forensic Males

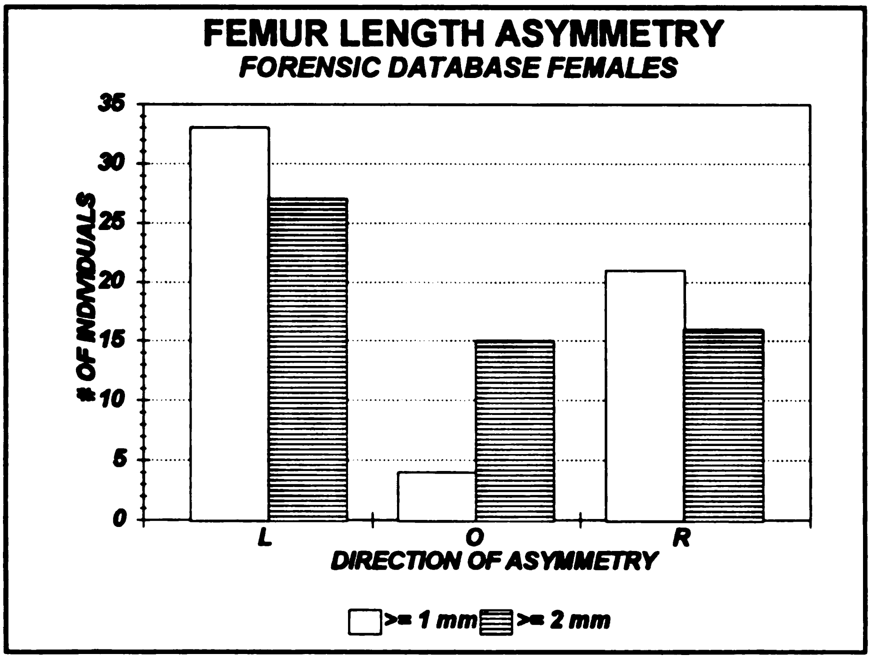

Figure 41 Femur Asymmetry Direction -- Forensic Females

Table 42 Combined Femur Length Asymmetry Direction (≥ 2 mm)

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	23	56.1%	17	37.0%	35	42.7%	27	46.6%
O	7	17.1%	20	43.5%	32	39.0%	15	25.9%
R	11	26.8%	9	19.6%	15	18.3%	16	27.6%
T	41		46		82		58	

In contrast with the Georgians, the Forensic Data Bank individuals areremarkably similar in their side-dominance distribution patterns (Table 42; Figures 40 and 41). In both sexes, a substantial number of individuals shift from left- or right-dominant to symmetrical when the threshold is raised from 1 mm to 2 mm. The higher threshold renders the Georgian and Forensic males statistically different ($\chi^2 = 6.14, p < .05$), but not the females. However, it also results in a significant difference between the pooled Georgian males and the pooled Georgian females ($\chi^2 = 7.09, p < .05$).

Femur Head Diameter—FH

It is not surprising that the head of the femur would appear relatively symmetrical, much like the head of the humerus. What is striking, however, is that even though the length of the femur shows an obvious pattern of left-dominance, the right side is dominant in femur head diameter (Table 43). The Georgians are remarkably similar in their distribution patterns, and none of the differences among them are statistically significant.

Table 43 Georgian Femur Head Asymmetry Direction

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	2	11.8%	1	3.7%	2	8.3%	2	10.5%
O	10	58.8%	12	44.4%	16	66.7%	13	68.4%
R	5	29.4%	14	51.9%	6	25.0%	4	21.1%
T	17		27		24		19	

Table 44 Combined Femur Head Asymmetry Direction

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	4	9.8%	3	6.5%	11	13.4%	10	17.2%
O	26	63.4%	25	54.3%	44	53.7%	32	55.2%
R	11	26.8%	18	39.1%	27	32.9%	16	27.6%
T	41		46		82		58	

The same right-dominant pattern appears in the Forensic Data Bank males and females (Table 44), although it is less profound than in the pooled Georgians. There does not appear to be any obvious sex-related pattern of variation in the direction of femoral head asymmetry, and there are no statistically significant differences between the Georgian and Forensic samples.

Femur Biepicondylar Width—FB

Similar to the case of femoral head diameter, biepicondylar width asymmetry in the femur shows a pattern of right-dominance in directionality among the Georgians, which contrasts with the direction of dominance in femur length. The sole exception is the St. Bride's males, but the slight apparent right dominance could easily be an artifact of sampling error (Table 45). Unlike the case for the head of the femur, there is a substantially higher level of symmetry in the St. Bride's males than in the other Georgian subsamples, and the greatest proportion of asymmetric individuals is seen in the Spitalfields males.

Table 45 Georgian Femur Biepicondylar Width Asymmetry Direction

	Spitalfields Males		Spitalfields Females		St. Bride's Males		St. Bride's Females	
L	3	17.6%	3	11.1%	4	16.7%	0	0.0%
O	4	23.5%	10	37.0%	17	70.8%	9	47.4%
R	10	58.8%	14	51.9%	3	12.5%	10	52.6%
T	17		27		24		19	

Because so few individuals in any of the Georgian subgroups display left-dominance, minimal cell-size requirements for a χ^2 comparison are not met and the usual

χ^2 assessment cannot legitimately be performed. However, if the left-dominant and symmetrical categories are pooled, minimum cell-size requirements are met and it is possible to perform a two-by-two χ^2 comparison of the subgroups (with a Yates correction for continuity, since there is only one degree of freedom). In this scenario, the St. Bride's male sample differs significantly from each of the Spitalfields males ($\chi^2 = 7.84, p < .01$), Spitalfields females ($\chi^2 = 7.17, p < .01$), and St. Bride's females ($\chi^2 = 6.31, p < .05$).

Table 46 Combined Femur Biepicondylar Width Asymmetry Direction

	Georgian Males		Georgian Females		Forensic Males		Forensic Females	
L	7	17.1%	3	6.5%	16	19.5%	12	20.7%
O	21	51.2%	19	41.3%	31	37.8%	26	44.8%
R	13	31.7%	24	52.2%	35	42.7%	20	34.5%
T	41		46		82		58	

When the Georgians are pooled and compared with the Forensic Data Bank individuals, the right-dominance pattern persists (Table 46). As was the case for the femur head, there are no obvious differences between the Georgians' patterns and those of the more recent sample, and none which are statistically significant.

Summary

Table 47 Summary: Differences in Direction of Humerus Asymmetry

	Length (1 mm)	**Length (2 mm)**	**Head Diameter**	**Biepicondylar Width**
Georgian ♂	—	—	—	—
Georgian ♀	—	—	<.05	—
Spitalfields ♂ / ♀	—	—	—	—
St. Bride's ♂ / ♀	—	—	—	—
Forensic ♂ / ♀	—	—	—	—
Georgian / Forensic ♂	<.001	<.0001	—	—
Georgian / Forensic ♀	<.01	<.001	—	—

The strong directional bias in the length of the humerus in the two Georgian samples is apparent in comparison with their Forensic counterparts. Because the latter group is so much less directional, the differences between the groups are highly significant (Table 47).

When a two-millimeter symmetry threshold replaces the one-millimeter threshold the population differences appear to be even more statistically significant. There is no significant difference in length asymmetry directionality among any of the Georgian subgroups.The only significant difference in direction of head asymmetry inexplicably occurs between the Georgian females. At first glance it seems surprising that there are no statistically significant differences among any of the subgroups with respect to biepicondylar width of the humerus.

Table 48 Summary: Differences in Direction of Femur Asymmetry

	Length (1 mm)	Length (2 mm)	Head Diameter	Biepicondylar Width
Georgian ♂	—	—	—	<.01*
Georgian ♀	—	<.05	—	—
Spitalfields ♂ / ♀	—	—	—	—
St. Bride's ♂ / ♀	<.05	<.01	—	<.05*
Forensic ♂ / ♀	—	—	—	—
Georgian / Forensic ♂	—	<.05	—	—
Georgian / Forensic ♀	—	—	—	—

Table 48 describes the patterns of asymmetry direction among the measurements of the femur. As was the case with the humerus length, increasing the symmetry threshold for the length of the femur results in more highly significant differences among some of the study subgroups. The St. Bride's males and females display the greatest difference in directionality patterns, but the Spitalfields and St. Bride's males differ significantly

ASYMMETRY MAGNITUDE

In this section, the magnitude of asymmetry for each of the measurements is described in terms of (1) signed values; (2) unsigned values; (3) signed percentage of total character size; and (4) unsigned percentage of total character size. For each measurement, the study subgroups are ordinally ranked from the most symmetrical to the least symmetrical on the basis of each of these assessments of asymmetry.

In addition to the ordinal ranking, summary statistics are provided in tabular form for the unsigned magnitude values of each measurement for the study subgroups. Summary statistics include the mean, standard error of the mean, standard deviation, and 95% confidence level. The Mann-Whitney *U* statistic is employed to assess the independence of the paired samples as a means for testing the core hypotheses of the study.

Humerus Length—HL

The magnitude of asymmetry in paired elements can be reported either in terms of signed or unsigned values. When a number of positive and negative values are averaged, the resulting mean is consistently smaller than if only unsigned asymmetry values are averaged. Because of the strong directional nature of humerus length asymmetry (as identified in the previous section) there is a relatively small difference between the means reported with the signed and unsigned values. However, the extent of the directionality will influence the amount of difference between the means.

Table 49 shows how the mean value of an asymmetry distribution changes when signed and unsigned values are compared among the study samples. Those subgroups

Table 49 Mean Humerus Length Asymmetries--Signed vs. Unsigned

	SIGNED	UNSIGNED
Spitalfields Males	3.57	3.90
Spitalfields Females	5.09	5.58
St. Bride's Males	3.57	4.47
St. Bride's Females	4.66	4.72
Georgian Males	3.57	4.14
Georgian Females	4.93	5.26
Forensic Males	0.76	2.69
Forensic Females	1.61	2.61

which display the greatest level of directionality (St. Bride's females, for example) have the smallest change in means; those which are less directional (Forensic males, for example) have a much greater change in means.

The extent of the directionality among the Georgians is displayed in the Figures representing the frequency distributions of the asymmetry (Figures 42 and 43). The distributions of humerus length asymmetry in each of the male subgroups display a pattern of bimodality that appears to be absent from their female counterparts. The implications of this apparent pattern are discussed in Chapter 6. This graphic display of the shape of the asymmetry patterns is instructive, since it reveals information that cannot be found in a straightforward reporting of summary statistics (Table 50).

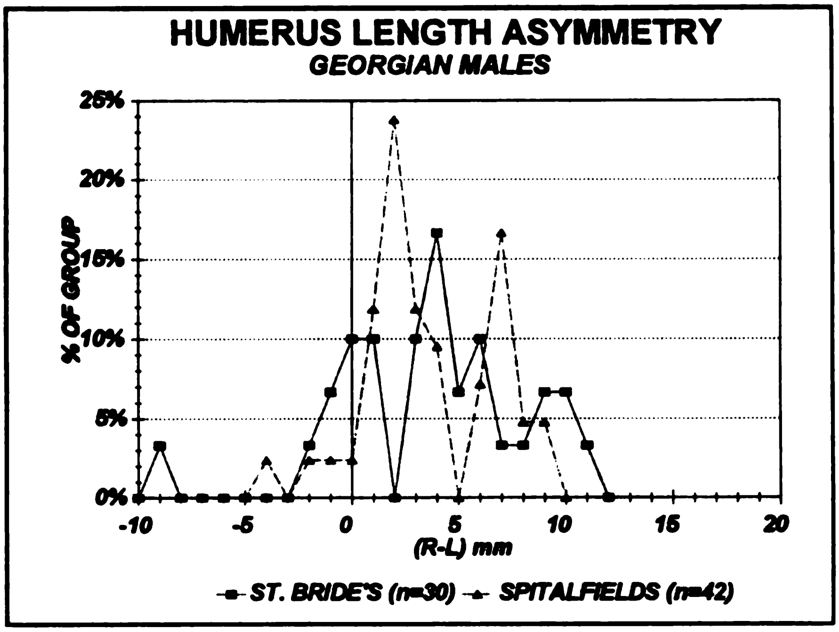

Figure 42 Georgian Male Signed Humerus Length Asymmetry

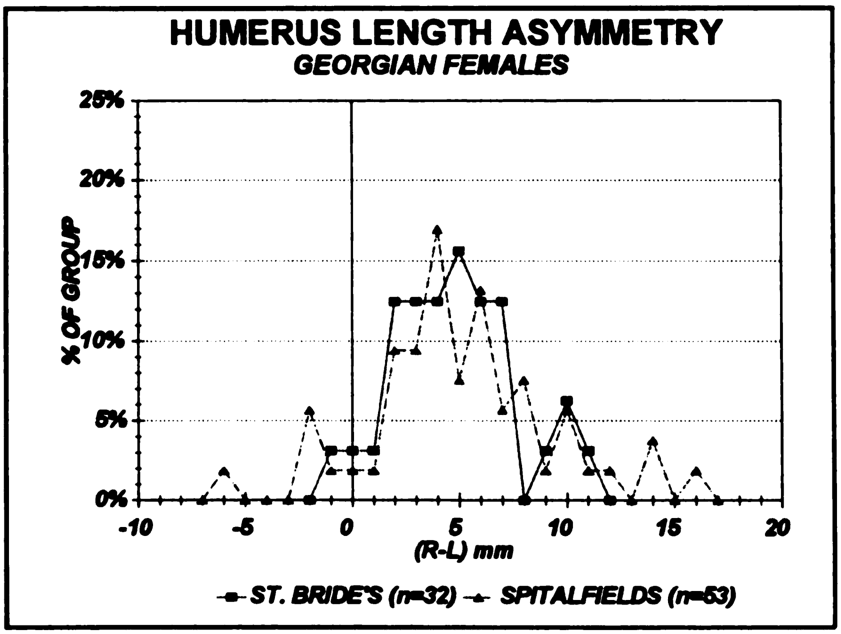

Figure 43 Georgian Female Signed Humerus Length Asymmetry

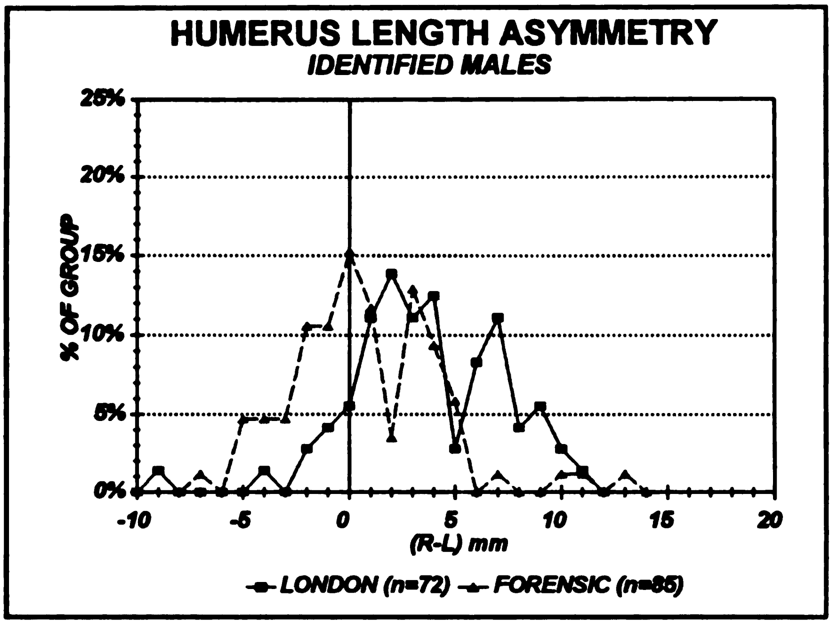

Figure 44 Identified Male Signed Humerus Length Asymmetry

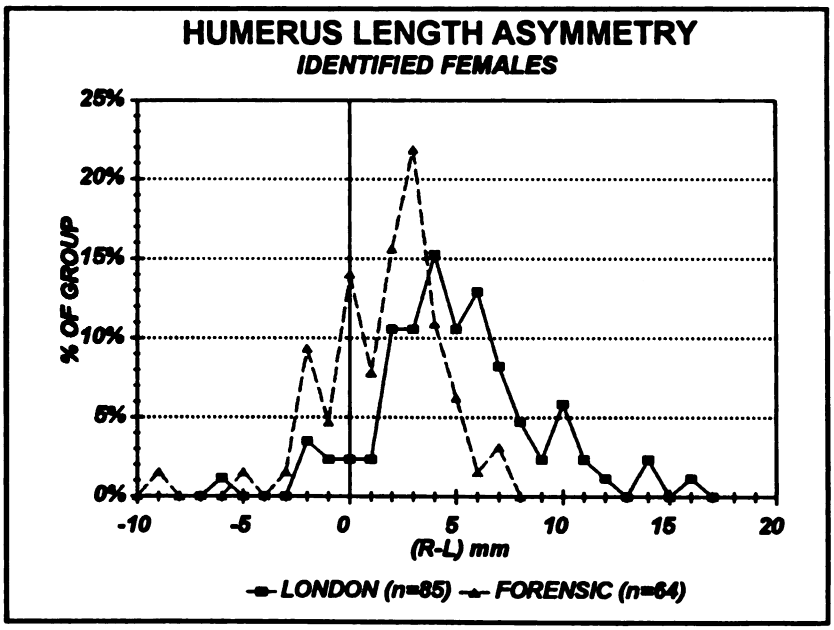

Figure 45 Identified Female Signed Humerus Length Asymmetry

Table 50 Paired Georgian Humerus Length Asymmetry Magnitude

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	3.90	5.58	4.47	4.72
SE	0.40	0.49	0.60	0.48
SD	2.59	3.55	3.30	2.70
.95 Confidence	0.78	0.95	1.18	0.93
N	42	53	30	32

The pooled Georgians differ markedly in asymmetry magnitude from the Forensic group ($z = 3.049$, $p < .005$).[20] Figure 44 contrasts the males, showing the relatively large number of left-dominant individuals in the Forensic sample. There are fewer left-dominant females in the Forensic sample, a pattern consistent with the greater level of right-dominance in humerus lengths among all the female study samples (Figure 45). However, the Georgian females are decidedly more asymmetric than their Forensic counterparts ($z = 5.606$, $p < .0001$).

The shape of the asymmetry magnitude distribution patterns changes when unsigned values are employed. Figures 46 and 47 show that the Georgian males appear much less similar when only the absolute magnitude of their asymmetry in considered. When the unsigned magnitude of asymmetry patterns is compared between the pooled

[20]Assessments of statistical significance of sample differences in asymmetry magnitude for the remainder of this chapter are based on z scores derived from the Mann-Whitney U statistic.

Table 51 Combined Humerus Length Asymmetry Magnitude

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	4.14	5.26	2.69	2.61
SE	0.34	0.35	0.26	0.23
SD	2.90	3.26	2.41	1.88
.95 Confidence	0.67	0.69	0.51	0.46
N	72	85	85	64

Georgians and the Forensic samples, the differences are even more profound (males: $z = 4.905$, $p < .0001$; females: $z = 5.346, p < .0001$.) (Table 51). Among the Forensic males, asymmetry greater than five millimeters is unusual, but that is not the case for the Georgians (Figure 48); the same is true for the females (Figure 49).

The ordinal ranking of the four Georgian subgroups does not shift when signed values are replaced by figures representing unsigned magnitude alone (Table 52)[21]. The Georgian females present the most asymmetry, followed by the Georgian males, with the Forensic Data Bank sample presenting with substantially less asymmetry. Even when the asymmetry patterns are scaled on character size, there is no change in the ordinal ranking. The only difference that appears among the four ranking methods is the slightly greater absolute asymmetry of the Forensic males in comparison with the Forensic females.

[21]In this Table, and in several that follow, SP = Spitalfields; SB = St. Bride's; FD = Forensic Database; and CG = Combined Georgians.

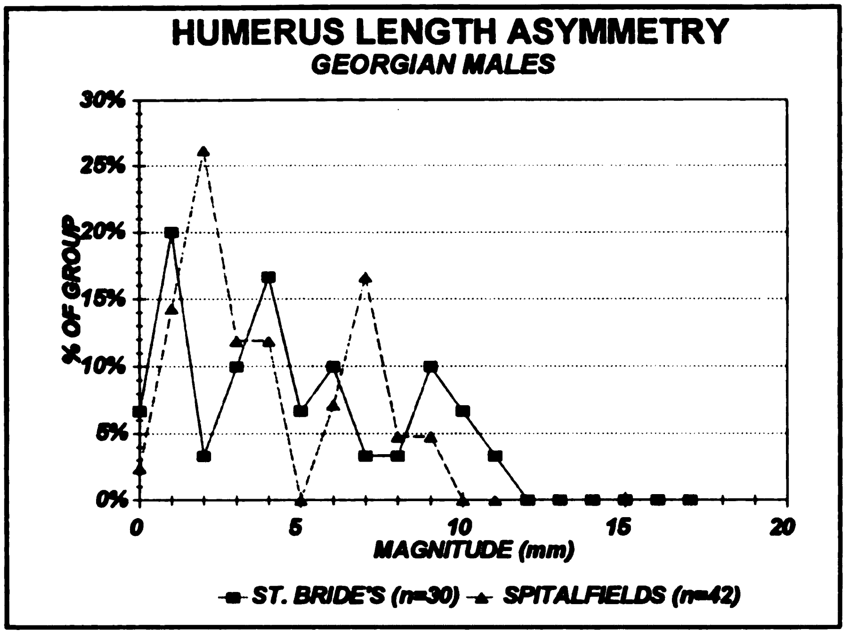

Figure 46 Georgian Male Humerus Length Asymmetry

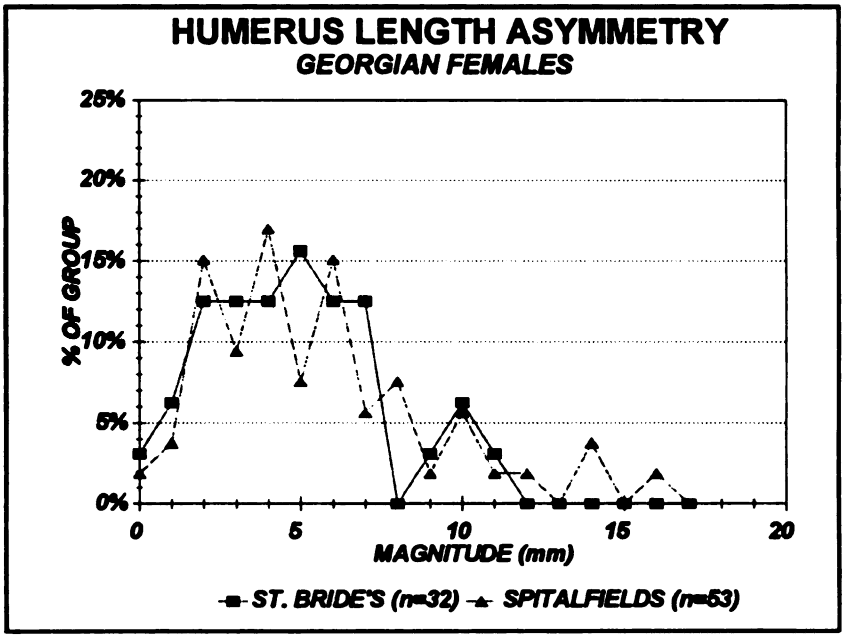

Figure 47 Georgian Female Humerus Length Asymmetry

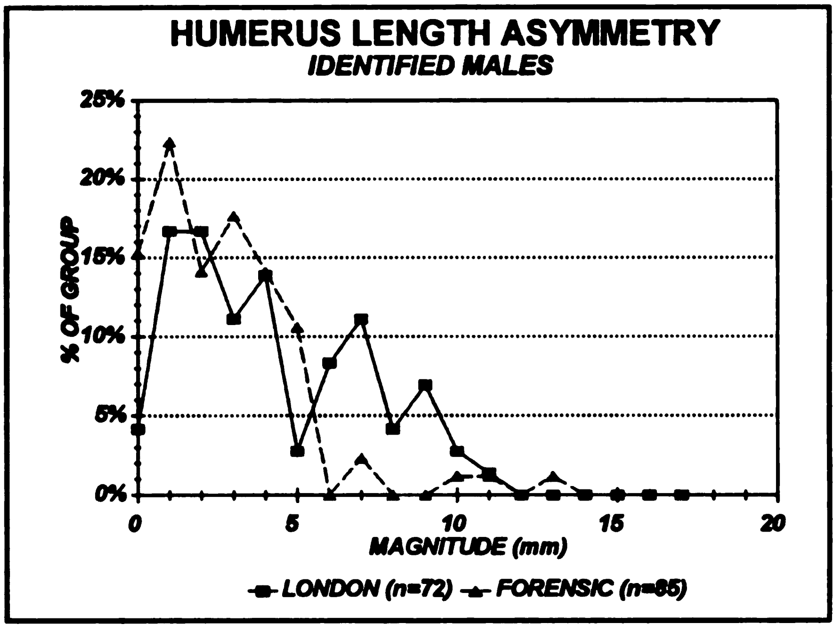

Figure 48 Identified Male Humerus Length Asymmetry

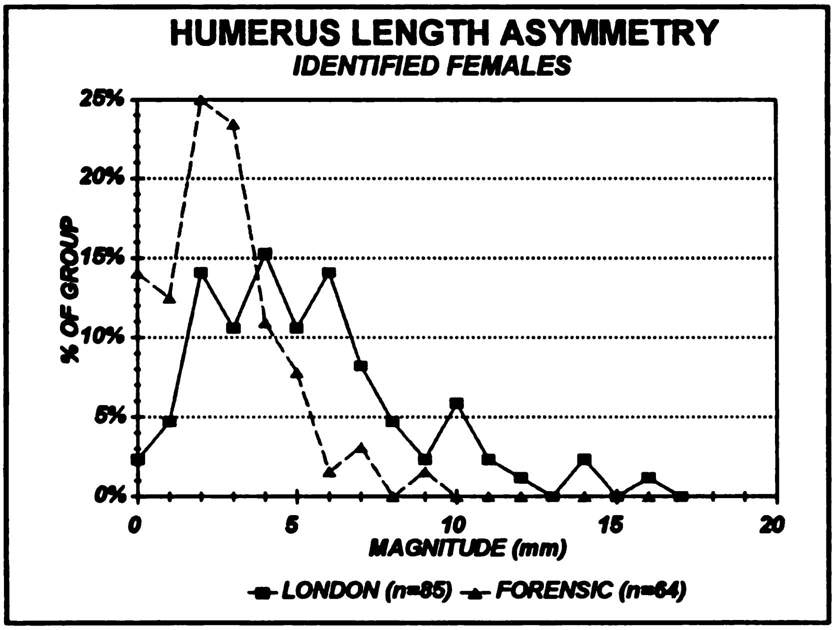

Figure 49 Identified Female Humerus Length Asymmetry

Table 52 Humerus Length Asymmetry—Ordinal Ranking

SIGNED (mm)		UNSIGNED(mm)		SIGNED (%)		UNSIGNED (%)	
SP♀	5.09	SP♀	5.58	SP♀	1.72%	SP♀	1.88%
CG♀	4.93	CG♀	5.26	CG♀	1.68%	CG♀	1.79%
SB♀	4.66	SB♀	4.72	SB♀	1.61%	SB♀	1.63%
SB♂	3.57	SB♂	4.47	SB♂	1.14%	SB♂	1.40%
CG♂	3.57	CG♂	4.14	CG♂	1.11%	CG♂	1.28%
SP♂	3.57	SP♂	3.90	SP♂	1.09%	SP♂	1.20%
FD♀.	1.61	FD♂	2.69	FD♀	0.53%	FD♀	0.85%
FD♂	0.76	FD♀	2.61	FD♂	0.22%	FD♂	0.81%

The statistical significance of differences between the Georgians and Forensic samples has already been noted, but there is also a significant difference between the males and females of Spitalfields in signed asymmetry magnitude ($z = 2.027$; $p < .05$). The Forensic males and females are also significantly different from each other in terms of signed asymmetry ($z = 2.121$; $p < .05$). There is not a corresponding significant difference for the St. Bride's sample. When patterns of unsigned asymmetry are compared between the sexes of the three samples, the significance of the Spitalfields difference increases slightly ($z = 2.338$; $p < .05$). At the same time the Forensic males and females are no longer statistically different, and the St. Bride's sample continue to not show statistically significant differences.

Table 53 summarizes the findings for the paired comparisons; note that there is no hint of a significant difference between the males of the Georgian samples, or between the females of the Georgian samples. Values in parentheses are based on Mann-Whitney

Table 53 Summary: Differences in Humerus Length Asymmetry Magnitude

	SIGNED		UNSIGNED	
	z	*p*	*z*	*p*
Georgian ♂	.011	—	.348	—
Georgian ♀	.698	—	1.066	—
Spitalfields ♂ / ♀	2.027 (2.038)	< .05 (< .05)	2.338 (2.357)	< .05 (< .05)
St. Bride's ♂ / ♀	1.000	—	.549	—
Forensic ♂ / ♀	2.121 (2.134)	< .05 (< .05)	.218	—
Georgian / Forensic ♂	4.906 (4.924)	< .0001 (< .0001)	3.049 (3.077)	< .005 (< .001)
Georgian / Forensic ♀	5.606 (5.637)	< .0001 (< .0001)	5.346 (5.391)	< .0001 (< .0001)

U statistics that were calculated with a correction for ties (as described in Chapter 4).

The *p* values that are listed in this Table are for a two-tailed probability.

Humerus Head Diameter—HH

The distribution of humerus head asymmetry for the Georgian males is represented in Figure 50 and for the females in Figure 51. When the pooled Georgians are compared with the individuals from the Forensic Data Bank, the slight right-dominance in the London groups contrasts markedly with the almost precise symmetry of the Forensic males and females (Figures 52 and 53).

Table 54 Georgians Humerus Head Asymmetry Magnitude

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	0.97	1.04	1.04	0.82
SE	0.20	0.13	0.15	0.14
SD	1.18	0.86	0.76	0.66
.95 Confidence	0.39	0.25	0.29	0.28
N	36	47	27	22

Summary statistics for the magnitude of head diameter asymmetry (Table 54) in the Georgians suggests a comparable range of asymmetry among all four of the study subgroups. Figures 54 and 55 indicate that most of the asymmetry is on the order of a one-millimeter difference.

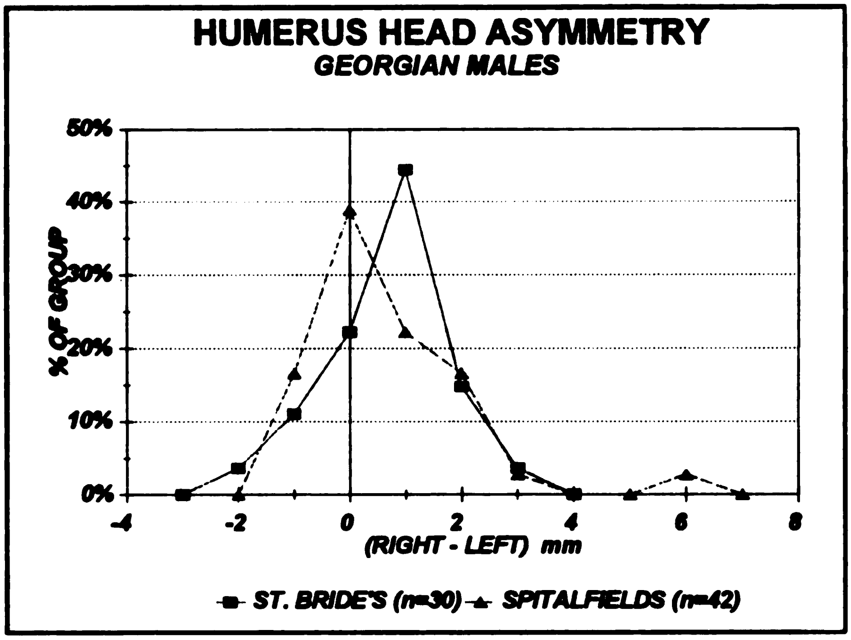

Figure 50 Georgian Male Signed Humerus Head Asymmetry

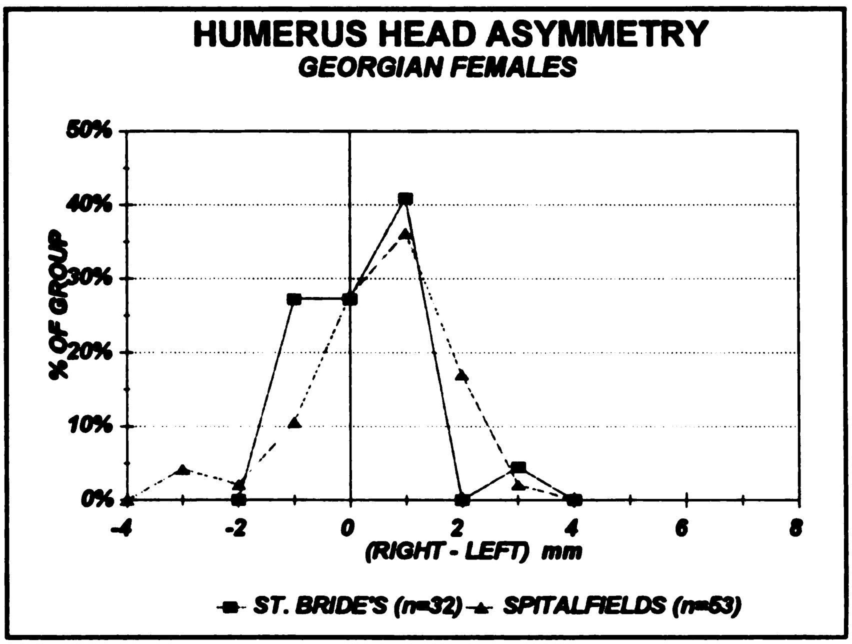

Figure 51 Georgian Female Signed Humerus Head Asymmetry

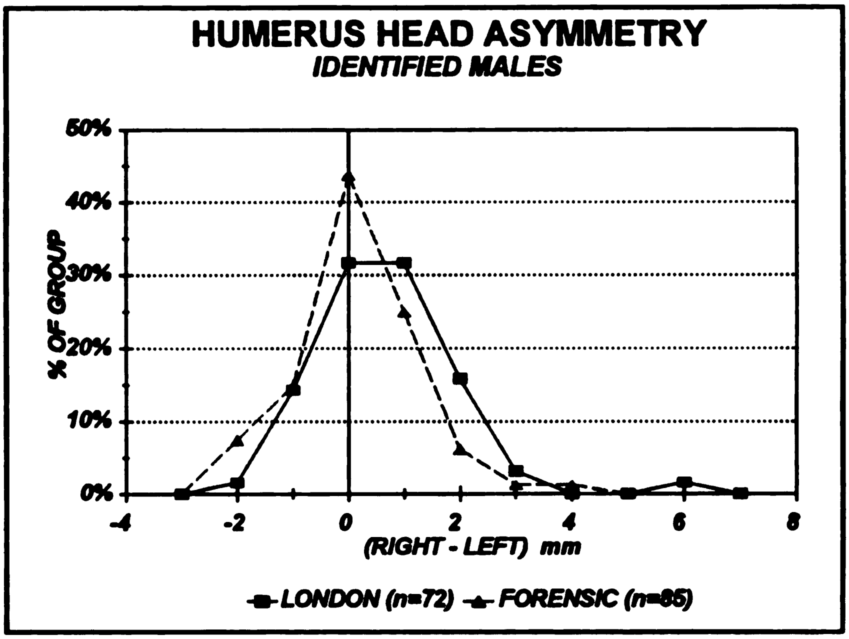

Figure 52 Identified Male Signed Humerus Head Asymmetry

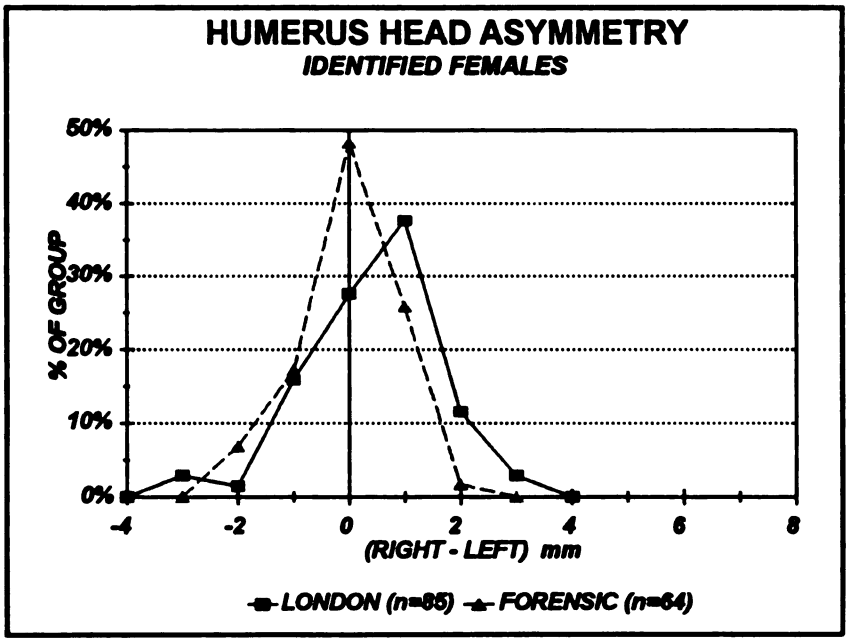

Figure 53 Identified Female Signed Humerus Head Asymmetry

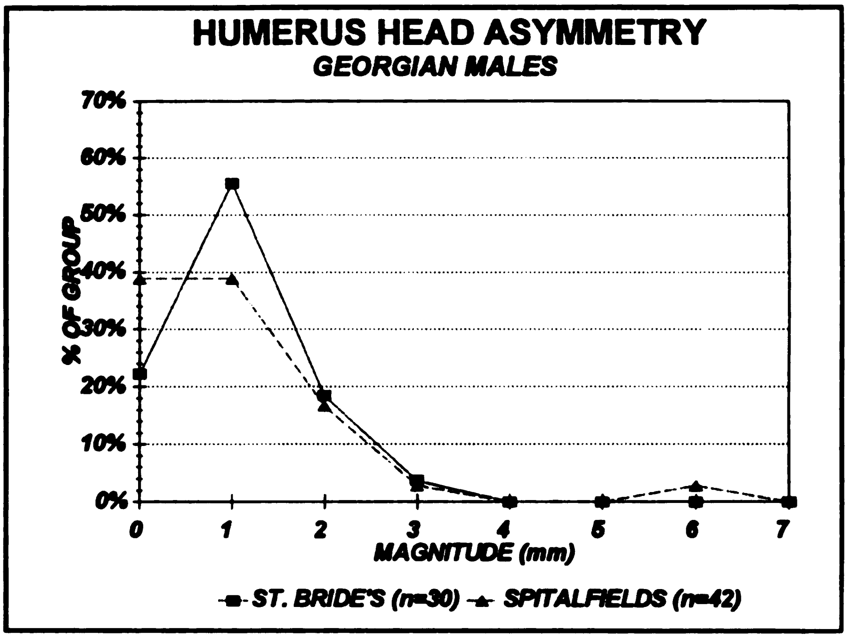

Figure 54 Georgian Male Humerus Head Asymmetry

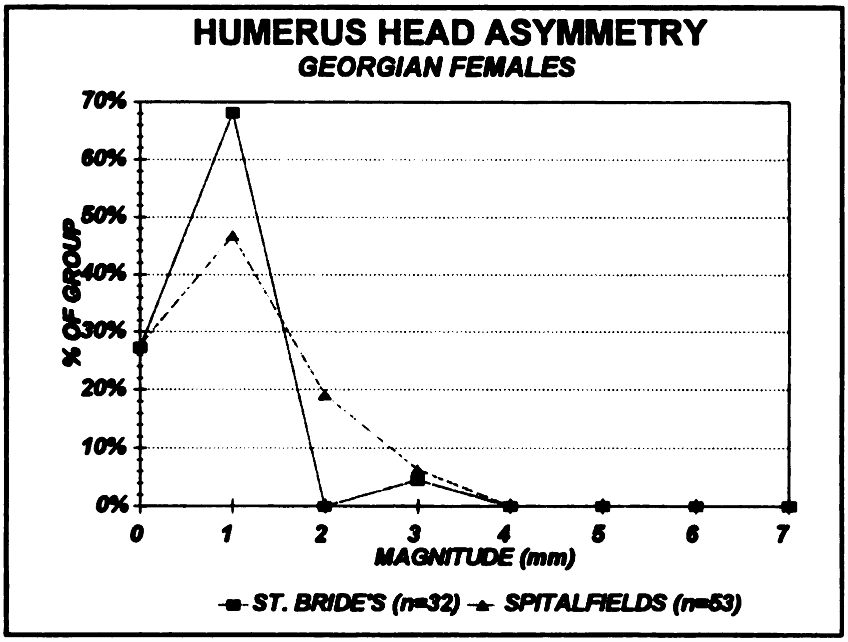

Figure 55 Georgian Female Humerus Head Asymmetry

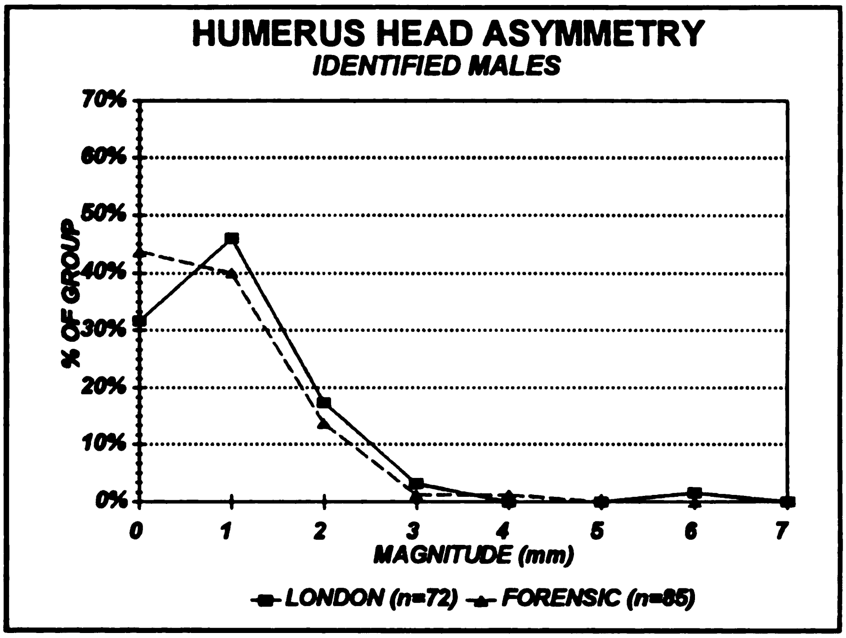

Figure 56 Identified Male Humerus Head Asymmetry

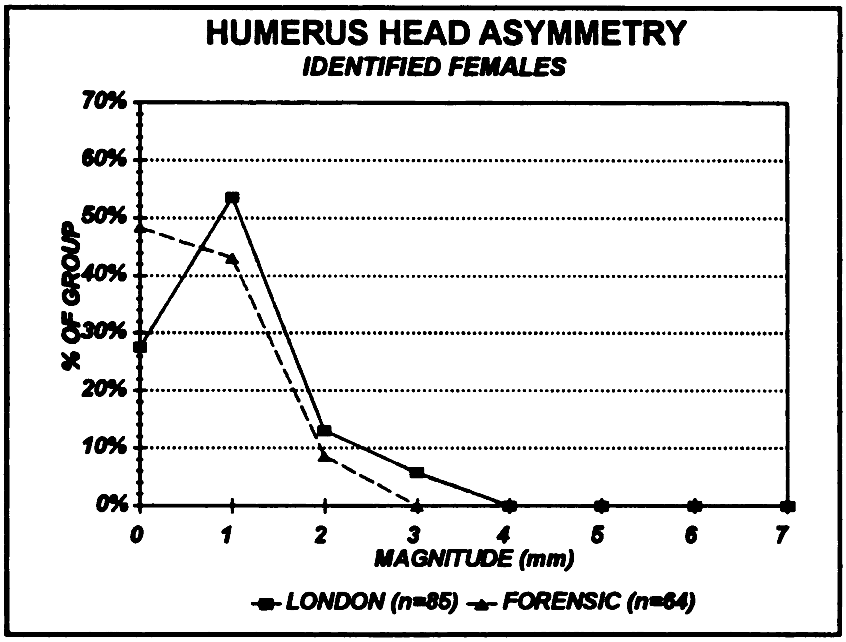

Figure 57 Identified Female Humerus Head Asymmetry

Table 55 Combined Humerus Head Asymmetry Magnitude

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	1.00	0.97	0.76	0.60
SE	0.13	0.10	0.09	0.08
SD	1.02	0.80	0.83	0.65
.95 Confidence	0.25	0.19	0.18	0.17
N	63	69	80	58

When the Georgians are compared with the Forensic Data Bank individuals, the apparent lack of asymmetry in the latter sample persists (Table 55). When the magnitude distributions are displayed graphically, however, the differences between the older and the more recent groups appear to be slight, for both the males and females (Figures 56 and 57).

Table 56 indicates that when the individuals are ordinally ranked, the Georgians are clearly more asymmetrical than the Forensic sample. It is also noteworthy that the Forensic females are the only subgroup which display a left-dominance pattern in head diameter asymmetry--albeit a very slight dominance.

Table 56 Humerus Head Asymmetry—Ordinal Ranking

SIGNED (mm)		UNSIGNED (mm)		SIGNED (%)		UNSIGNED (%)	
SB♂	0.67	SP♀	1.04	SB♂	1.41%	SP♀	2.56%
CG♂	0.65	SB♂	1.04	CG♂	1.36%	CG♀	2.38%
SP♂	0.64	CG♂	1.00	SP♂	1.32%	SB♂	2.20%
SP♀	0.49	CG♀	0.97	SP♀	1.18%	CG♂	2.11%
CG♀	0.42	SP♂	0.97	CG♀	1.01%	SP♂	2.05%
SB♀	0.27	SB♀	0.82	SB♀	0.65%	SB♀	2.00%
FD♂	0.16	FD♂	0.76	FD♂	0.32%	FD♂	1.57%
FD♀	-0.02	FD♀	0.60	FD♀	-0.04%	FD♀	1.42%

The only strong statistical differences between the study samples occur between the same-sex samples of the Georgians and the Forensic Data Bank, as described in Table 57.

Table 57 Summary: Differences in Humerus Head Asymmetry Magnitude

	SIGNED		UNSIGNED	
	z	*p*	*z*	*p*
Georgian ♂	.660	—	.840	—
Georgian ♀	1.094	—	.933	—
Spitalfields ♂ / ♀	.262	—	.822	—
St. Bride's ♂ / ♀	1.397	—	1.005	—
Forensic ♂ / ♀	.748	—	.8303	—
Georgian / Forensic ♂	2.249 (2.348)	< .05 (< .05)	1.397 (1.450)	< .10 (< .10)
Georgian / Forensic ♀	2.396 (2.510)	< .05 (< .05)	2.396 (2.510)	< .05 (< .05)

Humerus Biepicondylar Width—HB

Table 58 Georgian Humerus Biepicondylar Width Asymmetry Magnitude

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	1.56	1.15	1.63	1.23
SE	0.25	0.15	0.27	0.28
SD	1.48	1.00	1.42	1.31
.95 Confidence	0.48	0.29	0.53	0.55
N	36	47	27	22

Biepicondylar width of the humerus is the measurement in this study which is most likely to be directly modified by the effects of physical activity; therefore, asymmetry in these measurements would be most likely associated with side-activity differences among the populations. The Georgian males (Figure 58) display a greater range of variation in the distribution of asymmetry than the females (Figure 59; Table 58). All groups display a pattern of right-dominance; among the Georgians the St. Bride's females are the only subsample to have a modal asymmetry values of zero. A mode of zero is also present in the Forensic Data Bank males; in contrast with the Georgian males they appear more symmetrical (Figure 60). The pooled Georgian females manifest a normal distribution with a slight right-shift, not unlike their Forensic counterparts (Figure 61). When the magnitude of the asymmetry alone is considered, there is a gender difference between the male and female Georgians, but in this case the males, rather than the females, display more asymmetry

Table 59 Combined Humerus Biepicondylar Width Asymmetry Magnitude

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	1.58	1.17	1.20	0.84
SE	0.18	0.13	0.13	0.09
SD	1.44	1.10	1.18	0.67
.95 Confidence	0.36	0.26	0.26	0.17
N	63	69	80	58

A graphic display of the asymmetry magnitude shows very little difference among the Georgian males (Figure 62) and the Georgian females (Figure 63). When the pooled Georgians are compared with the Forensic samples, a new pattern emerges. The Forensic males display a greater magnitude of asymmetry than the Georgian females; this is the one instance in the study where the Georgians are not consistently the most asymmetric (Table 59). The Forensic males still display less asymmetry than the Georgian males (Figure 64), and the Georgian females are still somewhat more asymmetric than the Forensic females (Figure 65).

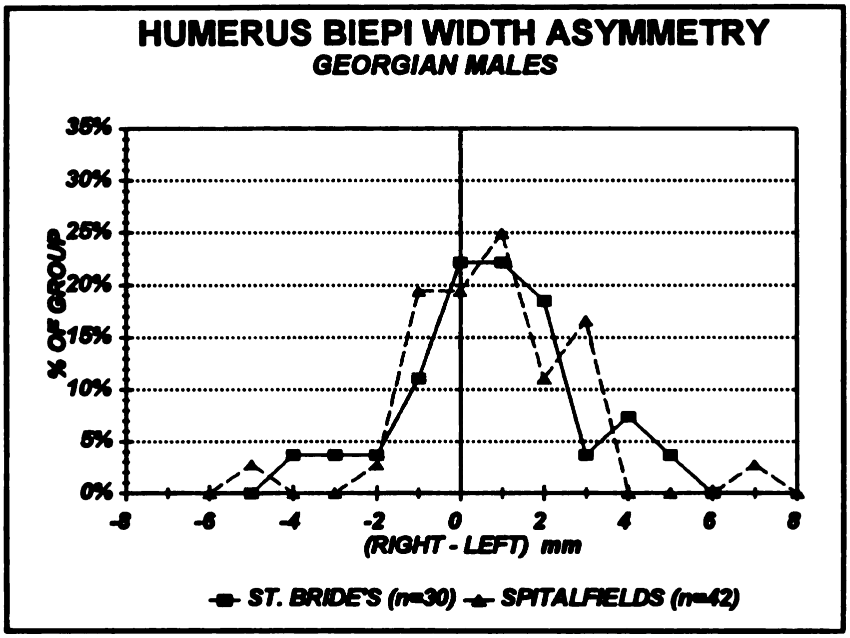

Figure 58 Georgian Male Signed Humerus Biepi Asymmetry

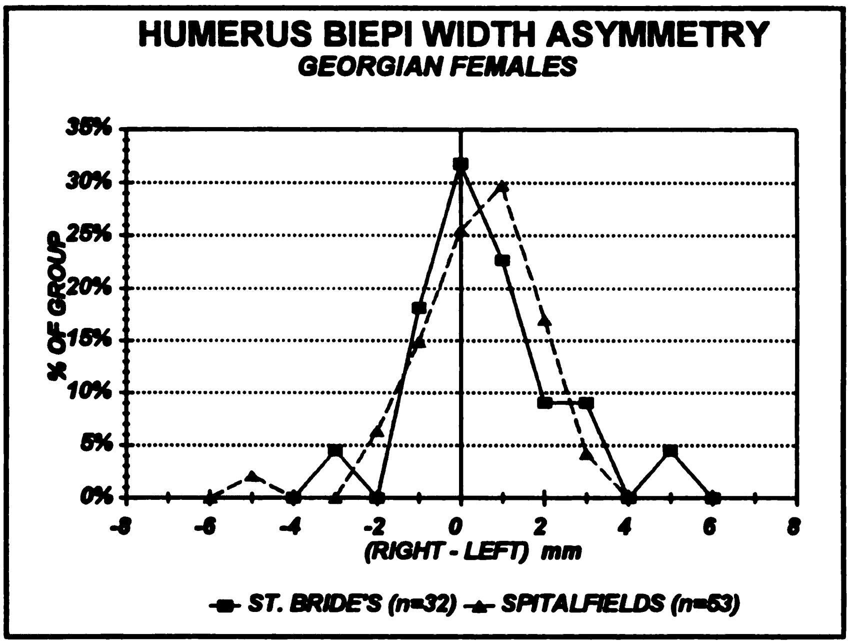

Figure 59 Georgian Female Signed Humerus Biepi Asymmetry

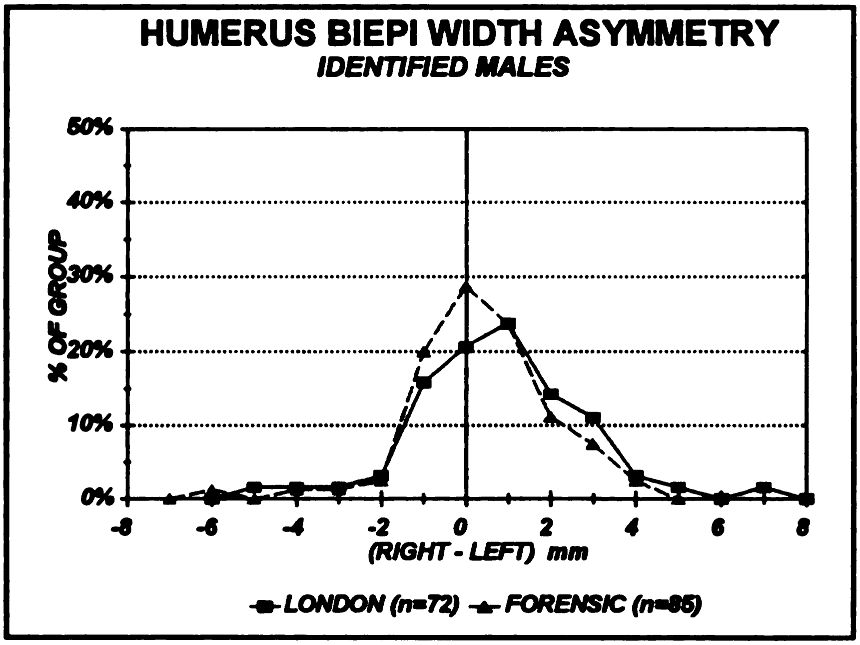

Figure 60 Identified Male Signed Humerus Biepi Asymmetry

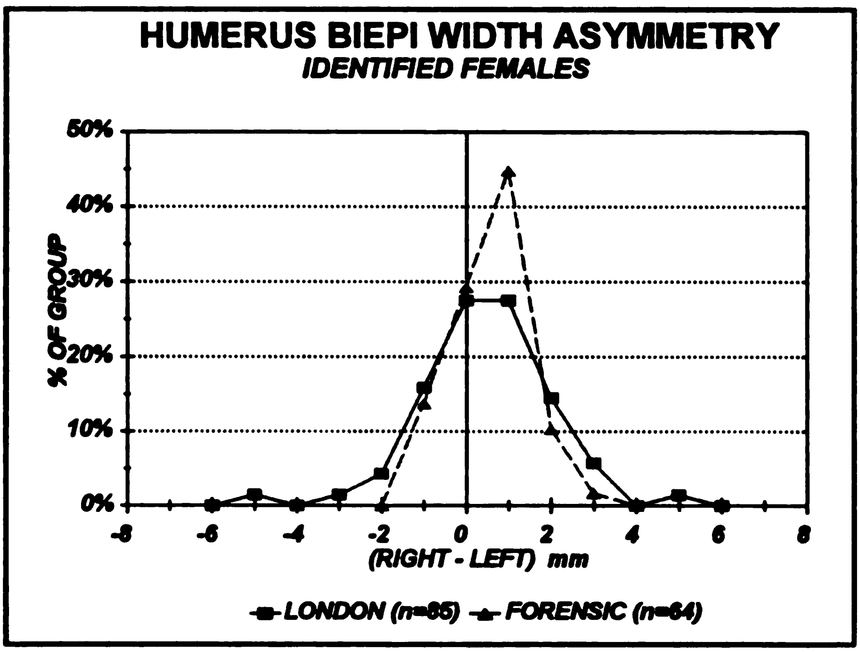

Figure 61 Identified Female Signed Humerus Biepi Asymmetry

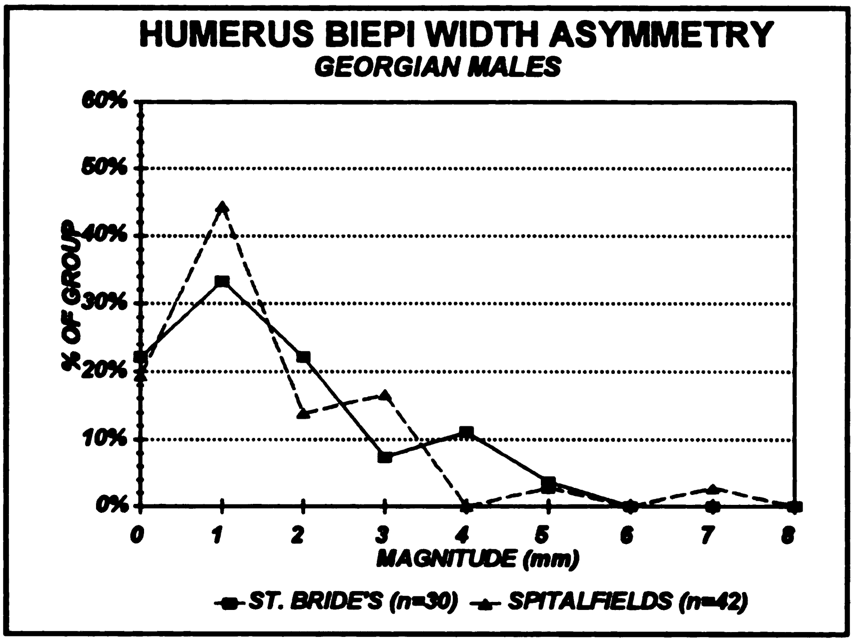

Figure 62 Georgian Male Humerus Biepi Asymmetry

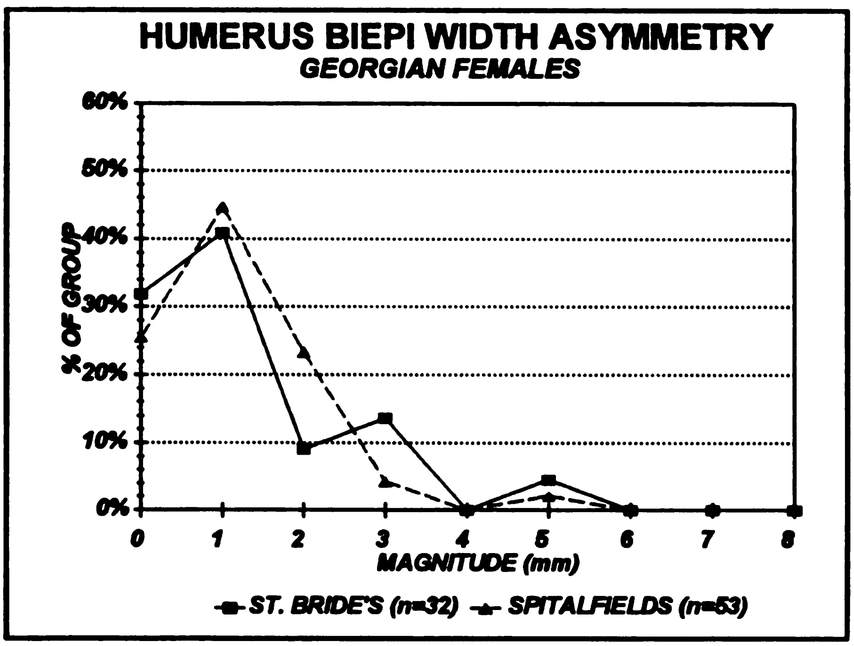

Figure 63 Georgian Female Humerus Biepi Asymmetry

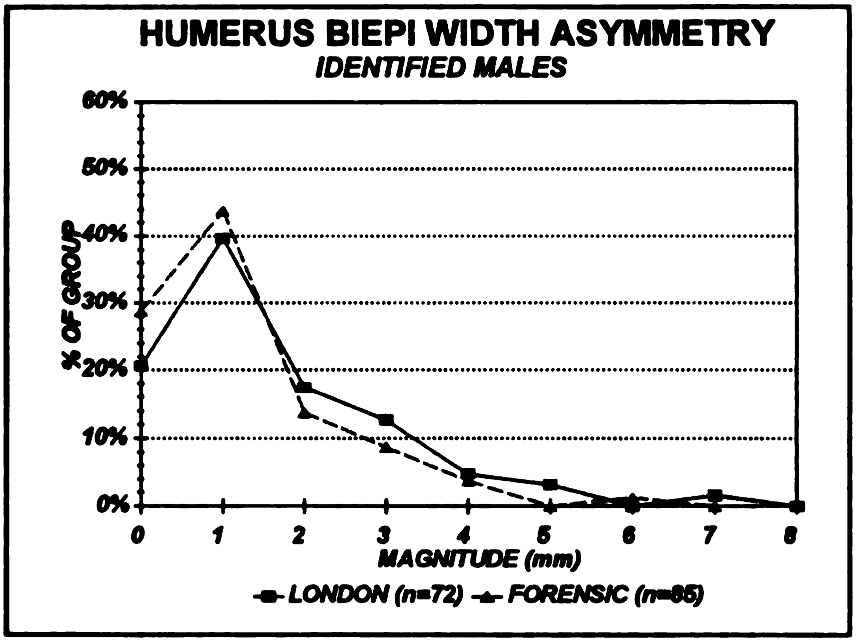

Figure 64 Identified Male Humerus Biepi Asymmetry

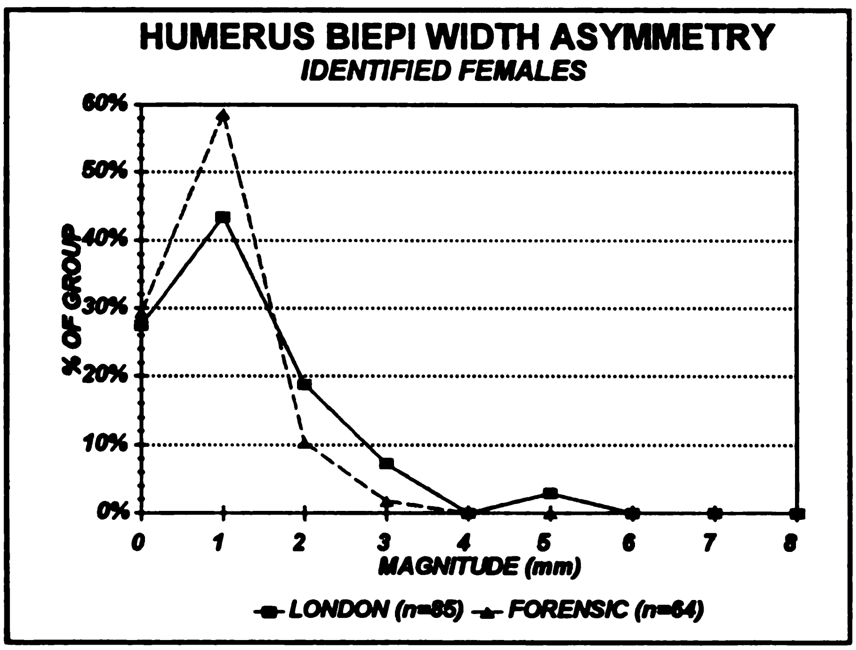

Figure 65 Identified Female Humerus Biepi Asymmetry

Table 60 Humerus Biepicondylar Width—Ordinal Ranking

SIGNED (mm)		UNSIGNED		SIGNED (%)		UNSIGNED (%)	
SP♂	0.78	SB♂	1.63	SP♂	1.30%	SB♂	2.62%
CG♂	0.76	CG♂	1.59	CG♂	1.25%	CG♂	2.58%
SB♂	0.74	SP♂	1.56	SB♂	1.19%	SP♂	2.55%
SB♀	0.59	SB♀	1.23	SB♀	1.09%	SB♀	2.28%
FD♀	0.57	FD♂	1.20	FD♀	1.02%	CG♀	2.18%
CG♀	0.45	CG♀	1.17	CG♀	0.83%	SP♀	2.13%
SP♀	0.38	SP♀	1.15	SP♀	0.71%	FD♂	1.84%
FD♂	0.38	FD♀	0.84	FD♂	0.60%	FD♀	1.51%

In the ordinal ranking of the groups, the place of the Forensic males presents a telling example of the importance of distinguishing between signed and unsigned values when making comparisons between study samples (Table 60). As noted above, in terms of magnitude alone the Forensic males display a level of asymmetry which is greater than the pooled Georgian females. However, when signed values are compared the picture looks very different. In fact, in the latter case the Forensic males are the least asymmetric of all the study subgroups. This is due to the relatively larger number of left-dominant individuals among the Forensic males, which counters the right-dominant individuals to make the group as a whole appear more symmetrical than it actually is. The same phenomenon appears to occur for the Forensic females as well.

In terms of the statistical significance of the differences among the studied groups, the only notable differences occur between the pooled Georgian males when they

Table 61 Humerus Biepicondylar Width Asymmetry Magnitude Differences

	SIGNED		UNSIGNED	
	z	*p*	*z*	*p*
Georgian ♂	.055	—	.299	—
Georgian ♀	.051	—	.180	—
Spitalfields ♂ / ♀	.786	—	1.029	—
St. Bride's ♂ / ♀	.502	—	1.065	—
Forensic ♂ / ♀	.895	—	1.268	—
Georgian / Forensic ♂	1.214	—	1.590	—
Georgian / Forensic ♀	.452	—	1.384	—

are compared with the Forensic males. However, these are not significant at an alpha of .05 for a two-tailed test of significance. The results of the Mann-Whitney tests are summarized in Table 61.

Femur Length—FL

Table 62 Mean Femur Length Asymmetries—Signed vs. Unsigned

	SIGNED	UNSIGNED
Spitalfields Males	-1.22	3.33
Spitalfields Females	-1.82	2.73
St. Bride's Males	-0.97	3.64
St. Bride's Females	-0.23	2.43
Georgian Males	-1.06	3.54
Georgian Females	-1.00	2.57
Forensic Males	-0.73	2.47
Forensic Females	-0.61	2.92

A number of studies suggest that the right-dominance in humerus length in human populations is often accompanied by a left-dominance in femur length. They also suggest that the magnitude of asymmetry is relatively smaller in femora when compared with humeri. These earlier findings are affirmed in the assessments of the study samples (Table 62). In all cases there is a net left-dominance in the asymmetry patterns. More importantly, there is no straightforward relationship between the signed and the unsigned values. The signed values suggest that femora display a very small magnitude of asymmetry; however, when unsigned values are reported it is clear that there is a clear pattern of asymmetry in femur length.The distribution of asymmetry for the Georgian males (Figure 66) and Georgian females (Figure 67) show both the left-shift and the relative symmetry of the femora in contrast with the humeri. When the Georgians are pooled and compared with the Forensic sample the same patterns persist. An intriguing phenomenon appears in the male samples wherein a bimodal distribution is apparent in both the pooled Georgians and the Forensic sample. This is consistent with the finding that femora maintain relatively equal loading on both the right and left sides to the extent that there should be some level of symmetry in the asymmetry distributions (Figure 68). There is a more indistinct picture of bimodality in the Forensic females, but there seems to be no such pattern in the pooled Georgian females (Figure 69). However, the Spitalfields females appear to display a bimodality in their femur length asymmetry, as well.

The combination of relatively small magnitude in asymmetry coupled with a lack of strong directionality in the asymmetry patterns suggest that the reporting of signed values has very limited explanatory value in the assessment of asymmetry in femur length. The Georgian males display a significantly greater magnitude of asymmetry than the females (Table 63); this is the reverse of the case for the length of the humeri. The St. Bride's males have a modal asymmetry value of four millimeters, compared to a mode of two millimeters for the Spitalfields males (Figure 70). The Georgian females both have a modal femur length asymmetry value of one millimeter, but the Spitalfields females also have another distinct peak at the four-millimeter level which substantially increases their mean (Figure 71).

Table 63 Paired Georgian Femur Length Asymmetry Magnitude

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	3.33	2.73	3.64	2.43
SE	0.62	0.46	0.36	0.35
SD	2.61	2.64	2.17	2.08
.95 Confidence	1.21	0.90	0.71	0.69
N	18	33	36	35

Table 64 compares the pooled Georgian sample with the Forensic Data Bank individuals. The Georgian males follow the typical pattern in which they display a substantially greater asymmetry than the Forensic males. In fact the latter sample has a modal asymmetry of one millimeter, and few individuals displaying greater than three millimeters of length difference; the Georgians show much more variation (Figure 72). The pattern is reversed for the females. The Forensic females display a greater magnitude of asymmetry than their Georgian counterparts, with a substantial proportion of the Forensic women manifesting asymmetry of up to five millimeters, and a modal value of three millimeters (which contrasts with the Georgian mode of one millimeter). The relatively high level of asymmetry in the Forensic females femur length reverses the pattern of the humeri wherein all three measurements wherein the Georgians displayed a

Table 64 Combined Femur Length Asymmetry Magnitude

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	3.54	2.57	2.47	2.92
SE	0.31	0.28	0.19	0.23
SD	2.31	2.35	1.87	1.88
.95 Confidence	0.62	0.56	0.38	0.46
N	54	68	93	65

greater magnitude of asymmetry (Figure 73).

If magnitude alone is a basis for comparison, the ordinal ranking of the four Georgian subgroups in terms of symmetry is modified as well. For example, the Spitalfields females appear to have the greatest mean levels of asymmetry when signed values are used in the calculation, but in terms of magnitude, both the Spitalfields and St. Bride's males show greater asymmetry. Likewise, the St. Bride's males present the largest mean values for asymmetry when the magnitude alone is considered; when signed values are compared, however, both the Spitalfields males and females appear to show greater asymmetry. There is a somewhat different pattern for the Forensic Data Bank males and females. The males show slightly more mean asymmetry than the females when the signed values are compared, but the females show a greater magnitude of

Table 65 Femur Length Asymmetry—Ordinal Ranking

SIGNED (mm)		UNSIGNED (mm)		SIGNED (%)		UNSIGNED (%)	
SP♀	-1.82	SB♂	3.64	SP♀	0.45%	SB♂	0.80%
SP♂	-1.22	CG♂	3.54	SP♂	0.27%	CG♂	0.78%
CG♂	-1.06	SP♂	3.33	CG♂	0.24%	SP♂	0.75%
CG♀	-1.00	FD♀	2.92	CG♀	0.24%	FD♀	0.67%
SB♂	-0.97	SP♀	2.73	SB♂	0.22%	SP♀	0.67%
FD♂	-0.73	CG♀	2.57	FD♂	0.15%	CG♀	0.63%
FD♀	-0.61	FD♂	2.47	FD♀	0.14%	SB♀	0.59%
SB♀	-0.23	SB♀	2.43	SB♀	0.04%	FD♂	0.52%

asymmetry than the males (2.9 mm vs 2.5 mm) (Table 65).

The statistical significance of the sample differences in the length of the femur are much less profound than for the humerus (Table 66).

Table 66 Summary: Differences in Femur Length Asymmetry Magnitude Patterns

	SIGNED		UNSIGNED	
	z	*p*	*z*	*p*
Spitalfields vs St. Bride's Males	.119	—	.477	—
Spitalfields vs St. Bride's Females	1.736 (1.748)	< .10 (< .10)	.626	—
Spitalfields Males vs Females	.384	—	.985	—
St. Bride's Males vs Females	.914	—	2.421 (2.449)	< .05 (< .01)
Forensic Males vs Females	.011	—	1.715 (1.744)	< .10 (< .10)
Georgian vs Forensic Males	.627	—	2.583 (2.622)	< .01 (< .01)
Georgian vs Forensic Females	.232	—	1.710 (1.734)	< .10 (< .10)

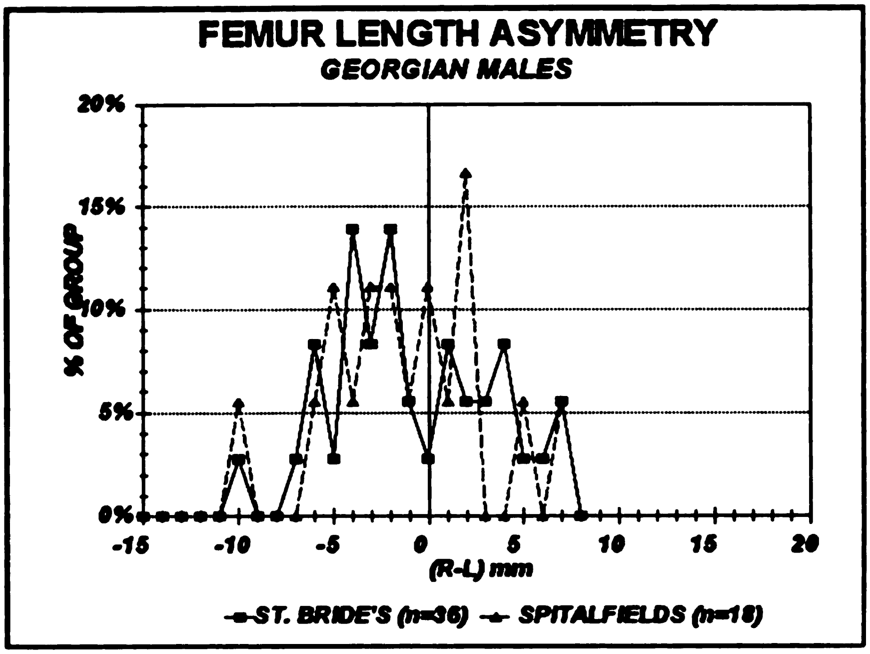

Figure 66 Georgian Male Signed Femur Length Asymmetry

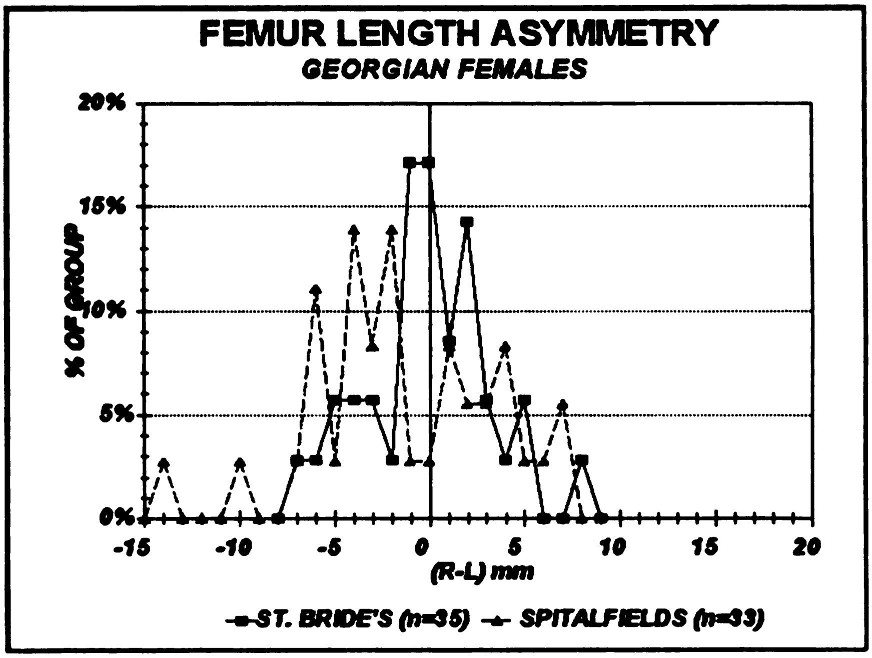

Figure 67 Georgian Female Signed Femur Length Asymmetry

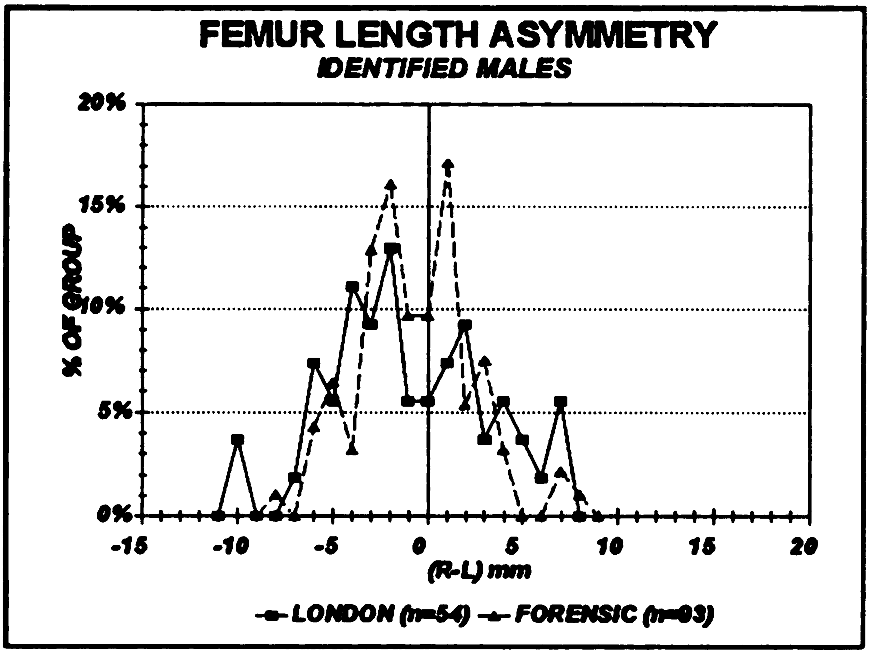

Figure 68 Identified Male Signed Femur Length Asymmetry

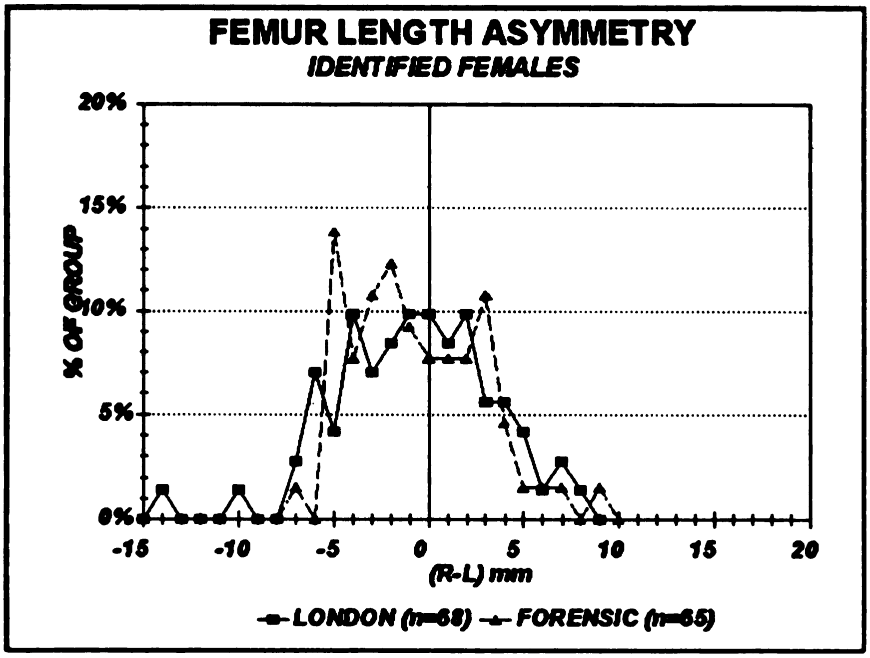

Figure 69 Identified Female Signed Femur Length Asymmetry

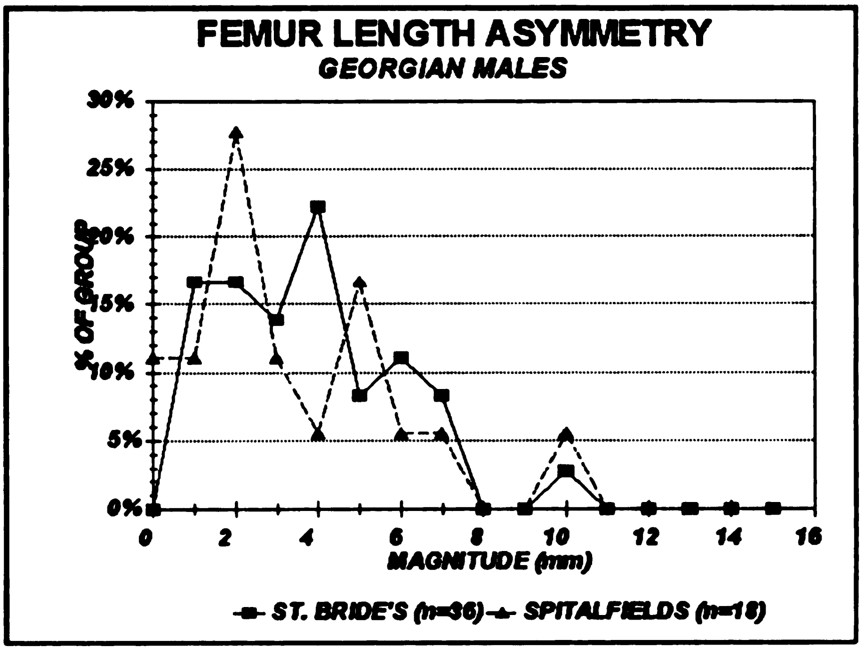

Figure 70 Georgian Male Femur Length Asymmetry

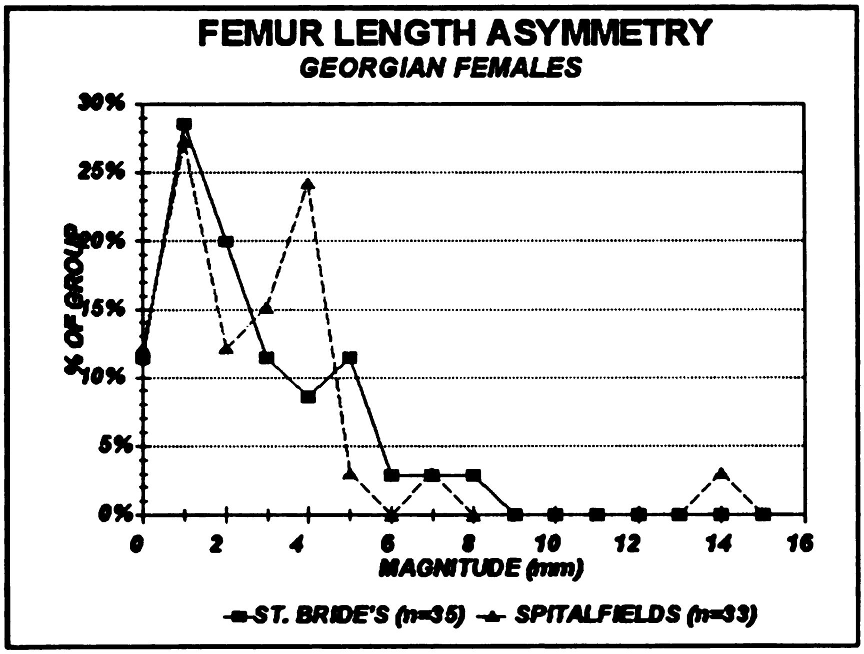

Figure 71 Georgian Female Femur Length Asymmetry

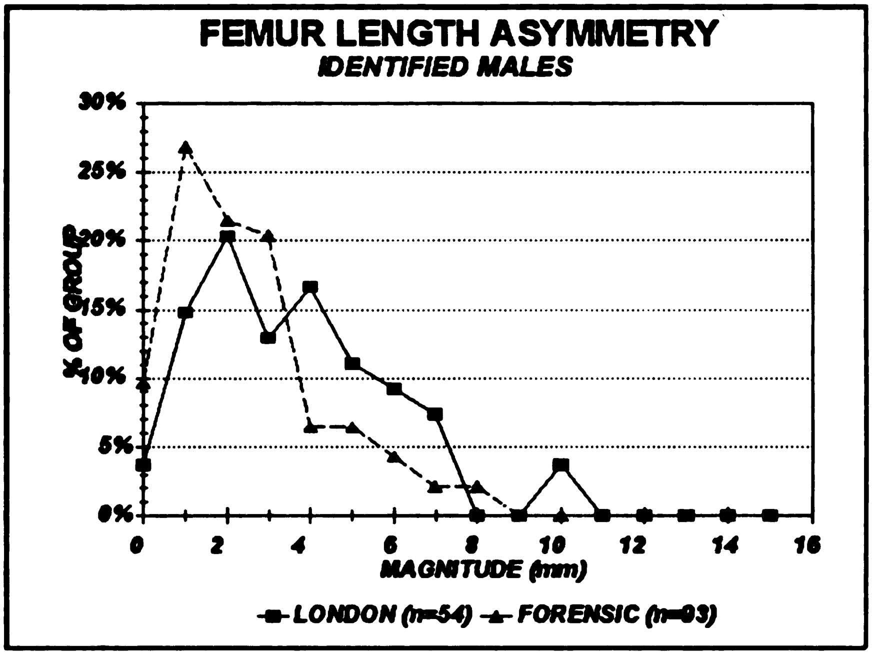

Figure 72 Identified Male Femur Length Asymmetry

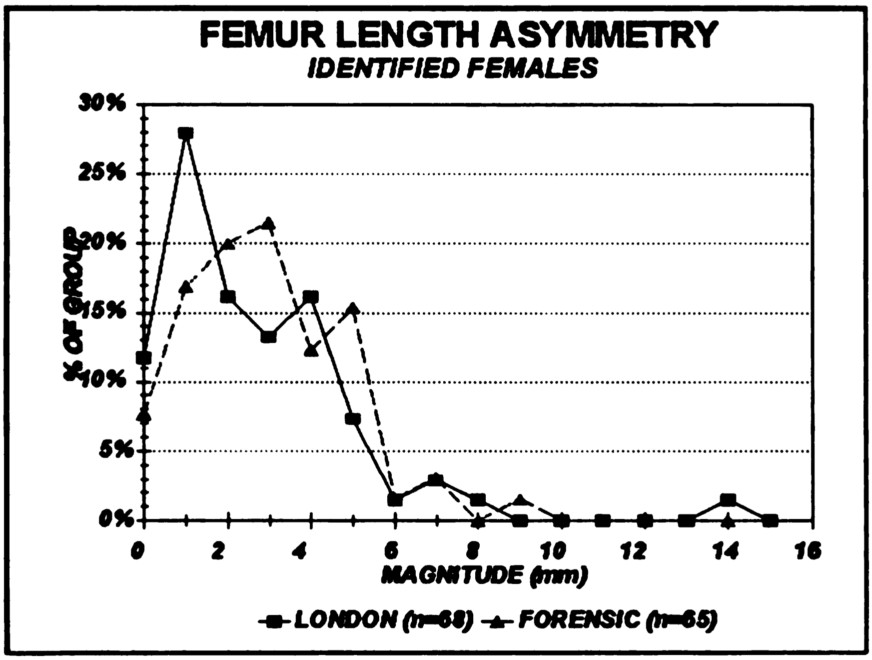

Figure 73 Identified Female Femur Length Asymmetry

Femur Head Diameter—FH

Table 67 Intact Georgian Femur Head Asymmetry Magnitude

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	0.65	0.85	0.79	0.68
SE	0.21	0.17	0.15	0.13
SD	0.86	0.86	0.72	0.58
.95 Confidence	0.41	0.33	0.29	0.26
N	17	27	24	19

Just as the diameter of the humeral head is not expected to vary substantially with physical activity, neither is the femoral head expected to do so. In fact the asymmetry distribution patterns for femur head differences are virtually the same as for the humerus heads. There is a very slight right-shift in the pattern, and the males and females are very similar. Among the Georgian samples, the St. Bride's males and females are slightly more asymmetrical than their Spitalfields counterparts (Figures 74 and 75). The pooled Georgian males are very similar in distribution pattern to the Forensic males (Figure 76), but the Georgian females display a right-shift which contrasts with the very slight left-shift in the Forensic females (Figure 77). Table 67 summarizes the findings for the Georgian samples in terms of unsigned magnitude values.

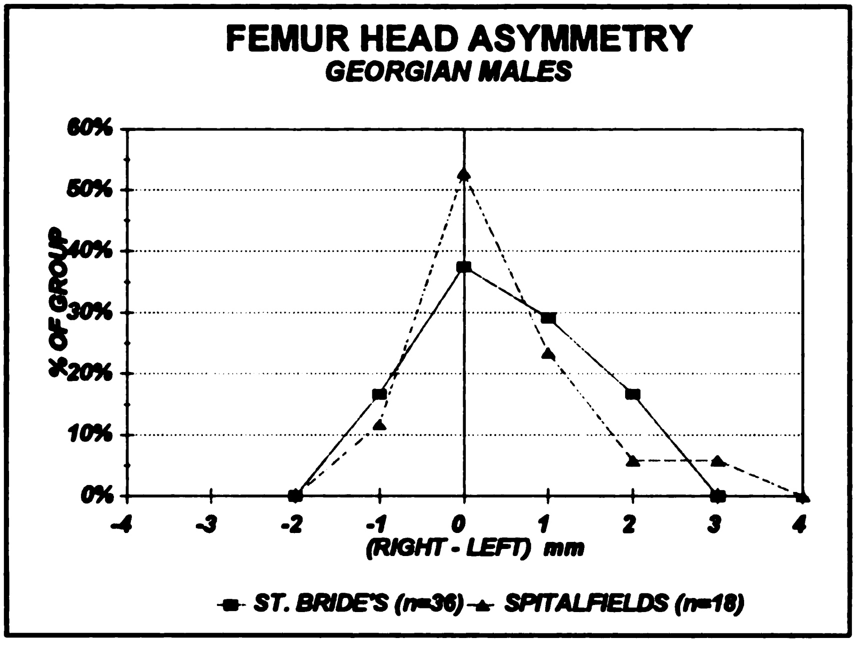

Figure 74 Georgian Male Signed Femur Head Asymmetry

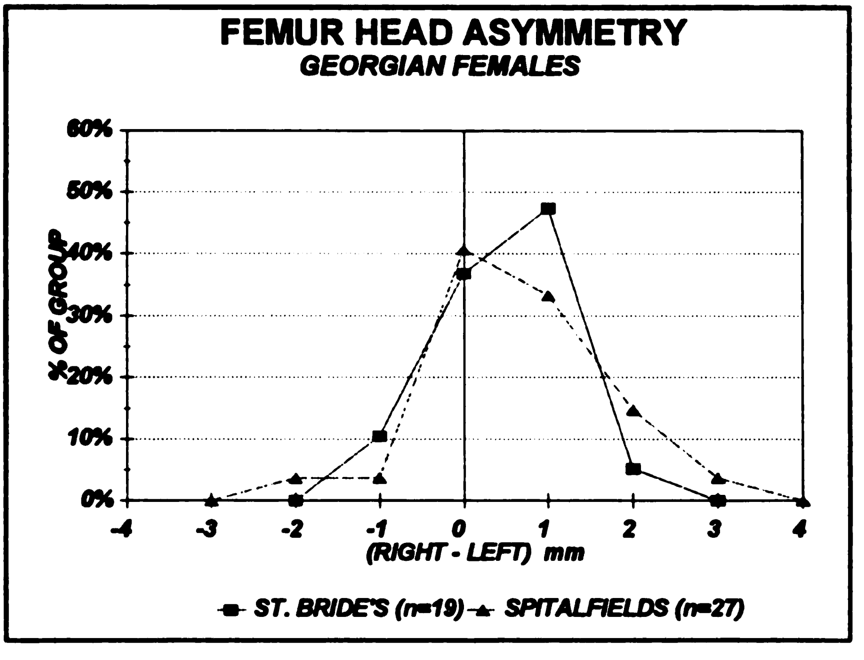

Figure 75 Georgian Female Signed Femur Head Asymmetry

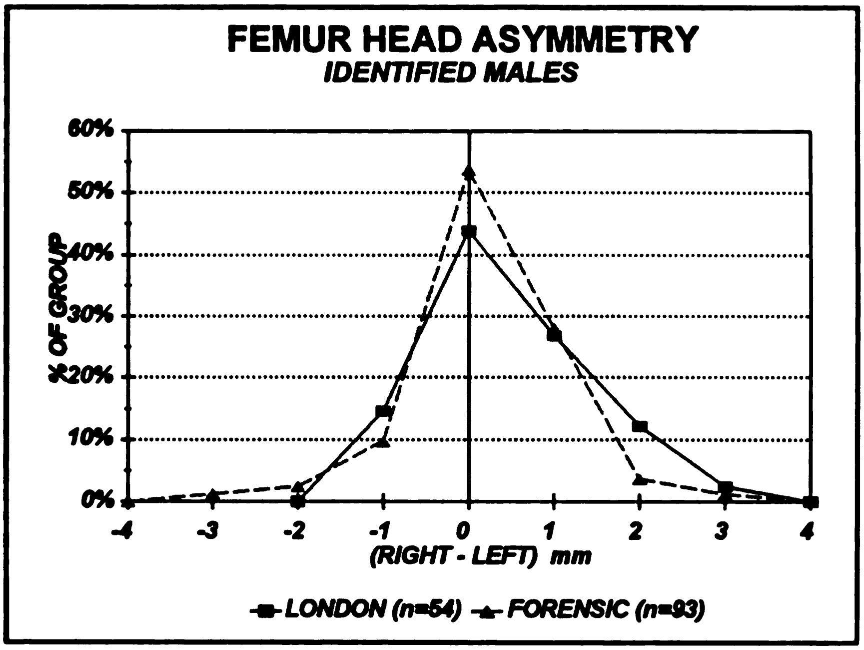

Figure 76 Identified Male Signed Femur Head Asymmetry

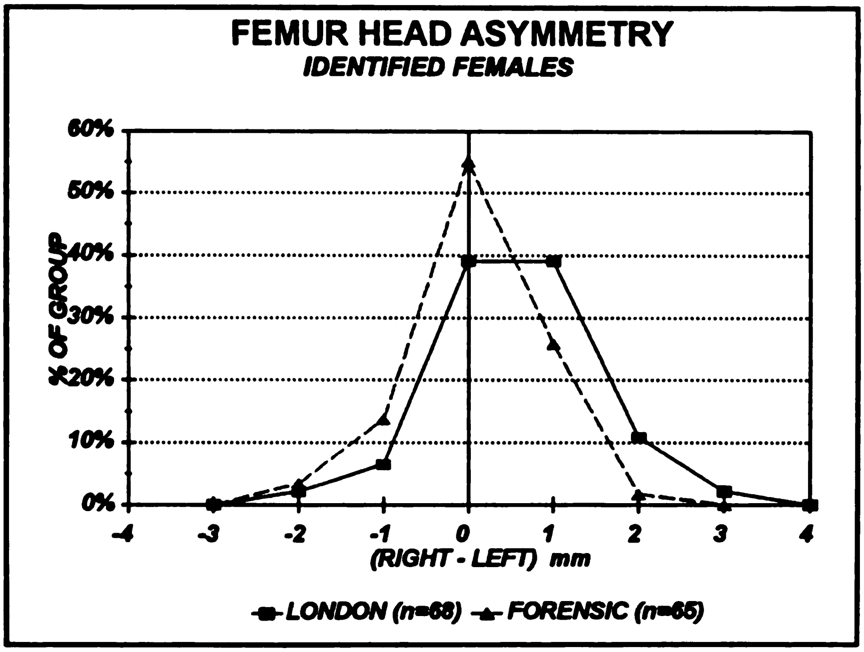

Figure 77 Identified Female Signed Femur Head Asymmetry

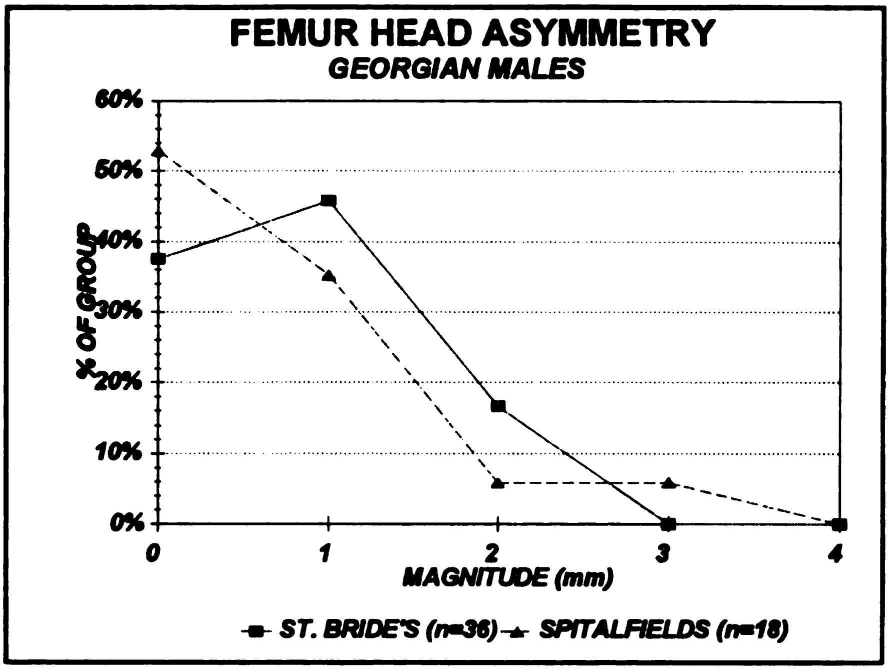

Figure 78 Georgian Male Femur Head Asymmetry

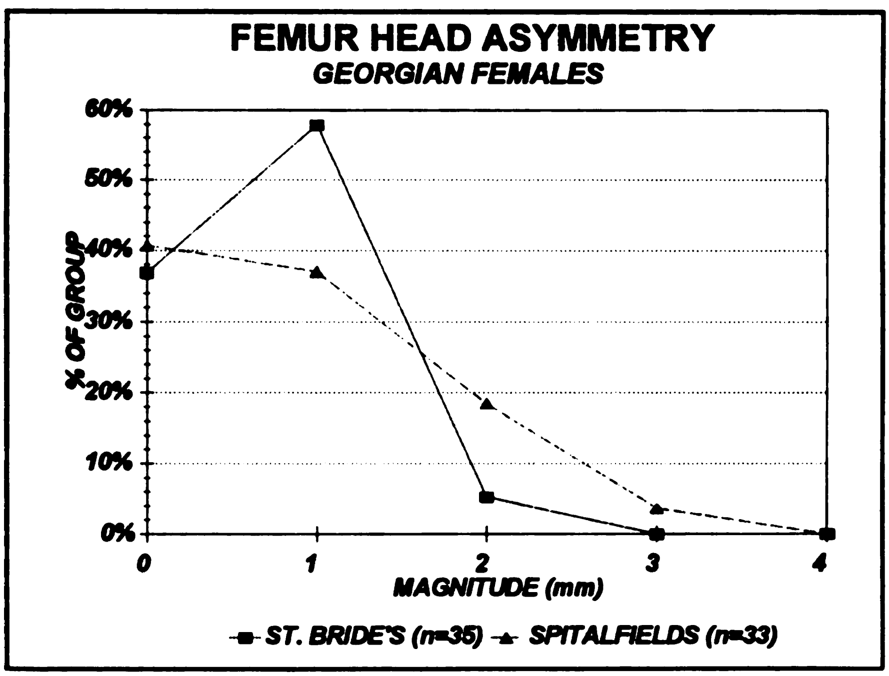

Figure 79 Georgian Female Femur Head Asymmetry

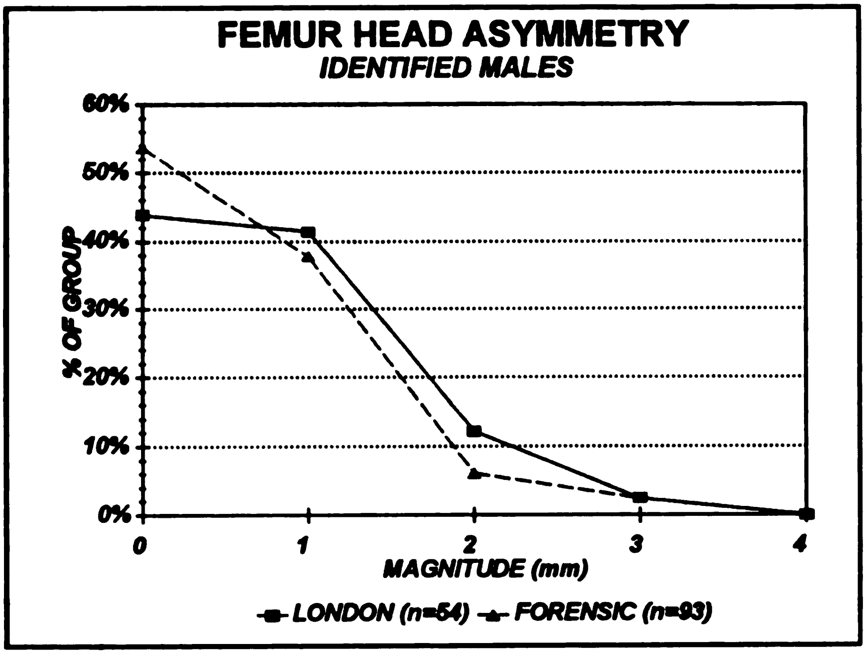

Figure 80 Identified Male Femur Head Asymmetry

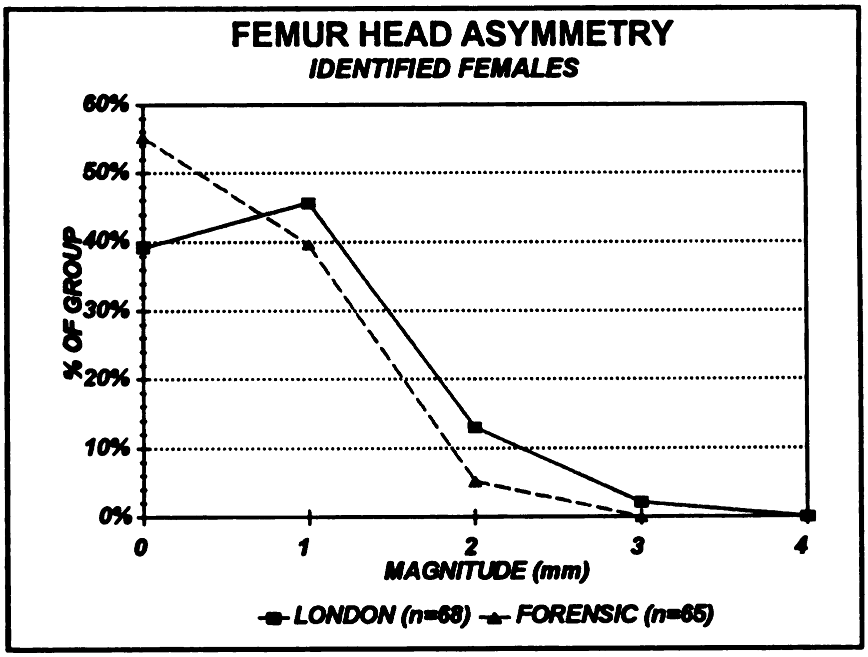

Figure 81 Identified Female Femur Head Asymmetry

In this instance, there is no obvious relationship between either the sexes or the populations with respect to the asymmetry patterns. That is, the St. Bride's males and the Spitalfields females display greater mean asymmetry magnitude than the Spitalfields males and the St. Bride's females. Both the St. Bride's males and females do have a modal head asymmetry value of one millimeter, which contrasts with the mode of zero that applies to the Spitalfields samples (Figures 78 and 79).

Table 68 Combined Femur Head Asymmetry Magnitude

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	0.73	0.78	0.57	0.50
SE	0.12	0.11	0.08	0.08
SD	0.78	0.76	0.72	0.60
.95 Confidence	0.24	0.22	0.16	0.15
N	41	46	82	58

The Forensic males and females also display a mode of zero for femoral head asymmetry, and in the end the distribution patterns for the pooled Georgians is quite similar to the Forensic sample, although the Georgians display a slightly greater magnitude of asymmetry (Table 68; Figures 80 and 81). Because head diameters are more symmetrical than are bone lengths or biepicondylar widths, the magnitude of differences among the study subgroups are small.

Table 69 Femur Head Diameter Asymmetry—Ordinal Ranking

SIGNED		UNSIGNED (mm)		SIGNED (%)		UNSIGNED (%)	
SP♀	0.63	SP♀	0.85	SP♀	1.45%	SP♀	2.02%
CG♀	0.57	SB♂	0.79	CG♀	1.31%	CG♀	1.85%
SB♀	0.47	CG♀	0.78	SB♀	1.11%	SB♂	1.71%
SB♂	0.46	CG♂	0.73	SB♂	0.96%	SB♀	1.62%
CG♂	0.44	SB♀	0.68	CG♂	0.89%	CG♂	1.55%
SP♂	0.41	SP♂	0.65	SP♂	0.80%	SP♂	1.32%
FD♂	0.21	FD♂	0.57	FD♂	0.43%	FD♂	1.17%
FD♀	0.09	FD♀	0.50	FD♀	0.22%	FD♀	1.17%

When asymmetry magnitude patterns among the study subgroups are ordinally ranked, there is again a general pattern in which the Georgian females display greater asymmetry than the males (Table 69). Likewise, the Forensic Data Bank samples are consistently more symmetrical than the Georgians, irrespective of which of the four techniques for calculating asymmetry is employed.

In terms of statistical significance of differences, the only remarkable differences occur between the forensic females and the Georgian females. The results of the calculations for all groups are presented in Table 70

Table 70 Summary: Differences in Femur Head Asymmetry Magnitude

	SIGNED		UNSIGNED	
	z	*p*	*z*	*p*
Spitalfields vs St. Bride's Males	.304	—	.807	—
Spitalfields vs St. Bride's Females	.435	—	.413	—
Spitalfields Males vs Females	.928	—	.819	—
St. Bride's Males vs Females	.147	—	.367	—
Forensic Males vs Females	.783	—	.309	—
Georgian vs Forensic Males	.888	—	1.046	—
Georgian vs Forensic Females	2.549 (2.756)	< .01 (< .01)	1.731 (1.920)	< .10 (< .10)

Femur Biepicondylar Width—FB

The epicondyles of the femur are primarily sites of ligamentous attachments, which makes them much less prone to direct activity-related changes than the epicondyles of the humerus. Among the study samples, they also do not display the wide range of variation that was present in the humeral biepicondylar widths. Among the Georgian males the St. Bride's sample is virtually symmetrical in its asymmetry distribution pattern, and the Spitalfields sample displays a distinctive right-shift (Figure 82). Both of the Georgian female sample have a right-shift, as well as a modal asymmetry value of one millimeter (Figure 83)

When the Georgians are pooled and compared with the Forensic sample, the males display virtually the same distribution pattern (Figure 84). The Forensic females display a virtually normal distribution as well, with only the slightest hint of a right-shift in distribution pattern (Figure 85). As was the case for the femoral head diameter, the Georgians do not display a distinctive population-related or gender-related pattern of asymmetry magnitude (Table 71). However, there is an unusual trend among the Georgians. The Spitalfields males and the St. Bride's females display the greatest magnitude of asymmetry, which is the reverse of the case of the femoral head diameters. The numbers are too small to suggest that there is any real inverse relationship between head diameter asymmetry and biepicondylar width asymmetry, but they do suggest that there is no obvious relationship between the two measurements. (See "Patterns in the Femur" for the results of the statistical testing of the relationships among measurements within the study samples.)

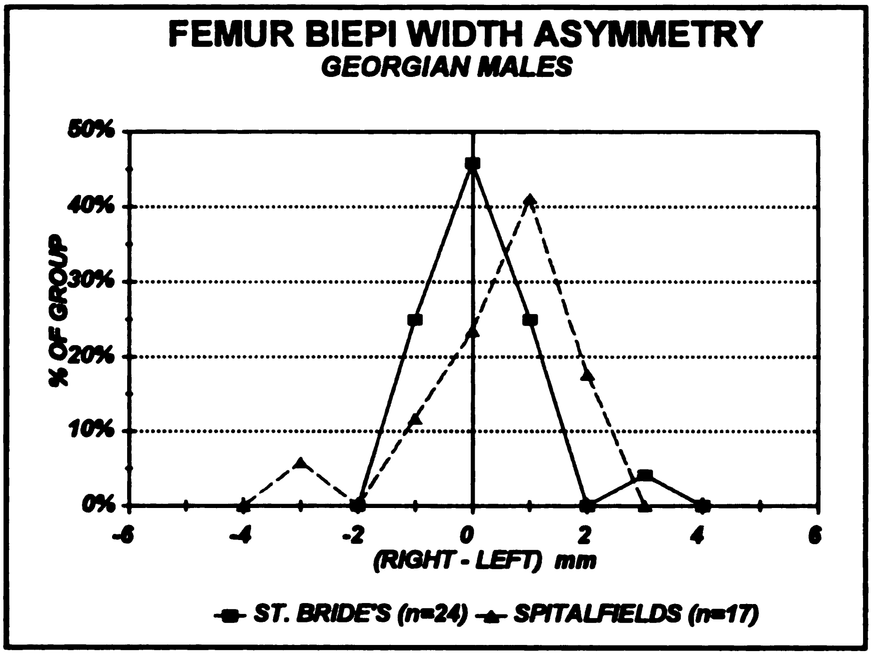

Figure 82 Georgian Male Signed Femur Biepi Asymmetry

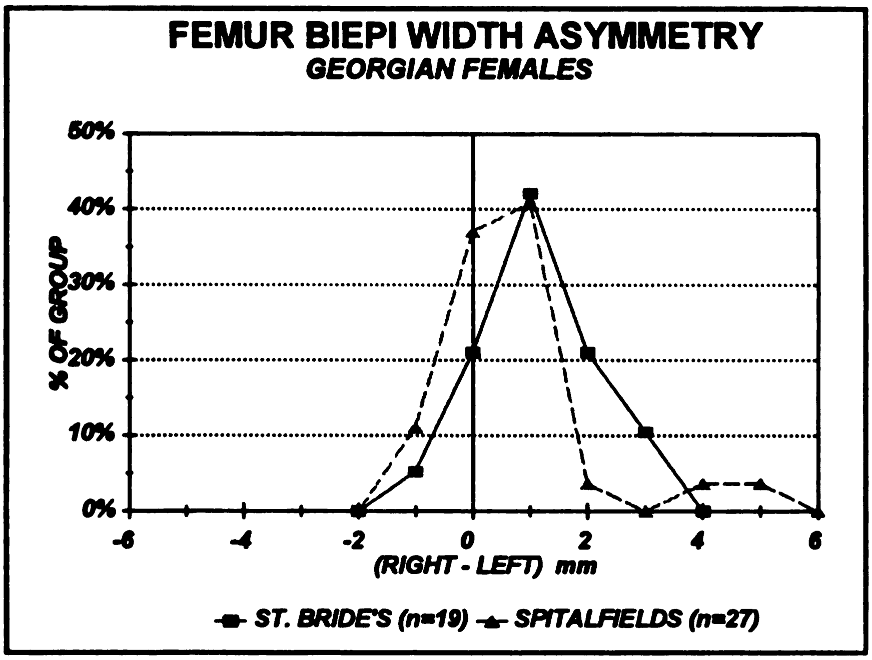

Figure 83 Georgian Female Signed Femur Biepi Asymmetry

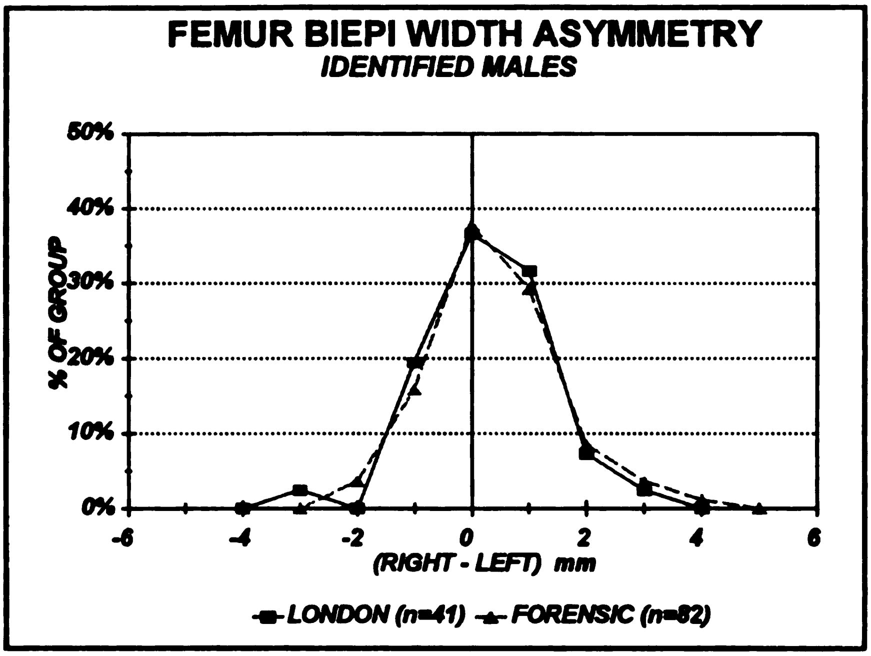

Figure 84 Identified Male Signed Femur Biepi Asymmetry

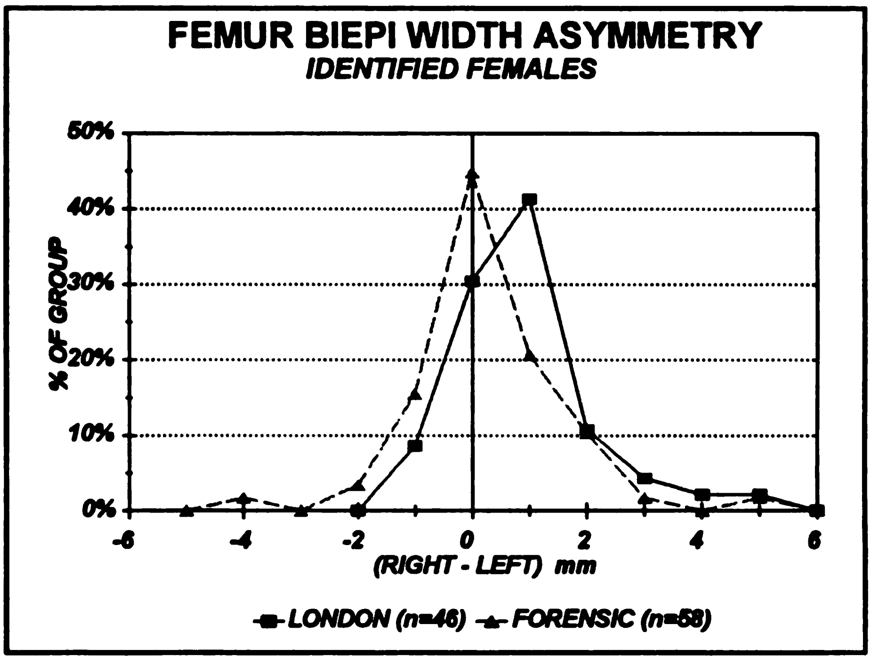

Figure 85 Identified Female Signed Femur Biepi Asymmetry

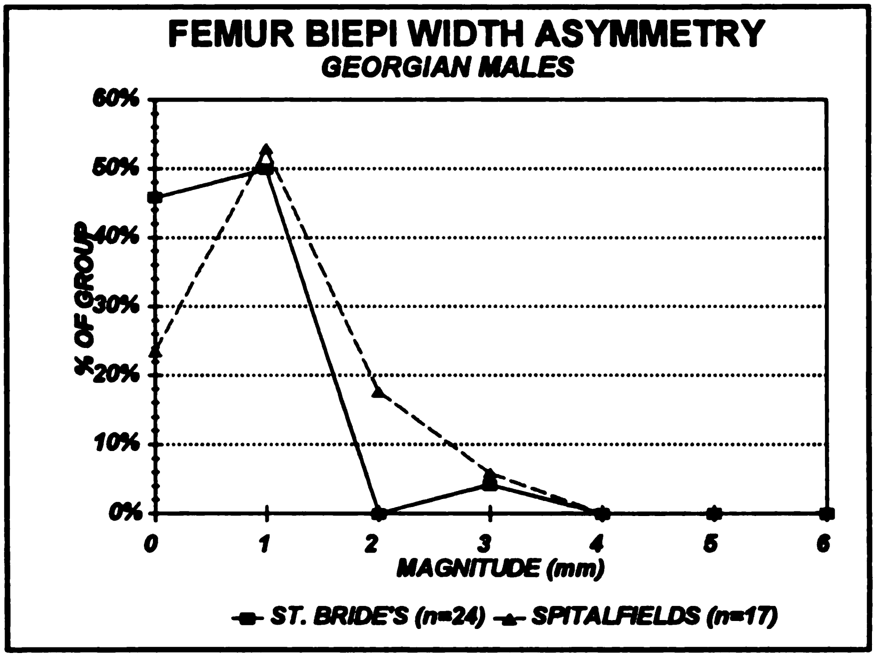

Figure 86 Georgian Male Femur Biepi Asymmetry

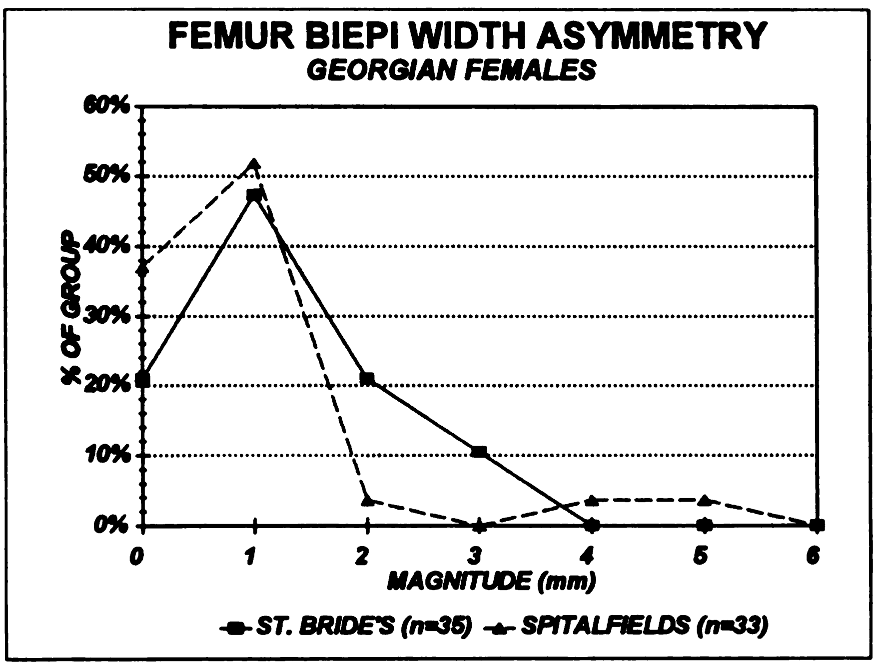

Figure 87 Georgian Female Femur Biepi Asymmetry

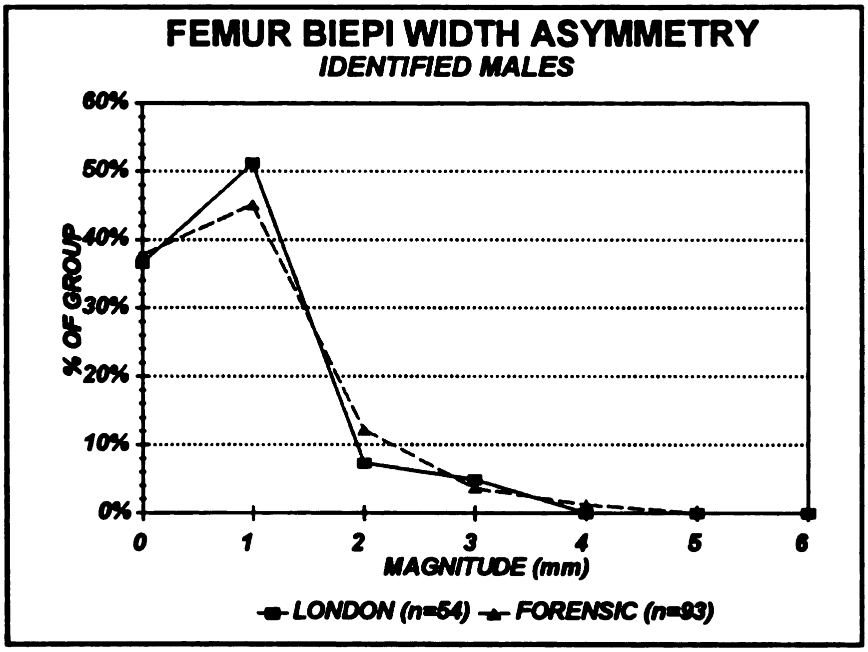

Figure 88 Identified Male Femur Biepi Asymmetry

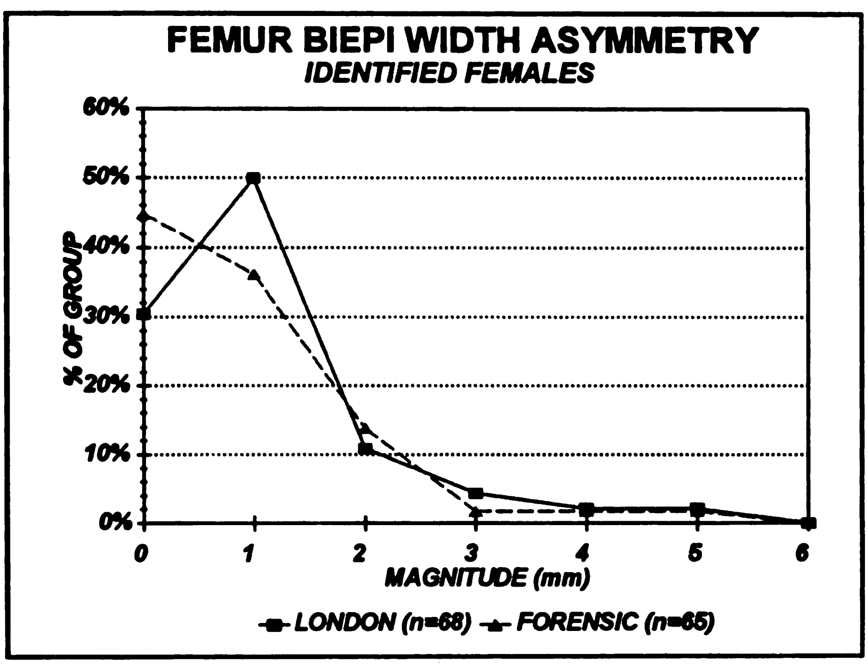

Figure 89 Identified Female Femur Biepi Asymmetry

Table 71 Georgian Femur Biepicondylar Width Asymmetry Magnitude

	Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Mean	1.06	0.93	0.63	1.21
SE	0.20	0.23	0.15	0.21
SD	0.83	1.17	0.71	0.92
.95 Confidence	0.39	0.44	0.28	0.41
N	17	27	24	19

All four of the Georgian subsamples display a modal value of one millimeter difference in biepicondylar widths (Figures 86 and 87).

When the pooled Georgians are compared with the Forensic Data Bank sample, there is again no clear pattern of either a gender or a population similarity in asymmetry magnitude (Table 72). The Forensic males are virtually the same as the Georgian males (Figure 88) and there is only a slight difference for the females. Because of the extremely high level of symmetry in the Forensic females, however, the modal value for

Table 72 Combined Femur Biepicondylar Width Asymmetry Magnitude

	Georgian Males	Georgian Females	Forensic Males	Forensic Females
Mean	0.80	1.04	0.85	0.84
SE	0.12	0.16	0.10	0.14
SD	0.78	1.07	0.86	1.04
.95 Confidence	0.24	0.31	0.19	0.27
N	41	46	82	58

that group is zero millimeters (in contrast with the other subgroups) (Figure 89).

When the biepicondylar width asymmetries are ordinally ranked, there is again no clear relationships among the study subgroups (Table 73).

Table 73 Femur Biepicondylar Width Asymmetry—Ordinal Ranking

SIGNED (mm)		UNSIGNED (mm)		SIGNED (%)		UNSIGNED (%)	
SB♀	1.11	SB♀	1.21	SB♀	1.53%	SB♀	1.67%
CG♀	0.87	SP♂	1.06	CG♀	1.19%	CG♀	1.44%
SP♀	0.70	CG♀	1.04	SP♀	0.96%	SP♂	1.29%
SP♂	0.47	SP♀	0.93	SP♂	0.56%	FD♀	1.12%
FD♂	0.39	FD♂	0.85	FD♂	0.47%	FD♂	1.01%
CG♂	0.27	FD♀	0.84	FD♀	0.36%	CG♂	0.98%
FD♀	0.26	CG♂	0.80	CG♂	0.32%	SB♂	0.77%
SB♂	0.13	SB♂	0.63	SB♂	0.14%	SP♀	0.66%

Table 74 Femur Biepicondylar Width Asymmetry Magnitude Differences

	SIGNED		UNSIGNED	
	z	*p*	*z*	*p*
Georgian ♂	1.508	—	1.680 (1.859)	< .10 (< .10)
Georgian ♀	1.629	—	1.439	—
Spitalfields ♂ / ♀	.205	—	1.012	—
St. Bride's ♂ / ♀	2.935 (3.063)	< .005 (< .005)	2.103 (2.294)	< .05 (< .05)
Forensic ♂ / ♀	.651	—	.459	—
Georgian / Forensic ♂	.335	—	.166	—
Georgian / Forensic ♀	2.541 (2.564)	< .05 (< .05)	1.096	—

Table 74 summarizes the results of the Mann-Whitney significance tests. In terms of statistical significance, there are notable differences between the sexes in the Georgian samples, and between the same-sex groups of St. Bride's and Spitalfields. Interestingly, however, the pooled Georgian males and females do not differ significantly from their Forensic counterparts, and there is no significant difference between the Forensic males and females in terms of femoral biepicondylar width asymmetry magnitude.

PATTERNS IN THE HUMERUS

One might assume that in any paired set of humeri a finding of right-dominance in bone length would be necessarily coupled with right-dominance in head diameter and/or biepicondylar width, as well. This assumption would make particular sense if physical activity patterns were the primary determinants of side-dominance patterns. To determine whether this was indeed the case, the study samples were used to test the hypothesis that there is a relationship between the direction of asymmetry in biepicondylar width of the humerus and the maximum length of the bone. Each individual who displays asymmetry in both of those measurements at a magnitude of one millimeter or larger was assessed to determine whether the direction of asymmetry in biepicondylar width was the same as, or different from, the direction of asymmetry in length. Persons who were coded as symmetrical in either of the measurements were not included in the assessment. Likewise, paired comparisons were made with the relationship between length and head diameter, as well as biepicondylar width and head diameter.

Table 75 shows the results of the comparisons for the four Georgian subgroups. The calculated p values represent the probability that the paired observed values would arise from a population where there is equal likelihood that individuals would fall into the two categories. For both the males and females of Spitalfields, the relationships between humerus length and biepicondylar width are highly significant, and the relationships between humerus length and head diameter are significant. The relationship between length and head diameter is significant for the St. Bride's males as well. None of the Georgian samples display a statistically significant relationship between the direction of

Table 75 Georgian Differences in Humerus Asymmetry Direction Patterns

		Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Length vs Biepicondylar Width	Same	21	24	9	7
	Diff	7	9	3	2
	p	<.01	<.01	<.10	<.10
Length vs Head Diameter	Same	15	17	8	3
	Diff	5	7	1	2
	p	<.05	<.05	<.05	—
Biepicondylar Width vs Head Diameter	Same	11	7	5	0
	Diff	4	10	2	1
	p	<.10	—	—	—

biepicondylar width and head diameter.

Sample size has a notable effect on calculated p values in a binomial test, and pooling the Georgians by sex increases the level of significance in this assessment, as evident in Table 76. The relationship between the biepicondylar width and length of the humerus is highly significant for both the Georgian males and females, in contrast with the Forensic males in particular. The Forensic females display a significant difference as well, the only statistically significant finding for the Forensic sample in the humerus. The difference between the Georgian and Forensic samples is noteworthy, for it indicates a significant relationship for the more highly directional group, but a lack of relationship for the less directional contemporary sample.

Table 76 Summary: Differences in Humerus Asymmetry Direction Patterns

		Georgian Males	Georgian Females	Forensic Males	Forensic Females
Length vs Biepicondylar Width	Same	30	31	29	25
	Diff	10	11	20	10
	p	<.005	<.005	—	<.01
Length vs Head Diameter	Same	23	20	24	15
	Diff	6	9	16	11
	p	<.005	<.05	—	—
Biepicondylar Width vs Head Diameter	Same	15	7	20	10
	Diff	6	11	12	9
	p	<.05	—	—	—

PATTERNS IN THE FEMUR

In order to assess the patterns of relationship between asymmetry direction among the three paired observations of paired femora, the same analytical scheme was applied to the femur as described for the humerus above. Those individuals who displayed a measurable asymmetry in both of the paired measurements under consideration were included in the assessment, and those which were symmetrical in either measurement were not included.

The findings for the Georgians are listed in Table 77. There are no statistically significant deviations from the null hypothesis that observations would fall equally into the same and different categories. For the Georgians, at least, there is no evidence for a relationship between direction of asymmetry in any of the paired measurements.

Table 77 Georgian Differences in Femur Patterns

		Spitalfields Males	Spitalfields Females	St. Bride's Males	St. Bride's Females
Length vs Biepicondylar Width	Same	8	8	2	3
	Diff	5	8	5	3
	p	—	—	—	—
Length vs Head Diameter	Same	3	6	2	2
	Diff	3	7	5	2
	p	—	—	—	—
Biepicondylar Width vs Head Diameter	Same	3	7	2	1
	Diff	2	2	2	1
	p	—	—	—	—

When the Georgians are pooled and compared with the Forensic sample, the pattern persists, as evident in Table 78. Even with the larger sample sizes, there are virtually no statistically significant deviations from the null hypothesis that same-side and opposite-side dominance would occur with equal probability. The one exception is the Forensic males, who display a highly significant pattern of reversed relationship between length of the femur and femoral head diameter. Earlier in this chapter the general pattern of right-dominance in head diameter and biepicondylar width of the femur in contrast with the left-dominant length of the femur were noted, but this is the only instance where the pattern is revealed to be statistically significant.

Table 78 Summary: Differences in Femur Asymmetry Direction Patterns

		Georgian Males	Georgian Females	Forensic Males	Forensic Females
Length vs Biepicondylar Width	Same	10	11	23	14
	Diff	10	11	21	16
	p	—	—	—	—
Length vs Head Diameter	Same	5	8	13	10
	Diff	8	9	29	13
	p	—	—	<.005	—
Biepicondylar Width vs Head Diameter	Same	5	8	14	10
	Diff	4	3	9	5
	p	—	—	—	—

PATTERNS IN THE HUMERUS AND FEMUR

The suggestion that there may be a tendency toward a difference in asymmetry direction of observations within a bone leads to the question of whether there is a notable pattern of cross symmetry in the study samples. To test this, individuals manifesting measurable asymmetry in length of the humerus and length of the femur were assessed in a manner very much like that described above for the individual bones. Asymmetry thresholds of both one millimeter and two millimeters were both used, to determine if they would have an effect on the results.

Table 79 lists the results for the Georgian subgroups. In each group there is a greater proportion of individuals displaying a crossed symmetry pattern rather than a same-side asymmetry pattern, typically by a two to one margin. In most cases, however,

Table 79 Georgian Cross Symmetry in Humerus and Femur Lengths

		Same-Side	Crossed	*p*
Spitalfields Males	1 mm	4	9	—
	2 mm	3	8	—
Spitalfields Females	1 mm	9	18	—
	2 mm	4	15	<.01
St. Bride's Males	1 mm	8	10	—
	2 mm	3	7	—
St. Bride's Females	1 mm	6	12	—
	2 mm	4	6	—

the differences are not large enough to reject the null hypothesis that the study samples were drawn from a population in which there is an equally likelihood of same-side and crossed asymmetry. The only notable finding is that the use of a two-millimeter asymmetry threshold results in a scenario where the Spitalfields females display a highly statistically significant pattern of crossed symmetry.

Table 80 pools the two Georgian samples and contrasts them with the Forensic sample. There is a statistically significant pattern of crossed symmetry in both the Georgian males and the Georgian females at the .05 level, if a two-millimeter threshold is employed to distinguish between symmetry and asymmetry. In contrast, there is substantially less crossed symmetry in the Forensic sample, and no evidence of a statistically significant pattern of cross symmetry in that sample.

Table 80 Combined Cross Symmetry in Humerus and Femur Lengths

		Same-Side	Crossed	*p*
Georgian Males	1 mm	12	19	—
	2 mm	6	15	<.05
Georgian Females	1 mm	15	30	—
	2 mm	8	21	<.05
Forensic Males	1 mm	31	29	—
	2 mm	15	17	—
Forensic Females	1 mm	19	27	—
	2 mm	12	21	—

Summary

Well over half of the Georgian males and females display a pattern of crossed symmetry in humerus and femur lengths, with the females presenting a greater extent of the pattern than the males. In contrast, the Forensic males and females are relatively more likely to display same-side symmetry, and the Forensic males demonstrate slightly more same-side asymmetry than crossed symmetry at the one-millimeter symmetry threshold. In all cases, raising the symmetry threshold from one millimeter to two millimeters accents the crossed symmetry phenomenon. By far, the predominant pattern is one of a right-dominant humerus coupled with a left-dominant femur.

SUMMARY: RESULTS OF HYPOTHESIS TESTING

Throughout this chapter, the hypotheses introduced in Chapter 2 have been tested by using statistical techniques that determine the probability that the two samples being compared are drawn from a single population. An alpha of .05 maintains consistency with the literature, and is used here to indicate *p* values that are adequately significant to indicate independence.

Table 81 Significant Differences in Humerus and Femur Dimensions

	Humerus			Femur		
	L	**H**	**B**	**L**	**H**	**B**
Georgian ♂						
Georgian ♀	✔					
Spitalfields ♂ / ♀	✔	✔	✔	✔	✔	✔
St. Bride's ♂ / ♀	✔	✔	✔	✔	✔	✔
Forensic ♂ / ♀	✔	✔	✔	✔	✔	✔
Georgian / Forensic ♂	✔	✔	✔	✔	✔	✔
Georgian / Forensic ♀	✔	✔	✔	✔	✔	✔

(1) <u>That the Georgian skeletal samples are drawn from a common population that is significantly different from the Forensic sample in terms of long bone dimensions</u>. This hypothesis is supported by *z* and *t* test comparisons of means for the study samples, as indicated in Table 81.

For five of the six paired measurements (length (L), head diameter (H), and biepicondylar width (B)) there is no statistical difference between the two Georgian male samples nor between the two Georgian female samples. The lone exception is maximum length of the humerus, which was significantly different ($p < .05$) for the Georgian females. These results do not allow rejection of the null hypothesis that both Georgian samples were drawn from a single population. In contrast, the pooled Georgians differ very significantly from the Forensic sample in each of the six paired measurements, with the twentieth-century group larger in each instance. For both males and females, comparisons of bone dimensions between the pooled Georgians and the Forensic sample clearly indicate a rejection of the null hypothesis that they are drawn from the same population.

Table 82 Significant Differences in Humerus Asymmetry Among the Study Samples

	Length			**Head Diameter**			**Biepicondylar Width**		
	D	U	S	D	U	S	D	U	S
Georgian ♂									
Georgian ♀				✔					
Spitalfields ♂ / ♀		✔	✔						
St. Bride's ♂ / ♀									
Forensic ♂ / ♀			✔						
Georgian / Forensic ♂	✔	✔	✔			✔			
Georgian / Forensic ♀	✔	✔	✔		✔	✔			

(2) That an individual's sex is a primary determinant of long bone asymmetry patterns. Table 82 reviews the results of the study regarding asymmetry patterns in the

Table 83 Significant Differences in Femur Asymmetry Among the Study Samples

	Length			Head Diameter			Biepicondylar Width		
	D	U	S	D	U	S	D	U	S
Georgian ♂							✔		
Georgian ♀	✔								
Spitalfields ♂ / ♀									
St. Bride's ♂ / ♀	✔	✔					✔	✔	✔
Forensic ♂ / ♀									
Georgian / Forensic ♂	✔	✔							
Georgian / Forensic ♀						✔		✔	

humerus for the three paired measurements under consideration. Table 83 reviews the study's results regarding the comparisons of asymmetry patterns in the three paired measurements in the femur. Taken together, the information contained in these two Tables summarizes the study findings for hypothesis two and hypothesis three. In the Tables, statistical significance at the .05 level is indicated for direction of asymmetry (D), unsigned magnitude (U), and signed magnitude (S). Given these results, there is not strong support for this hypothesis. The Spitalfields males and females differ significantly in both unsigned and signed humerus length asymmetry, but this pattern is not shared by their counterparts from St. Bride's. Forensic males and females differ significantly in terms of signed humerus length magnitude, but this is the only measurement among the six in which they display significant sex-related variation. In the femur, the only sex-related difference in asymmetry patterns is seen among the St. Bride's males and females.

(3) That a population's setting (in terms of time and space) is a primary determinant of long bone asymmetry patterns. The study results offer strong but not unequivocal support for this hypothesis. In humerus length, both the males and the females of the Georgians and Forensic samples differ significantly in direction of asymmetry, as well as its signed and unsigned magnitude. There are also significant differences between these samples in the magnitude of humerus head asymmetry. In the femur, the Georgian and Forensic males differ significantly in bone length, and the females differ in terms of signed magnitude of head diameter and unsigned magnitude of biepicondylar width.

Table 84 Significant Differences in Asymmetry Direction Between Measurements

		Spitalfields		**St. Bride's**		**Georgian**		**Forensic**	
		♂	♀	♂	♀	♂	♀	♂	♀
Length vs Biepicondylar Width	Humerus	✔	✔			✔	✔		✔
	Femur								
Length vs Head Diameter	Humerus	✔	✔	✔		✔	✔		
	Femur							✖	
Biepicondylar Width vs Head Diameter	Humerus					✔			
	Femur								
Humerus vs Femur Length			✖			✖	✖		

(4) That physical activity is a primary determinant of long bone length asymmetry. Table 84 summarizes the results of comparing the direction of asymmetry

among various pairs of measurements. Statistically significant patterns of same-side dominance are indicated by a check (✔) and opposite-side dominance by a cross (✖). If physical activity were associated with bone length asymmetry, then there should a significant same-side relationship between direction of asymmetry in biepicondylar width and length of the bone.

This is clearly the case for the humerus, except for the Forensic males. The Spitalfields sample displays a significance at $p < .01$, and the St. Bride's males and females both exhibit significance at the level of $p < .10$. The apparent lack of significance for the St. Bride's sample may be an artifact of small sample size, on which the binomial test is highly dependent. If the St. Bride's sample size were doubled, assuming the same ratio of same-side to opposite-side dominance, both the males and females would exhibit significance at $p < .05$. When the Georgians are pooled, the extent of same-side dominance in humerus length and biepicondylar width is very highly significant for both males and females ($p < .005$).

There is virtually no such relationship in the femur for any of study samples, and there appears to be no relationship between directional asymmetry, femoral length, and biepicondylar width. It is noteworthy that femur length is longer on the left in all the groups, yet both head diameter and biepicondylar width are generally right-dominant. These trends are not statistically significant except for the Forensic males, which inexplicably display a very highly significant opposite-side dominance pattern between femoral length and head diameter. It is noteworthy that the comparison of side-dominance patterns in humerus and femur length asymmetry demonstrates a significant proportion of cross symmetry in the Georgian groups which is not seen as strongly in the

Forensic sample.

In contrast, the distinct patterns of same-side dominance in the humerus support this hypothesis. Because paired humeri are more likely to be subject to bilaterally dissimilar activity patterns than are the femora, and because the epicondyles of the humerus are more associated with muscle attachments than are the epicondyles of the femora, the evidence from the humerus for an activity-related effect on humerus asymmetry is more compelling than the seemingly contradictory evidence from the femur.

CHAPTER 6—DISCUSSION

The analysis of bilateral asymmetry in human limb bones is an increasingly prominent aspect of the biocultural approach to human skeletal biology. The literature review in Chapter 2 indicates that several recent studies draw attention to asymmetry in the cross-sectional geometry of long bone diaphyses. Researchers have acknowledged the presence of directional asymmetry in linear dimensions of long bones as well; however, the existence of these asymmetry patterns are either reported with little comment, or attributed to the effects of fluctuating asymmetry. As a result, the nature of metric asymmetry patterns in the linear dimensions of long bones has not been well characterized in human populations. The purpose of this study is to set a foundation for future biocultural analyses by assessing the nature of asymmetry variation in related and unrelated skeletal populations.

SUMMARY OF THE STUDY STRATEGY

This study assesses limb bone asymmetry patterns in two skeletal samples from Georgian-era London church crypts (St. Bride's, Fleet Street, and Christ Church, Spitalfields), which are compared with figures derived from the Forensic Data Bank at the University of Tennessee. The Georgian crypt samples are particularly valuable because they are drawn from a group of individuals associated with a common setting in space and time. These characteristics set them apart from the Forensic sample, which represents individuals from the United States in the twentieth century. The lifeways of the Forensic individuals are not documented, so it is difficult to confidently offer a basis of comparison between them and the Georgians in terms other than their setting in space and time. It is important to note--and this cannot be emphasized too strongly--that the hypotheses in this study are constructed to draw inferences about the nature of bilateral asymmetry patterns in major long bones, and not to draw inferences about the skeletal samples being studied. The only assumptions that can confidently be made about the samples is that the Georgians are associated with a common setting in time and space which is distinctly different from that of the Forensic sample.

Six paired measurements are compared among the three skeletal samples: maximum length, vertical head diameter, and biepicondylar width of the humerus; and maximum length, head diameter, and biepicondylar width of the femur. Study hypotheses test whether the samples and the sexes display statistical independence in the distribution of (a) direction of asymmetry, (b) signed and unsigned magnitude of asymmetry; and (c) size of the linear dimensions themselves. The two Georgian samples are first assessed separately, then pooled and compared with the Forensic sample; in each case the sexes are treated separately. The linear dimensions are assessed using t and z test statistics, the direction of asymmetry is assessed using χ^2 analysis, and the signed and unsigned magnitude of asymmetry are assessed using the Mann-Whitney U test statistic. The significance of same-side versus crossed symmetry patterns both within and across bone pairs are assessed using the binomial test.

As one would expect, in each measurement there is a clear pattern of sexual dimorphism in character size, with the males significantly larger than the females in all cases. There is also a highly significant difference in the bone dimensions when the Georgian males and compared with the Forensic males, and when the Georgian females are compared with the Forensic females; in this instance the Georgians are consistently smaller in size. It is not surprising that the Georgians are relatively smaller in size than the twentieth-century sample; however, the Georgians display a substantially greater magnitude of asymmetry than the Forensic sample. Specifically, the Georgian females display the greatest asymmetry in humerus length, and the Georgian males display the greatest asymmetry in femur length. Asymmetry patterns are more often significantly different in Georgian-Forensic comparisons than in comparisons between the sexes of each sample, or between same-sex subgroups of the Georgian samples; this indicates that setting in time and space, but not sex, is a determinant of asymmetry patterns in long bone dimensions. One may feel compelled to speculate about specific environmental or activity-related factors that account for the differences between the eighteenth- and twentieth-century populations, but the nature of those factors is elusive because little is known about the specific lifeways of the individuals that comprise the Forensic sample.

It is possible to draw some inferences (see Hypothesis 4) about physical activity in these samples as they are revealed in skeletal morphology, if one is willing to accept as given France's (1988) assertion that those aspects of bone which are muscle attachments are particularly subject to modification by activity. There is a statistically significant same-side relationship between biepicondylar width and maximum length of the humerus which suggests a correlation between physical activity and bone length asymmetry. The fact that the same-side relationship pattern does not persist in femora is still consistent with the suggestion, since the epicondyles of the femur are more associated with ligamentous attachments, rather than muscle attachments, and would be less likely subject to activity-related modification.

Another noteworthy finding of this study relates to direction-of-asymmetry patterns as contrasted between the humerus and femur. Notwithstanding the existence of variation between the Georgian and Forensic samples, in each there is a net same-side dominance in each of the dimensions measured on the humerus, yet this is not the case for the femur. Among those individuals who display measurable asymmetry in both humerus length and epicondylar width, in particular, there is a statistically significant same-side relationship between these measurements. In contrast, there is a general tendency for left-dominance in femoral length to be coupled with right dominance in femoral head diameter and biepicondylar width. These tendencies in the femur are not statistically significant, except for the case of the Forensic male sample, which shows the crossed pattern to be highly statistically significant. Nonetheless, these observations underscore the fact that a given bone pair may be right-dominant in some dimensions at the same time that they are left-dominant in others.

SIGNIFICANT ISSUES IN THE STUDY FINDINGS

In addition to testing the hypotheses that were presented at the end of Chapter 4, the primary value of this research is as a methodological critique of asymmetry assessments. Although the issues discussed in this section—and which were stated in Chapter 2—are concerned specifically with the assessment of linear asymmetry patterns, some of the implications apply to the assessment of cross-sectional asymmetry patterns as well. This section outlines the most significant issues, and their implications for future research.

Given the lack of attention directed to linear asymmetry patterns in the osteological literature, the first significant finding to come from this project is the unequivocal affirmation that the directional nature of asymmetry in both humerus and femur lengths is a real phenomenon, and that it is inappropriate to simply attribute bone length asymmetry to the phenomenon of fluctuating asymmetry. Because the asymmetry truly is distributed in a directional manner, and because the extent of the directionality varies between the humerus and the femur, there arises two troublesome methodological issues relating to how the asymmetry should be reported, particularly when making comparisons between skeletal samples.

Reporting Asymmetry Magnitude--Signed or Unsigned?

The first issue is whether to employ signed or unsigned values in reporting the magnitude of the asymmetry that is used as the basis for comparison between populations. The choice of strategy will affect the comparison, and the effect will be different in different bones insofar as their asymmetry distribution patterns vary. In the case of the humerus, where the prevalence of directionality to one side within a population is relatively more pronounced than in the femur, there is relatively greater concordance between signed and unsigned magnitude values. In contrast with the prominent right-dominance in humerus length, within a population the directionality of femur length dominance is less one-sided. That is, even though a majority of individuals are left-dominant in femur length, there is also a substantial minority of individuals that are right-dominant. Because of this, the average signed value for magnitude of asymmetry within a population will appear to be quite small (as seen in the sample data example from Chapter 2).

There is no clear preference for using either the signed or unsigned values for determining population averages, since each has distinct disadvantages. When signed values are used the true magnitude of the asymmetry is obscured by the canceling effect of positive and negative values. When unsigned values are used the direction of the asymmetry is totally removed from the assessment. Even if unsigned values are used in conjunction with a separate assessment of directionality the relationship between direction and magnitude is still not clearly portrayed. The only effective way to characterize asymmetry patterns, then, is to report them in terms of each of the three attributes described here: unsigned asymmetry magnitude, signed asymmetry magnitude, and directionality.

While the use of these three distinct attributes may be adequate for characterizing the findings for a single skeletal sample, it also renders comparisons between skeletal samples substantially more complex. However, the use of nonparametric statistical techniques which involve rank ordering of the individuals in the samples being compared can be a powerful tool for undertaking the assessment of signed asymmetry magnitude. In the situation where two samples are being compared the Mann-Whitney *U* statistic offers an attractive tool for assessment. In the case of nominal variable assessment of asymmetry direction, χ^2 analysis is appropriate if sample sizes are sufficiently large.

The Asymmetry Threshold Issue

The second primary issue surrounds the arbitrary nature of asymmetry labels, and the manner in which increasing the measurement threshold of symmetry differentially affects populations depending on their asymmetry distribution patterns. These considerations are relatively trivial in cases of non-directional asymmetry, but they can have serious implications in situations where asymmetry patterns are clearly directional.

As outlined in Chapter 2, metric observations of paired skeletal elements can be placed into three mutually exclusive categories of left-dominant, symmetrical, and right-dominant. If the distribution of asymmetry is normal with a mean of zero, increasing the asymmetry threshold will draw an equal number and proportion of individuals from both the right-dominant and left-dominant categories into the symmetrical category. However, if the distribution is directional then increasing the threshold will draw a greater number of individuals from one side and a greater proportion of individuals from the other. In the case of humerus length, which has a strong tendency toward right dominance, this means that increasing the threshold from one millimeter to two millimeters will shift more individuals from the right-dominant category to the symmetrical category than are shifted from the left-dominant category to the symmetrical category. However, a greater proportion of the left-dominant individuals will shift from the left-dominant category to the symmetrical category than are shifted from the left-dominant category to the symmetrical category.

When patterns of direction in asymmetry of humerus length and femur length are assessed using two different thresholds of asymmetry (one-millimeter and two-millimeters) the statistical significance of the differences between the sexes was shown to vary. Specifically, differences in the direction of humerus length between the Georgian and Forensic samples appear statistically significant with a greater level of confidence when assessed at the higher symmetry threshold; this is true for both the males and females. Likewise, the higher asymmetry threshold is associated with greater confidence in the statistical significance of direction of asymmetry patterns in femur length between the sexes in both Georgian samples. Researchers need to bear in mind that the threshold of asymmetry chosen for a given study will affect the results of the analysis; to facilitate effective comparisons between sample groups, it is important that the threshold values be stated explicitly in any study of metric asymmetry.

Are Asymmetry Distribution Patterns Unimodal?

Another intriguing finding derived from this research is that the distribution of asymmetry in humerus and femur lengths in a skeletal population does not appear to be unimodal. The relatively small sample sizes associated with each group here leads this assertion to be made with caution, but the consistency in the bimodal pattern among the males of the populations is remarkable. While it is possible that the apparent bimodality reflects two distinct subpopulations in each sample, there is no obvious documentary evidence to support such a suggestion. Detailed discussion of the bimodality issue goes beyond the hypotheses in this study, but it is clearly an issue that merits follow-up in a future investigation.

Nonetheless, one implication of this finding is that statistical techniques which rely on assumptions of unimodal normal distributions may be essentially inappropriate for characterizing the true nature of postcranial bone length asymmetry. Whether the asymmetry of other components of the long bones (head diameter, biepicondylar width, etc.) is also non-normally distributed is unclear. The data presented in the current study do not suggest a unimodal normal in those measurements. Because nonparametric statistical techniques do not assume an underlying unimodal normal distribution in the character being studied, there is additional reason for employing these techniques in the assessment of directional asymmetry patterns.

Summary

Perhaps the most important contribution of the present study is to provide a framework for future studies of the nature of skeletal asymmetry in populations that accounts for both the direction and magnitude of asymmetry. It is critical to underscore that parametric tests of asymmetry magnitude offer an incomplete picture of the true nature of directional asymmetry, and that the significance of asymmetry patterns between populations is most appropriately assessed by median-based statistics (such as the Mann-Whitney *U*) or nominal scale statistics (such as χ^2 analysis of asymmetry direction between populations). Future studies of asymmetry, both of linear dimensions and of diaphyseal morphology, should consider the use of these statistical techniques.

ISSUES INVOLVED WITH DOCUMENTED HISTORIC POPULATIONS

Typically skeletal biologists are frustrated by the lack of supporting documentation associated with the populations that they study. In the case of prehistoric American populations, for example, the lifeways of groups is spoken of in very broad terms. Such is not the case with the skeletal populations of 18th century London. Not only were parish and municipal records well-maintained, there have also been many books written on the topic of Georgian London. Some have dealt with London in general (Bayne-Powell 1938; George 1965; Marshall 1968; Porter 1994), others with London as the focal point of the nation as a whole (Porter 1990), and yet others with specific geographic areas within the metropolitan area of London. For example, volumes have been written on the East End of London by Smith (1939) and Rose (1951), among others. In fact, several books have been written about the history of Fleet Street itself (for example, Bell 1912, Boston 1990, and Morgan 1973).

It would seem that this abundance of information could greatly simplify the task of characterizing the lifeways of the individuals interred in the crypts of Christ Church and St. Bride's. To some extent this is true; however, the historical data make clear that there is a wide level of variability in lifeways even among the so-called "middling sort" of 18th century London. One might argue that it would be possible to determine a meaningful subset of the population, and try to derive a representative sample of those individuals. In the case of the church crypt sample, for example, the interred individuals shared some characteristics. With respect to socioeconomic status, they were typically of the "middling sort", as Cox and Molleson (1993) indicates. Indeed, the financial cost of a lead coffin was not cheap, and most of less well-to-do individuals were interred in the Churchyard (Litten 1991). This is not always the case, though, since a few individuals of rather meager income were interred in crypts, either because of specific ties to the Church, or because more well-to-do members of the family were associated with the Church.

The issue of representativeness has taken a more prominent role in discussions of osteological analysis of the past decade, and reflected by the fact that a symposium on representativeness was held at the 1993 meetings of the American Association of Physical Anthropologists. The problem is generally phrased as such: How accurately does a skeletal population represent the community of individuals from which it was derived? With the recent surge in studies involving historic skeletal populations, particularly those populations for which contemporary documents exist, this question has become much more important.

Another consideration sets these skeletal populations apart from the generally accepted understanding of most archaeological skeletal populations. It is important to recognize that persons interred in a given crypt did not necessarily reside in close proximity to the church. Cox located the addresses at baptism and marriage for twenty-eight individuals from the Spitalfields identified population, and found that "only four were baptized, married, and died resident in the parish of Christ Church" (Cox 1989:26). A review of address listings at the time of death for the St. Bride's population reveals a similar phenomenon. Nonetheless, the majority of individuals from both Georgian samples were residents of greater London (Cox and Molleson 1993; Scheuer, personal communication).

Reliability of Written Documentation

Other assumptions about the persons located in the crypts are dashed in the process of research. One of the most important ones has to do with the reliability of written documents. Bowman et al. (1993) found this to be a troubling aspect of their research of the St. Bride's collection. They identified three particular problematic areas: (1) Contradictory information; for example, when church records and death registration records gave different information about a single individual. (2) Ambiguous information; with respect to interpreting cause of death from these documentary evidence, for example, it is difficult to associate the term "Decline" with a particular pathological process. (3) Deliberate corruption of records; the classic example from the St. Bride's collection is the falsification of cause of death so as to not publicly reveal a case of suicide (Bowman et al. 1993).

Cox (1993) is stronger in her critical stance toward the relationship between skeletal biology and history. She argues that skeletal biologists risk drawing spurious conclusions if they are not critical in their assessment of the historical record of the population they investigate. Waldron's (1991) study of the correlation between occupation and osteoarthritis among the Spitalfields weavers exemplifies Cox's concern. Since a significant number of the persons interred in Christ Church were listed in historic documents as silkweavers, on the surface Waldron's task appeared to be quite straightforward. However, on closer examination Waldron found that the job title of silkweaver could have a range of meaning. Journeymen weavers, for example, were known for working extremely long hours, while master weavers had a much more relaxed way of life. Because master weavers were typically journeymen themselves at a younger age, it is unclear what meaningful distinction should best be drawn between the two groups of weavers.

A Sex-Gender Distinction?

Another intriguing issue relates to the apparent differences in asymmetry patterns between the males of St. Bride's and Spitalfields, as well as between the females of the two sites. If the women of St. Bride's and Spitalfields are comparable in terms of space, time, and socioeconomic status, as well as sex, they should therefore show similar asymmetry patterns; likewise, the men of the two sites should be comparable in terms of asymmetry as well. However, they do not seem to be similar in this regard, and the most obvious explanation for the discrepancy is that there are issues related to gender and the environment which are different for the two populations.

One way to characterize a distinction between genetic sex differences and environment- or activity-related differences between the sexes is to refer to the differences as gender differences, rather than sex differences. The concept of gender does not appear regularly in the skeletal biology literature. In studies of past human populations, skeletal biologists have accepted that there is a high level of consistency in gender-stratified physical activity patterns. In other words, it appears to be assumed that all women within a skeletal sample (that represents a population) engage in comparable physical activities, and that the same is true for the men within the sample. The assumption is embraced to the extent that no efforts are taken to separate the genetic effects of sex from the environmental effects of gender-related differences in skeletal morphology. To be fair, those researchers studying undocumented skeletal populations in particular do not have any way of knowing with any certainty the extent of consistency in gender-stratified physical activity patterns, and hence have no basis for distinguishing between the effects of sex and gender.

Perhaps with the availability of historical documentation and well marked populations for study there is room in the literature of skeletal biology to clarify a distinction between "sex" differences and "gender" differences in the human skeleton. The latter term can be a useful tool applied to variation in skeletal morphology which is not readily attributable to genetic influences. In cases where males and females within a skeletal population manifest differential patterns of physiological stress markers which would be associated with differential access to food resources, the term "gender" is more appropriately descriptive than "sex" to label the distinction.

CONCLUSION

The introductory chapter opened with reference to a fictional detective who applies principles of osteological analysis to reconstruct the lives of individuals on the basis of their skeletal remains. In reality, such reconstruction is not a simple and straightforward task, as those who perceive the pitfalls of the osteological paradox are quick to warn. Even in the seemingly simple task of assessing bilateral asymmetry in linear dimensions of long bones, there are several methodological issues, and problems in interpretation, that complicate the assessment. Because of the growing importance of bilateral asymmetry in biocultural osteology studies, these issues and problems merit a close examination.

Drawing on recent scholarly interest in biocultural interpretations of bilateral asymmetry in limb bone morphology, this project was initiated to determine the extent to which three factors--gender, physical activity, and setting in time and space--are observed to affect patterns of bilateral asymmetry in the linear dimensions of long bones.

There has been little research on this topic, since earlier studies of asymmetry predated the biocultural approach and were primarily descriptive in nature. The more recent research has focused on cross-sectional analysis of limb bone diaphyses, and not addressed the phenomenon of directional asymmetry in the linear dimensions of the bones.

The Hypotheses

The four hypotheses presented in Chapter 4 were constructed to assess the likelihood that the skeletal samples under study would be drawn from a single population. Results of the hypothesis testing are presented at the end of Chapter 5, and summarized here, as well (Table 85):

(1) <u>That the Georgian skeletal samples are drawn from a common population that is significantly different from the Forensic sample in terms of long bone dimensions</u>. This hypothesis is unequivocally supported by *z* and *t* test comparisons of means for the study samples.

(2) <u>That an individual's sex is a primary determinant of long bone length asymmetry patterns</u>. This hypothesis is not supported either by χ^2 tests of asymmetry direction or Mann-Whitney *U* assessments of the signed and unsigned magnitude of asymmetry patterns.

(3) <u>That a population's setting (in terms of time and space) is a primary determinant of long bone length asymmetry patterns</u>. The study results offer strong support for this hypothesis, but the differences are not statistically significant for all measurements for both sexes.

(4) <u>That physical activity is a primary determinant of bone length asymmetry</u>. This hypothesis is strongly supported by the findings of the study. There is a statistically significant same-side relationship between biepicondylar width of the humerus and humerus length for each of the study subgroups except the Forensic males. There is not a similar relationship in the femur, however. This is not inconsistent with the hypothesis, however, since the biepicondylar width of the femur is not associated with muscle attachments in the same way that the biepicondylar width of the humerus is.

Table 85 Summary of Statistical Significance Between the Sexes

		ST. BRIDE'S	SPITALFIELDS	FORENSIC
HL	Direction (1 mm)		<.05	
	(2 mm)			
	Signed		<.05	<.05
	Unsigned		<.05	
HH	Direction			
	Signed			
	Unsigned			
HB	Direction			
	Signed			
	Unsigned			
FL	Direction (1 mm)	<.05	—	
	(2 mm)	<.01	<.05	
	Signed			
	Unsigned	<.05		
FH	Direction			
	Signed			
	Unsigned			
FB	Direction			
	Signed	<.005		
	Unsigned	<.05		

Table 86 Summary of Statistical Significance Among Populations

		GEORGIANS		GEORGIAN / FORENSIC	
		♂	♀	♂	♀
HL	Direction (1 mm)			<.001	<.01
	(2 mm)			<.0001	<.001
	Signed			<.0001	<.0001
	Unsigned			<.005	<.0001
HH	Direction				
	Signed			<.05	<.05
	Unsigned				<.05
HB	Direction				
	Signed				
	Unsigned				
FL	Direction (1 mm)			—	
	(2 mm)			<.05	
	Signed				<.01
	Unsigned			<.01	<.05
FH	Direction				
	Signed				<.01
	Unsigned				
FB	Direction	<.01	<.01		
	Signed				<.05
	Unsigned				

Implications of the Study for Biocultural Questions

While the explicit goal of this dissertation is to set a foundation for future biocultural research, there are biocultural implications in the study results themselves. The most important implication arises from the evidence that setting in time and space, but not sex, appears to influence patterns of asymmetry in the linear dimensions of long bones. This means that there is a legitimate basis for addressing biocultural questions by assessing long bone linear asymmetry since some aspect (or aspects) of culture—physical activity, environmental stressors, nutritional status, and/or socioeconomic factors—affects the manisfestation of these asymmetry patterns. Further research with better controlled populations will be necessary to establish the relative importance of these factors in determining asymmetry patterns, but given the results of this study it appears that such research would be fruitful.

In addition to testing the hypotheses listed above, this study revealed several other interesting patterns that speak to bioculturally focused research questions. They include the following:

(1) <u>Although there is a common pattern of left-dominance in femur length, there does not appear to be a similar pattern of left-dominance in either the diameter of the femoral head or of the biepicondylar width of the femur</u>. This characteristic was consistent in all three of the study populations, and was evident in both sexes. There are two implications of this finding. First, it indicates that researchers cannot assume that a side-dominance pattern in one linear dimension of a bone pair should be associated with a similar side-dominance pattern in other aspects of the bone. In other words, a researcher who studies asymmetry in femoral head diameter in one skeletal sample would

not have a legitimate basis for comparing those patterns with results of another researcher's study of asymmetry in femur length. A second implication is that, within the femur, asymmetry in bone length, head diameter, and biepicondylar width are not associated with physical activity and therefore would have limited application in biocultural studies that address activity patterns.

(2) <u>There are apparently "sex-related" differences in asymmetry patterns which present themselves differently in different populations</u>. That is, there are differences in the sexes which do not appear to reflect genetic differences between males and females. If that were the case, then the Georgian and Forensic females would show greater consistency in their asymmetry patterns. Because these differences result from the interaction of culture and biology, characterizing the differences as "sex-related" may be inaccurate. When the impact of culture is juxtaposed with sex factors to affect skeletal morphology, it may be more appropriate to apply a concept that acknowledges the influence of culture, such as gender, to describe these differences. At the same time, it is important to not simply employ the term "gender-related" in lieu of "sex-related" to characterize all differences in male and female skeletal material, since these are two distinct concepts. That is, there are clearly some differences in skeletal morphology, such as sexual dimorphism in the size of the femoral head, that are truly sex-related and that do not result directly from an interaction of culture and genetic differences.

(3) <u>The Forensic Data Bank sample is generally substantially more symmetrical than are the Georgian populations</u>. Although the Forensic humeri and femora are significantly larger than the Georgians in all six of the linear dimensions under study in no instance do they present the greatest magnitude of asymmetry. This is in spite of the

fact that asymmetry magnitude is calculated four different ways (signed, unsigned, percentage signed, and percentage unsigned). In fact, in the case of humerus length, humerus head diameter, and femoral head diameter the Forensic males and females display the smallest magnitude of asymmetry in all four variations of its calculation.

This finding is particularly surprising given the obvious differences between the Forensic sample and the Georgian sample. Although both samples are derived from a relatively restricted temporal range the Forensic sample reflects a much broader range of socioeconomic status and geographic origin than the Georgians. This would suggest that the Forensic sample should show a greater range of variation than the Georgians—not the reverse.

It remains to be seen exactly what factors underlie the difference. One possibility is that the Georgians represent a culturally restricted population which shows an abnormally high level of directionality to asymmetry. Secondly, there may be something significantly different about the lifeways of the more modern Forensic Data Bank sample which is associated with the difference. It may be that twentieth-century youths engage in more sedentary behaviors than their eighteenth-century counterparts; this would be consistent with less directionality in asymmetry patterns. This is an interesting speculation, since it suggests that the female Georgians, in showing greater asymmetry than the other groups, were the least sedentary of all the sample skeletal populations in the study.

(4) <u>Although the two Georgian populations were comparable in most respects, the St. Bride's males and females displayed a somewhat longer mean femur length than their Spitalfields counterparts</u>.

Because femur length is the bone measurement most commonly used in univariate estimations of living stature, this finding suggests that the St. Bride's population were taller than the Spitalfields population. The differences in mean femur length between the two skeletal samples are not statistically significant, however. This finding is consistent with the assessment of East London vs. West London differences in socioeconomic status which were outlined in Chapter 3. That is, the celebrated poverty of London's East End may be manifest in the shorter stature of the Spitalfields skeletal population. In spite of the two crypt populations having a "middle class" socioeconomic status at the time of death, it is possible that the effects of relative poverty in childhood might persist as a permanent reduction in adult stature. Addressing this issue is an excellent example of a future comparative endeavor involving these two samples and the documentary record that surrounds them.

Suggestions for Further Study

As long as researchers are realistic in their expectations of studies involving documented historic skeletal samples, the St. Bride's and Spitalfields identified skeletal collections offer skeletal biologists a unique opportunity for assessing skeletal morphology within a well-documented and culturally homogeneous pair of skeletal samples. The trend noted in the previous paragraph indicates that it is still unclear the extent to which the two Georgian skeletal samples should be interpreted as a single population or as two distinct populations. Further studies on these two groups which combine skeletal analysis with ethnohistorical research will refine our understanding of meaningful similarities and differences in the skeletal morphology of the people of St. Bride's, Fleet Street and Christ Church, Spitalfields.

In addition to setting the stage for future comparative studies involving these two Georgian skeletal samples, this research also sets a baseline for comparative studies of asymmetry in the linear dimensions of long bones in other reference skeletal samples to further characterize if asymmetry patterns can be used to draw inferences about biocultural issues in unknown skeletal populations. As records of osteometric observations become computerized it will become easier to undertake the statistical analysis that would adequately compare varied populations.

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