

SEXUAL DIMORPHISM AND THE TRANSITION TO AGRICULTURE:
A META-ANALYSIS

By

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The degree of sexual dimorphism found in human populations has declined throughout the history of anatomically modern humans. Researchers have specifically suggested that the transition to agriculture led to a decline in sexual dimorphism due to the reduction in gendered biomechanical loads and a nutritional decline. To test this theory, data were compiled from studies which compared populations spanning the transition to agriculture. Meta-analyses were then conducted using the available postcranial measurements of preagricultural and agricultural groups to observe any changes in sexual dimorphism. Of the five North American populations compared, only 10.5% showed a significant decline in sexual dimorphism. A non-statistical analysis of the literature did not demonstrate any noteworthy difference in the degree of sexual dimorphism in populations before and after the adoption of agriculture. In contrast to the theory that sexual dimorphism declines with the transition to agriculture, in most cases, no significant change occurs.

INTRODUCTION

In modern human groups, the average male is almost 1.1 times as tall as the average female, and, according to Krantz (1982: 86), they are “correspondingly more massive.” Compared to extant ape populations, the degree of sexual dimorphism in humans represents a moderate degree of dimorphism. Gorillas and orangutans have an enormous degree of sexual dimorphism where females may only weigh half as much as their male counterparts. Gibbons and siamangs exhibit very little sexual dimorphism in body size; females are 94% of the size of males. Humans and chimpanzees are similar in degree of dimorphism, with females at 78% and 81% of male body size, respectively (Campbell and Loy, 2000).

Within modern human groups, it has been found that the degree of sexual dimorphism varies by population. Eveleth (1975) measured individuals of African, Amerindian, and European origin and found that in the measurement of adult stature, Africans were the least sexually dimorphic population. Amerindians were the most sexually dimorphic population, with Europeans ranking in between Africans and Amerindians. However, it is important to remember that stature is just one measurement of dimorphism. In my own investigations (Vick, unpublished), I found that Amerindians were highly dimorphic in the measurement of maximum femur length (commonly used to calculate stature), but did not express greater dimorphism in other osteometric measurements such as femoral circumference or humeral length.

In contrast to Eveleth, Gaulin and Boster (1985) have suggested that the degree of sexual dimorphism found in human populations is actually quite consistent and that evidence to the contrary may simply be the product of small sample size. Nevertheless, these researchers, along with numerous others, have continued to conduct studies which attempt to explain sexual dimorphism based on cultural differences in human populations. Marriage patterns, work load, parental investment, division of labor and subsistence type are just a few of the cultural variables tested for their association with sexual dimorphism (Gaulin and Boster, 1992; Holden and Mace, 1999; Ruff, 1987; Wolfe and Gray, 1982a; Wolfe and Gray, 1982b)

Sexual dimorphism in humans has varied over time. Over the course of human evolution, from the australopithecines to anatomically modern humans, the degree of sexual dimorphism has declined (Frayer and Wolpoff, 1985; Krantz, 1982). Likewise, within *Homo sapiens sapiens*, there has been a subsequent decline in sexual dimorphism from the Upper Paleolithic to the present (Borgognini Tarli and Repetto, 1997; Brace, 1973; Brace and Ryan, 1980; Frayer, 1980; Frayer, 1981; Frayer and Wolpoff, 1985; Meiklejohn et al., 1984).

The decreases in dimorphism seen in *Homo sapiens sapiens* have generally been associated with changes in subsistence or technology, most notably from the Upper Paleolithic to the Mesolithic. During the Upper Paleolithic, humans were big game hunters. Then, as the Upper Paleolithic ended with glacial retreat and the large scale extinction of many big game species, the Mesolithic hunter had to adapt by hunting smaller species, like pigs and deer, rather than, for example, mammoths. The prevailing theory to explain this transition is that as the game became smaller, so too did the hunter

(Brace and Ryan, 1980; Frayer, 1980; Frayer, 1981). Brace and Ryan (1980) argue that an increase in male body size occurred during the Pleistocene as an adaptive strategy for hunting large game prior to technological sophistication. But, with technological advances, the extinction of large game species, and the metabolic demands of a large body, the selective pressure for large male body size decreased. It is believed that female activity patterns did not change as greatly as male activity patterns during the Mesolithic transition. As a result, mean female size did not change drastically, resulting in an overall decline in sexual size dimorphism (Frayer, 1981). Brace and Ryan (1980) take this theory to the next level by suggesting that the degree of sexual dimorphism in modern populations is directly related to the amount of time that has passed since that population's dependence on hunting large game. This theory is based on Brace's (1963) theory of probable mutation effect which states that in the absence of selection, random mutations will lead to the reduction of associated features. For the effects of the probable mutation theory to be observable in modern populations, Brace and Ryan make several assumptions. First, selection among big game hunters would need to have been constant across populations. In addition, populations would have to remain reproductively isolated. Otherwise, the differences in the progressive reduction in dimorphism due to the probable mutation effect would not be discernible.

Researchers have also hypothesized that a further reduction in sexual size dimorphism occurred as humans shifted from a hunting and gathering economy to agriculture (Armelagos and Van Gerven, 1980; Boyd and Boyd, 1989; Frayer, 1980; Frayer and Wolpoff, 1985; Hinton and Carlson, 1979; Holden and Mace, 1999; Kennedy et al., 1987; Lazenby, 2002; Ruff, 1987; Wolfe and Gray, 1982b). In contrast to data

available for the Upper Paleolithic – Mesolithic transition, which despite the small sample size, strongly support a decrease in sexual dimorphism, data for a possible decrease in sexual dimorphism after the shift to agriculture are more equivocal.

Archaeological, morphometric, and pathological data have been collected which describes the transition to agriculture. While specific biological responses to the adoption of agriculture vary regionally, there appears to have been an overall decline in human health (Cohen and Armelagos, 1984). As human groups became more sedentary, populations increased, as did rates of infectious diseases. People who raised livestock were even more prone to diseases due to exposure to animal vectors (Ortner, 2003). Chronic malnutrition also increased with agriculture. While groups were better able to store excess food for times of shortage, the nutritional quality of the food declined. In contrast, hunter-gathering populations had the advantage of mobility; if an area was no longer productive due to drought or other circumstances, they could easily move. Sedentism resulted in reduced evidence of musculoskeletal stress such as the incidence of degenerative joint disease and overall decline in robusticity. However, a reduction in physical stress may not be an indicator of positive change for several reasons. Cohen and Armelagos (1984) point out that the higher frequency of degenerative joint disease in hunter-gatherer populations may be complicated by the higher age at death among these groups as contrasted with more sedentary populations. Therefore, reduction in the frequency of degenerative joint disease may not be an indication of a decreased workload. In addition, physical activity is associated with bone remodeling. Evidence suggests that a low level of physical activity during a person's life may be associated with a higher propensity for bone fractures in later life (Ruff, 1991). Overall, the

transition to agriculture was marked by a decline in both the quality and duration of life (Cohen and Armelagos, 1984), characteristics which need to be considered when evaluating why changes in sexual dimorphism would occur during this time period.

To understand how a change in the subsistence economy could affect the degree of sexual dimorphism, it is first necessary to understand the causative factors affecting sexual dimorphism. There is general consensus that genetics affect sexual dimorphism; however, the nature or strength of this relationship is not understood. Eveleth (1975) is frequently cited as a primary source supporting the genetic contribution to sexual dimorphism. Eveleth's comparison of the sexual dimorphism of adult height in different "ethnic groups" concluded that there is a difference in the level of sexual dimorphism between these groups. While the sources of Eveleth's data are not given, the groups compared were broadly defined as Europeans, Negroes, Amerindians, Asiatics, and New Guineans. These "ethnic groups" are reminiscent of the major continental races and the comparison is based on the assumption that these groups are genetically distinct from one another. However, genetic variation does not observe socially constructed racial designations. The vast majority of genetic variation occurs within racial groups rather than between them.

Eveleth's (1975) study found that the degree sexual dimorphism found in each ethnic or racial group did not meet the expectations of the nutritional hypothesis - that the most dimorphic populations should have the most nutritious diet. In consequence, Eveleth concluded that there must be a genetic factor controlling the level of sexual dimorphism in each population. To arrive at this conclusion, Eveleth only considered two causal agents affecting dimorphism. There is no consideration of climate, gendered

access to resources, or any other factors associated with human morphology or sexual dimorphism. While there are many criticisms of Eveleth's studies, other studies comparing the amount of dimorphism in different populations have found similar results (Holden and Mace, 1999). We are all aware that the size of an individual is highly related to the size of his or her parents, but this does little to explain the ultimate cause of sexual dimorphism.

In the animal kingdom there is a relationship between overall body size and the degree of sexual dimorphism found in a species (Frayer and Wolpoff, 1985). According to Rensch's Rule (Rensch, 1959), sexual dimorphism increases with body size in taxa where males are the larger sex (Gustafson and Lindenfors, 2004). While Rensch's rule is widely accepted, studies suggest that this relationship is less apparent in primates than in other taxa (Frayer and Wolpoff, 1985). When size variation is compared by a method which includes phylogenetic data, the results are even less clear (Gustafson and Lindenfors, 2004). Gustafson and Lindenfors (2004) conducted a study of sexual dimorphism in human populations where data on mean male and female height were compared to genetic phylogenies. The results indicate that both male and female stature is associated with phylogeny and that there is no evidence for an allometric relationship between male and female stature in human populations (Gustafson and Lindenfors, 2004). This study serves as additional support that the genetic component to dimorphism needs to be considered in cross-cultural studies and that sexual dimorphism is not simply a byproduct of overall size.

The theory of sexual selection, more specifically, intrasexual selection, is commonly used to explain how sexual dimorphism develops in non-human animals

including primates. Intrasexual selection is based on the idea that competition exists within the members of one sex for reproductive access to the other sex. The sex which is competed for is generally the one that has a higher energy investment in the success of the offspring. In the case of humans, as well as in most other mammals, females make the greater investment in young; therefore, there is male-male competition for access to females (Trivers, 1972). While the relationship of size to reproductive success is difficult to measure, larger size may be linked to dominance by offering an advantage in aggressive encounters, and some studies demonstrate a positive relationship between dominance and reproductive success. As a result, larger males are able to pass their genes to subsequent generations more effectively, thereby increasing the degree of sexual dimorphism in size (Trivers, 1972). Based on theories of sexual selection, sexual dimorphism should be greatest in populations where there is the most competition for access to females.

Because paternity is often difficult to determine, mating or marriage practices have been used to test the sexual selection hypothesis. Alexander et al. (1979) conducted a study to determine whether or not breeding systems were correlated with sexual dimorphism in a variety of species, including humans. In all nonhuman groups it was found that the degree of polygyny (measured as a deviation from monogamy by harem size) was positively correlated with sexual dimorphism in body size. Primate species, such as hamadryas baboons, which are characterized by single-male, multi-female groups, have a high degree of sexual dimorphism in body size. Conversely, the *Callitrichidae*, characterized by monogamy and polyandry, have a very small degree of sexual dimorphism, with females larger than males in some cases (Rowe, 1996).

Alexander et al. (1979) also found a correlation between breeding system and sexual dimorphism in human populations, but their methods and results have been challenged by Gray and Wolfe (1980) who found no such correlation in their own research. In the studies of Alexander et al. (1979) and Gray and Wolfe (1980), all monogamous societies were divided into two groups: those with socially imposed monogamy, and those with ecologically imposed monogamy. Alexander et al. (1979) argue that socially imposed monogamy should be included with polygyny and that only ecologically imposed monogamy can be expected to follow the hypothesized pattern of sexual dimorphism based on theories of sexual selection. Unfortunately the methodology utilized by Alexander et al. (1979) of estimating heights by sight, leaves their results subject to speculation. When Gray and Wolfe (1980) reanalyzed the data, they found no significant correlation between sexual dimorphism and mating pattern, but they did find less variability in male and female height in polygynous societies, perhaps suggesting they are under greater selective pressure for height or some correlate of height.

According to the theory of sexual selection, there is greater variance in reproductive success for individual males in polygynous societies as opposed to monogamous ones. In any study of mating or marriage it is understood that true rates of paternity are not always easy to determine. However, marriage systems provide a readily available variable to study how sexual selection affects sexual dimorphism in humans under the assumption that a husband is likely to be the father of a woman's offspring.

Sexual dimorphism can be influenced by circumstances of the environment. A number of studies have shown that sexual dimorphism in stature can decrease when people are under nutritional stress and increase under conditions of optimal nutrition

(Brauer, 1982; Gray and Wolfe, 1980; Lieberman, 1982; Stini, 1969; Stini, 1982; Wolanski and Kasprzak, 1976). The theoretical basis for this is found in the fact that males and females experience differential success in dealing with stressors like starvation and disease due to hormonal and metabolic differences (Ortner, 2003; Stini, 1969). The greater fat and nutrient reserves characteristic of human females are thought to be an adaptation for the increased metabolic demands of lactation and gestation in producing offspring. As a result of these physiological differences, males experience a greater reduction of lean body mass during periods of nutritional inadequacy than their female counterparts. When periods of starvation occur during growth, the reduction in body mass is accompanied by reduced skeletal growth (Stini, 1975).

In Stini's (1975) analysis of the transition to hunting and gathering, he states that "severe nutritional imbalances...are much more common in agricultural areas than among hunters and gatherers although starvation is no stranger to hunting populations in most parts of the world" (p. 64). The greater prevalence of these nutritional shortages in agricultural societies forms the basis for the theory that sexual dimorphism declined with the transition to agriculture. If nutritional deficiencies lead to a decline in dimorphism, this shift should primarily be due to a reduction in male size. However, while it is apparent that nutrition affects sexual dimorphism to some degree (Brauer, 1982; Hall, 1982), many researchers think that it is not the leading factor affecting sexual dimorphism on an evolutionary scale (Eveleth, 1975; Larsen, 1984; Stini, 1969).

Related to the issue of sexual selection are theories of parental investment. The theory of sexual selection suggests that the pressure for sexual selection is decreased when both male and female invest in the rearing of their offspring. In most primate

species, the female invests much more energy in raising the next generation than does the male. In contrast, tamarins and marmosets are most noted for male parental investment. It is in these species that the least degree of sexual dimorphism occurs (Rowe, 1996). Studies suggest that parental investment favors the sex where the most variance in reproductive success occurs (Morbeck, 1997). Because the variance in reproductive success is generally greater for males, investing in young males can greatly increase a parent's fitness.

Cultural studies of human groups also show that parental investment varies based on the gender of the child. Holden and Mace (1999) found that sexual dimorphism in stature is negatively correlated with the amount of work women perform. Likewise, female juvenile mortality rates are higher than those for juvenile males in areas where females contribute less to subsistence. These patterns follow geographical patterns of sexual dimorphism (Holden and Mace, 1999). Rivers (1982) studied survival rates under conditions of famine and disaster to determine whether proof could be found for theories of differential survival based on sex. It was found that sex discrimination and preferential treatment of male children confounded the results of the study. While females may have a natural advantage under times of stress, males often receive cultural advantages that may more than make up for any differential survival rates. Similar conditions may affect the degree of sexual dimorphism found in a population.

Biologists may also view sexual dimorphism as a product of optimal biomass distribution for the species. When conditions select for large males, it is advantageous for the female of the species to be as much smaller as possible while still being able to achieve reproductive success (Bramblett, 1994). The optimum female size is large

enough to bear the physical demands of labor, but small enough to reduce the metabolic demands associated with large size. By considering sexual dimorphism as an optimal biomass distribution, DeVore and Washburn (1963) are proposing that males and females may be better able to utilize their resources if they fill different ecological niches. If niche divergence is amplified with an increase in sexual dimorphism, then the selective pressures affecting males and females are progressively more different.

Ethnographic research (Murdock and Provost, 1973) suggests that there is greater overlap between male and female subsistence activities in agricultural populations than is found in hunting and gathering populations. In addition, biomechanical data suggest that the forces affecting males and females are more similar in an agricultural population than among hunter-gatherers. For example, Ruff (1987) found that when comparing cross-sectional properties of bone, there was a decline in sexual dimorphism with the transition to agriculture indicating a reduction in the division of labor associated with agricultural tasks. Ruff (1987) did not code for nutritional changes in this analysis because he believes that cross-sectional data is a reflection of mechanical environment as opposed to dimensional variables which may be better indicators of nutrition. Holden and Mace (1999) compared populations in the *Ethnographic Atlas* with regard to marriage practices, subsistence and the division of labor. They “concluded that in contemporary humans, neither hunting nor agriculture has any effect on sexual dimorphism. [Instead] It is the amount of subsistence work done by men and women, rather than the type of subsistence practiced, which has an effect on sexual dimorphism in different societies.” (p. 42). As women contribute more to the subsistence economy, it appears that the degree of sexual dimorphism is reduced. Holden and Mace (1999) used stature as their

only measurement of dimorphism while Ruff (1987) used only the cross-sectional properties of bone. Ruff compared individuals from what is believed to be a genetically related population in which the transition to agriculture took place. Holden and Mace compiled data from various populations around the globe, and, while hunter-gatherers and agriculturalists are both represented, there is no genetic control which connects one group to the other.

Sexual selection, parental investment, nutrition, environmental conditions, marriage or mating patterns, body size, ecological niche, and the division of labor by sex have all been used to explain sexual dimorphism in humans and other animal species. The etiology of sexual dimorphism has proven itself complex and not easily understood. All the same, sexual dimorphism is still one of the indices commonly included by anthropologists to describe biological change in response to agriculture and in other studies of human health.

From the theories presented above, we can see that there are two major forces behind the theory that sexual dimorphism declines with the transition to agriculture. First, it has been shown that rates of chronic malnutrition are higher in agricultural populations than among hunter-gatherers (Cohen and Armelagos, 1984; Stini, 1975). Based on studies of secular declines in sexual dimorphism among malnourished populations (Brauer, 1982; Wolanski and Kasprzak, 1976), it is reasonable to assume the same trend would apply to the transition to agriculture. Second, it is believed that the biomechanical forces affecting males and females are more similar among agriculturalists than hunter-gatherers due to a reduced division of labor among agriculturalists.

Not all of the data collected support this theory. Wolfe and Gray (1982a) compared extant populations and found the opposite of what was expected; the agricultural populations were more sexually dimorphic in stature than were the hunting and gathering populations they sampled. Data from archaeological populations that have undergone the transition to agriculture have found conflicting results (cf. Boyd and Boyd, 1989; Larsen, 1984; Martin et al., 1984; Ruff, 1987).

Most studies which compare the degree of sexual dimorphism in hunter-gatherers versus agriculturalists have looked at extant unrelated populations (Holden and Mace, 1999; Wolfe and Gray, 1982a). These studies ignore possible genetic contributions to sexual dimorphism or regional differences in the ways in which agriculture was adopted or in the nutritional quality of the food sources cultivated.

Archaeological investigations into the transition to agriculture have unearthed a number of sites containing human remains which temporally span the transition in subsistence economy. These remains are often of presumably genetically related individuals which eliminates having to account for the influence of genes on sexual dimorphism. By using meta-analysis I have aggregated data from individual archaeological sites which span the transition to agriculture in order to test the hypothesis that there was a decrease in sexual dimorphism with the advent of agriculture.

By investigating the relationship between sexual dimorphism and the transition to agriculture I am examining what dimorphism means in terms of human biology and the role of cultural factors in this relationship. In archaeological contexts, inferences regarding human behavior are often made based on the degree of dimorphism in a population (Bridges, 1989; Bridges, 2000; Ruff, 1987). In studies of human health,

overall size and the degree of dimorphism are used as indices for the health of human populations (Brauer, 1982; Stini, 1969; Stinson, 1985; Wolanski and Kasprzak, 1976). In order to make these inferences or utilize these indices, it is first necessary to understand the role of sexual dimorphism on an evolutionary scale.

METHODS

Meta-Analysis

Meta-analysis is a statistical technique that allows researchers to aggregate data from multiple individual studies. When a number of studies address a single issue, the results of said studies do not always agree and the call for more research is often repeated in the literature. The recurring call for additional research has left many questioning the validity of continuing to perform these individual studies and has created the need for cumulative techniques for approaching data (Hunter et al., 1982; Rosenthal, 1984).

To explore the impact of the adoption of agriculture on human sexual dimorphism, I first conducted a survey of the results of extant studies investigating the skeletal consequences of this transition. Preliminary investigation of the results of these studies shows that sexual dimorphism decreases in some areas, increases in others, and in some, there appears to be no change. Any literature review can provide the information necessary for a qualitative summary of the data, but a quantitative review is advantageous in that it can be methodically scrutinized (Wood and Christensen, 2004). By aggregating all the available data collected by various researchers into a single and more comprehensive result, meta-analysis serves as a tool to evaluate existing theories (Wood and Christensen, 2004).

Choosing Data Sets

The first step in any meta-analysis is to conduct a thorough literature review to find all sources of data on the subject. The articles discussed in this project were found using

a variety of techniques, most importantly the ancestry approach. Rosenthal (1984) describes the ancestry approach as a means of gathering new resources by using the bibliographic information found in an initial article. For this study, *Paleopathology at the Origins of Agriculture* (Cohen and Armelagos, 1984) served as the primary bibliographic source. I also conducted a number of searches using the internet resources Web of Science and First Search. Keywords for these searches included combinations of the following terms: sexual dimorphism, dimorphism, subsistence, agriculture, change, temporal, femur, femoral, osteometric, morphology. While these searches did provide a few relevant articles which could then be mined for bibliographic sources, they were largely unsuccessful. Likewise, on-line searches of individual anthropological journals were ineffective. The keywords mentioned above were used in on-line searches of the following journals: *American Journal of Physical Anthropology*, *Journal of Human Evolution*, *Southeastern Archaeology*, *American Journal of Archaeology*, *Journal of Anthropological Archaeology*, *International Journal of Osteoarchaeology*, *Current Anthropology*, and *Yearbook of Physical Anthropology*.

The majority of relevant data were not found in studies of sexual dimorphism, but rather, in studies which investigated within sex variation over time. The purpose of the original publication did not affect the outcome of my study except in cases where *P* values or test statistics were provided in lieu of complete data. The statistical values provided by the original authors could not be used because different questions were being asked of the data.

The primary stipulations for data inclusion in this project were twofold: 1) studies had to present data from both before and after the adoption of agriculture and 2) studies

had to demonstrate geographic continuity. Prior studies of temporal changes in sexual dimorphism have not always limited their samples geographically, sometimes taking a preagricultural sample from one area and a postagricultural sample from another (Brace and Ryan, 1980; Frayer, 1980). By limiting samples to those found in approximately the same region, I am hoping to control for genetic factors i.e., that the pre- and post-agricultural data are not known to be from genetically unrelated groups. While testing populations within the same geographic area cannot always assure genetic continuity, archaeological evidence can indicate whether the people in a region are from related cultural groups or whether there is evidence of population migrations. The introduction of new subsistence strategies or technologies may be suggestive of exchange with an outside population. However, I only included populations where archaeological information was consistent with genetic continuity. In addition to the issue of genetic continuity, the plants cultivated in different areas of the world may have also had an effect on the biological response to a subsistence shift since studies show that the effects of agriculture were not uniform worldwide (Cohen and Armelagos, 1984). Geographic continuity therefore helps control for this moderating factor.

Although review of the literature provided information on changes in sexual dimorphism spanning the adoption of agriculture, the majority of these only present a score for percent dimorphism or a difference in means. For the purposes of meta-analysis, only those studies which provided sample sizes, means, and a measure of dispersion (standard deviation or standard error) for any measurement variable were included. A variety of measurement variables, both linear and biomechanical, were included in the meta-analyses.

In any meta-analytical process it is assumed that all studies are independent. Therefore, when multiple studies are conducted using the same data, it is important that the meta-analyst does not consider any group of data more than once. This limited the number of studies included in the meta-analysis to five, all of which were from areas within the continental United States. In Bridges (1989) and Boyd and Boyd (1989), Archaic and Mississippian populations were considered. Ruff and Larsen (1990) divided the populations they studied into precontact preagricultural and precontact agricultural. Contact populations were excluded from this analysis to control for disease and other changes associated with European contact. In the studies of Brock and Ruff (1988) and

Table 1: Sample Composition for Meta-analysis

Source	Location	Preagricultural sample	Postagricultural sample
Boyd and Boyd (1989)	Tennessee	Middle and Late Archaic	Late Mississippian
Bridges PS (1989)	Alabama	Archaic	Mississippian
Bridges PS (2000)	West Central Illinois	Middle Woodland	Mississippian
Brock and Ruff (1988)	New Mexico	Early Villages	Aggregated Villages
Ruff and Larsen (1990)	Georgia Coast	Precontact Preagricultural	Precontact Agricultural

Bridges (2000), the earliest groups studied did have some horticultural supplementation to their diet, but intensive agriculture did not occur until later. Table 1 lists the original authors' descriptions of the pre-and post-agricultural samples used for this meta-analysis. Populations that were considered "transitional" by the author(s) were not considered in this study.

Data Analysis: Meta-analysis

Deriving the t-statistic. For each measurement variable in each study a t-statistic for change in dimorphism was calculated using the following formula:

$$t = (\bar{X}_{PM} - \bar{X}_{PF}) - (\bar{X}_{AM} - \bar{X}_{AF}) / \sqrt{(SE_1 + SE_2 + SE_3 + SE_4)} \quad (1)$$

where P and A represent pre-agriculturalist and agriculturalist males and females, respectively. Because probability is based on sample sizes which are not consistent across the selected studies, a simple comparison of test statistics across studies could not be performed.

Determining effect sizes. Meta-analyses rely on effect sizes to test the homogeneity of populations before the individual test statistics can be compared or combined. Effect sizes are calculated from the test statistic, but are measures of magnitude rather than probability. There are several different types of effect size indicators, the most common being Pearson's r , Cohen's d , and Glass' Δ . Cohen's d , and Glass' Δ are both used to investigate the standardized differences between means of independent groups (Source: <http://web.uccs.edu/lbecker/Psy590/es/htm> , last accessed March 23rd, 2005). For these meta-analyses, Pearson's r was chosen as the effect size indicator because the variables under investigation are not considered to be independent. The effect size r was computed for each measurement variable using the following formula:

$$r = \sqrt{\left(t^2 / t^2 + (N_1+N_2+N_3+N_4-4) \right)} \quad (2)$$

where N 's represent the sample size of each sex, before and after the adoption of agriculture.

The sign of the t statistic should be preserved when converting to r . That is, if t is negative, r should be too. A negative t statistic occurs when the direction of the result is in the opposite direction of the hypothesis. In the case of this study, a negative result indicates that sexual dimorphism increases rather than decreases. A t statistic of zero

indicates that there is no change in the degree of dimorphism over the time period considered.

Rather than performing a single analysis of all measurement variables within each study, a meta-analysis was performed on each set of variables, since using multiple data from a single site in a meta-analysis would violate the assumption of independent samples. For example, all the data available on the mid shaft circumference of the femur were compiled, but these data were not combined with the data on femoral length.

For each measurement variable, the effect sizes were compared and a sample weighted mean correlation was computed using the following equation:

$$\bar{R} = \Sigma [N_i r_i] / \Sigma N_i . \quad (3)$$

The dispersion was described by the variance formula:

$$S_r^2 = \Sigma [N_i (r_i - \bar{r})^2] / \Sigma N_i . \quad (4)$$

Tests of homogeneity. Effect size estimates were compared to determine whether the studies were from a homogeneous population. Tests of homogeneity do not suggest that every variable within a group is the same, but rather that there is no indication of an outside factor, or moderator variable, influencing the relationship being studied.

Homogeneity is necessary when comparing or combining the probabilities of individual studies. The following chi-square formula was used to test for homogeneity:

$$X_{k-1}^2 = (\Sigma N_i / (1 - \bar{r})^2) S_r^2 \quad (5)$$

where k is equal to the number of studies used in the meta-analysis. The null hypothesis was that the studies are homogeneous and a P value of 0.05 was required to reject the null hypothesis.

An alternative method proposed by Hunter et al. (1982) was also performed to test for the presence of a moderator variable. This method compares the error variance and uncorrected variance. The error variance was calculated:

$$S_{er}^2 = k (1 - \bar{r}^2)^2 / \sum N_i \quad (6)$$

The error variance was then divided by the uncorrected variance:

$$S_{er}^2 / S_r^2. \quad (7)$$

If $S_{er}^2 / S_r^2 < 0.75$, then a moderator variable is present. A heterogeneous population or the presence of a moderator variable suggests that there is a factor outside those being tested that may be influencing the results of the study. These tests do nothing to suggest what that outside influence may be. When a moderator variable is present, the probabilities of individual studies cannot be combined with reliable results (Source: <http://www.fammed.ouhsc.edu/tutor/metanal.htm>, last accessed March 24th, 2005).

Combining probabilities. There are several methods of combining the probabilities of individual studies, but the number of applicable methods is limited by the small number of studies included in this analysis. The method of adding Z 's is the most appropriate under the circumstances of this study since it can be used regardless of the size of the study. However, it is limited in that it assumes unit variance (Rosenthal, 1984). The Z statistic is based on the area under a standard normal probability curve where the mean is zero and the standard deviation is one. A Z score is associated with the probability that a given value is Z standard deviations away from the mean (Ott and Longnecker, 2001). Adding the Z 's first requires that we convert our t statistic to Z using the following equation:

$$Z = t (1 - (t^2 / 4df)) \quad (8)$$

where df equals the degrees of freedom. In this case, the degrees of freedom were equal to the sample size of each study divided by four. The Z 's are then added using the following formula:

$$Z = \sum Z / \sqrt{K} \quad (9)$$

where K is the number of studies included in the analysis. Probability was then determined using the statistical tables provided by Ott and Longnecker (2001). Results were determined significant at the 0.05 level.

Data Analysis: Non-statistical Analysis of Data Not Appropriate for Meta-Analysis

Not all of the information gathered regarding changes in morphology spanning the transition to agriculture could be included in the meta-analysis due to insufficient data. Several publications presented the mean measurements for males and females with no measurement of dispersion. In the non-statistical analysis, these studies were compared to those used in the meta-analysis. For each of these populations, dimorphism ratios were produced using the following formula:

$$\ln \bar{X}_M - \ln \bar{X}_F \quad (10)$$

where \bar{X}_M is the male mean and \bar{X}_F is the female mean. According to the laws of logarithms, $\ln \bar{X}_M - \ln \bar{X}_F$ is equal to $\ln (\bar{X}_M / \bar{X}_F)$, a measure of proportion. The decision to use this method of calculating a score of dimorphism was based on Smith, who demonstrated that compared to other methods for finding dimorphism ratios, this method is believed to have fewer problematic mathematical features (1999). Ratios were compared to determine whether there was an increase or decrease in sexual dimorphism over time. In this analysis there was no attempt to determine the degree or significance of the change. The non-statistical analysis was completed to determine whether trends found in the meta-analysis were consistent over a larger population sample and

geographical area. All formulas in the meta-analysis and the comparison of ratios were calculated using Microsoft Excel.

Table 2: Sample Composition for Non-statistical Analysis

Source	Location	Preagricultural sample	Agricultural sample
Angel (1984)	Eastern Mediterranean	Mesolithic	Late Neolithic
Boyd and Boyd (1989)	Tennessee	Middle and Late Archaic	Late Mississippian
Bridges PS (1989)	Alabama	Archaic	Mississippian
Bridges PS (2000)	West Central Illinois	Middle Woodland	Mississippian
Brock and Ruff (1988)	New Mexico	Early Villages	Aggregated Villages
Clark (1988)	Dickson Mounds, IL	Pre-Mississippian	Mississippian
Martin (1984)	Lower Nubia	Preagricultural	Intensive Agricultural
Meiklejohn et al. (1984)	Western Europe	Mesolithic	Neolithic
Perzigan et al. (1984)	Ohio River Valley	Late Archaic	Ft. Ancient
Rathbun (1984)	Iran & Iraq	Preagricultural (Hotu)	Neolithic
Rose (1984)	Caddo Culture Area	Fourche Maline	Caddo II
Ruff and Larsen (1990)	Georgia Coast	Precontact Preagricultural	Precontact Agricultural
Smith et al. (1984)	Levant	Natufian	Neolithic and Chalcolithic
Ubelaker (1984)	Ecuador	Sta. Elena	Ayalan and Guangala

RESULTS

The Meta-analysis

From the five studies selected for inclusion in the study, twenty-two individual meta-analyses were conducted. An individual meta-analysis was performed for each variable, the majority of which were taken on the femur and humerus. The linear measurement variables included in meta-analyses were length and mid shaft circumference. At midshaft for both the femur and the humerus, the following biomechanical variables were included: cortical area, minimum bending strength, maximum bending strength, shape index (I_{\max} / I_{\min}), and polar second moment of area (J). Two studies included subtrochanteric biomechanical data which were included in the meta-analyses. Meta-analyses of the tibia, ulna, and radius are limited to midshaft circumference data as biomechanical variables were considered for these bones in only one of the studies included in this analysis.

For an individual meta-analysis to be included in the final analysis, it was necessary that the effect sizes be homogeneous. A comparison of the effect sizes by chi-square showed that a moderator variable was present in three meta-analyses: femoral cortical area, humeral mid shaft circumference and radial mid shaft circumference. In these three cases, the presence of a moderator variable was confirmed using Hunter's (1982) alternate approach. While tests of homogeneity indicate the presence of a moderator variable, they do not provide information on the nature of this outside influence. Since the source of the moderator variable could not be determined from the

Table 3: Summary of Meta-Analyses

Measurement Variables	\bar{r}	Z	P value
Femur			
Length	-0.0317	-1.7002	0.9554
Midshaft Circumference	-0.0824	-1.4782	0.0929
Min Bending Strength (size standardized at midshaft)	-0.0731	-0.9215	0.8212
Max Bending Strength (size standardized at midshaft)	0.0625	0.7756	0.2206
Femoral Shape Index (I_{\max}/I_{\min})	0.0452	0.4558	0.3300
Femoral J (size standardized at midshaft)	0.0401	0.4034	0.3446
Subtrochanteric Cortical Area (size standardized)	0.1991	1.3859	0.0838
Subtrochanteric Min. Bending Strength (size stand.)	0.1408	1.2116	0.1131
Subtrochanteric Max. Bending Strength (size stand.)	0.1867	1.6103	0.0537 *
Subtrochanteric Femoral Shape Index (I_{\max}/I_{\min})	0.1546	0.4167	0.3409
Subtrochanteric J (size standardized)	0.2010	1.7342	0.0418**
Humerus			
Humerus Length	0.0054	-0.0941	0.5359
Humerus Cortical Area (size standardized at midshaft)	0.0507	0.4692	0.3228
Humerus Min. Bending Strength (size standardized)	0.1361	1.3011	0.0968
Humerus Max. Bending Strength (size standardized)	0.1635	1.8789	0.0307**
Humerus J (size standardized at midshaft)	0.1232	0.3216	0.3745
Humeral Shape Index (I_{\max}/I_{\min})	-0.1420	-0.8878	0.8106
Other			
Tibia Midshaft Circumference	0.0178	0.1956	0.4247
Ulna Midshaft Circumference	0.0131	0.1747	0.4325

Table does not include meta-analyses in which a moderator variable was found to be present through the chi-square test. For additional data, see appendix.

\bar{r} = sample weighted mean effect size

Z = test statistic

** Significant ($p < 0.05$)

* Near Significant ($0.1 > p > 0.05$)

data, these three meta-analyses were removed from further study. In the meta-analysis of femur length, a chi-square test suggested the population was homogeneous but Hunter's (1982) alternative approach detected the presence of a moderator variable. Although Hunter's approach detected the presence of a moderator variable, the result of 0.68 was not far below the 0.75 threshold for significance. The chi-square test strongly suggested the population to be homogeneous and as such this meta-analysis was not excluded from the final study, leaving nineteen meta-analyses for comparison in the final analysis.

The femur. In the eleven independent meta-analyses of the femur, three (27%) of the sample weighted mean correlations (\bar{r}) were negative. A negative effect size indicates that the degree of sexual dimorphism in the femur increased, rather than decreased, with the shift to agriculture. Two of the three negative effect sizes were for linear measurement variables: length and midshaft circumference. The third measurement variable was a derived biomechanical variable.

Only one femoral measurement variable experienced a significant decline with the transition to agriculture: the subtrochanteric polar second moment of area (J). J is found by summing I values from two perpendicular measurements. When a section is perfectly cylindrical, J is a measure of strength under torsional twisting. Although these sections are likely elliptical, the cited authors have used this measure as an estimate of torsional or twisting strength (Bridges, 2000; Brock and Ruff, 1988; Ruff and Larsen, 1990). A second femoral measurement variable, subtrochanteric maximum bending strength, had a near significant result of $p = 0.0537$. Both of these measurement variables are biomechanical and provide information on skeletal strength and robusticity.

The humerus. Of the six meta-analyses performed on the humerus, only the humeral shape index (I_{\max}/I_{\min}) had a negative sample weighted mean correlation. All other results were positive suggesting that a slight decline occurs more often than an increase. In only one meta-analysis was the change in sexual dimorphism significant. The degree of sexual dimorphism found in the maximum bending strength of the humerus is significantly less in agricultural than in preagricultural populations.

Combined meta-analyses. The majority of meta-analyses show no significant change in the degree of sexual dimorphism between preagricultural and agricultural populations. Two measurement variables (10.5% of the total) had a significant decline in the amount of sexual dimorphism and a third measurement variable had a near significant decline. These three measurement variables, humeral maximum bending strength, subtrochanteric maximum bending strength, and subtrochanteric J, are all biomechanical rather than linear variables, indicating that sexual differences in strength experienced a decline.

A decline in dimorphism indicates that either the male mean is decreasing or the female mean is increasing. The original data from the significant and near-significant meta-analyses were examined to determine whether or not the within sex changes which occurred with the adoption of agriculture were largely male or female. The preagricultural and agricultural mean measurements for males and females were subtracted from one another to determine whether the greatest temporal differences could be attributed to the males or females. The results of this investigation were inconclusive. In some cases the males experienced the greater change and in other cases females

exhibited a greater change. Therefore, it does not appear that significant changes in dimorphism can be attributed to one sex across studies.

Non-Statistical Analysis

A comparison of the sexual dimorphism ratios ($\ln \bar{X}_M - \ln \bar{X}_F$) for all studies, including those used in the meta-analysis, showed that sexual dimorphism decreased in 54% of cases, only slightly more than half. Measurements of the femur were less likely to decrease in dimorphism than were measurements of the humerus. While this comparison has no statistical significance, it mirrors what is found through the meta-analysis. Overall, there does not appear to be a noteworthy difference in the degree of sexual dimorphism found in populations before and after the adoption of agricultural subsistence. However, there is a slight trend toward a decline in dimorphism for all bones with the exception of the femur. Similar trends appear when linear and biomechanical data are compared.

To determine whether the data available provided information on geographical differences in patterns of sexual dimorphism, studies were divided on the basis of geographical location into New World and Old World samples. However, of the total 207 data points, only five were from Old World populations. Of these, three showed an increase in sexual dimorphism ratios and two exhibited a decrease. Four of the measurement variables were measures of stature (without indication as to which long bones were used for the calculation) and one measurement variable was for maximum femur length. Due to insufficient data from Old World sites, it was impossible to compare Old and New World populations. However, the limited Old World data appear to reflect the trend found throughout the total data set.

Table 4: Non-Statistical Analysis of Changes in Sexual Dimorphism Ratios

	Increase	Decrease		
Total (207)	93	44%	113	54%
Femur (106)	62	58%	44	42%
Humerus (56)	21	37.5%	21	62.5%
Radius (12)	1	8%	11	92%
Tibia (14)	1	7%	13	93%
Ulna (10)	2	20%	8	80%
Linear Variables (74)	28	38%	46	62%
Femur (27)	19	70%	8	30%
Humerus (10)	2	20%	8	80%
Biomechanical Variables (115)	58	50%	57	50%
Femur (72)	41	57%	31	43%
Humerus (43)	17	40%	26	60%

DISCUSSION

Theoretically there are two reasons why a decline in sexual dimorphism would accompany a transition to agriculture. First, cultural research has shown that the type of work performed by males and females in agricultural cultures is more similar than the gendered duties of the hunter-gatherer. Murdock and Provost (1973) conducted a cross-cultural study of work in which they coded all tasks performed by each sex and whether the activities were assigned to males or females, partially or completely. There was a greater delineation between male and female duties in hunting and gathering populations than among agriculturalists. Theoretically sexual dimorphism decreased as male and female mechanical loads became more similar with the transition to agriculture. In addition, nutrition generally declined with the transition to agriculture. Nutritional decline occurred due to several factors. First, the amount of protein in the diet declined. Agricultural sedentism meant that an area around a village could easily be over hunted. Second, for the mobile hunter-gatherer there is greater variation in the types of plant food collected. The few agricultural crops did not always provide the nutritional value associated with variation, particularly in the case of maize (Cohen and Armelagos, 1984; Larsen, 1995). Under conditions of nutritional stress, males are less likely than females to reach their full potential size, thereby reducing the degree of sexual dimorphism (Stini, 1969).

If the degree of sexual dimorphism in a population does not decline with the transition to agriculture, it may be explained in several ways. First, the changes in

nutritional value may not have been great enough to effect a change in the morphology of a population, or, perhaps, changes in morphology were short-lived and difficult to discern in the archaeological record. Other cultural variables, such as preferential treatment of male children, may obscure any nutritional changes which may have affected dimorphism (Ortner, 2003; Rivers, 1982). In reference to the biomechanical argument, changes in loading may not have been of the type or intensity to change sexual dimorphism. Finally, males and females may have both changed their behaviors in such a way that the level of dimorphism remained the same with the adoption of agricultural subsistence.

This meta-analytical survey found that the decline in sexual dimorphism with the shift to agriculture was significant in two of nineteen measurement variables (10.5% of the total). While four measurement variables showed an increase in dimorphism over time (21% of the total), none of these results were significant. The meta-analyses therefore suggest that there is a slight trend toward a reduction in dimorphism, but, overall, the temporal changes in sexual dimorphism with the change in subsistence are not great. It is important to remember that the meta-analyses conducted in this study addressed changes in sexual dimorphism rather than within sex changes in morphology. Many of the individual studies compared did find significant changes in morphology with the transition to agriculture that were not addressed by the meta-analyses conducted here.

At the Upper Paleolithic – Mesolithic transition, the changes in morphology which accounted for a decline in sexual dimorphism were mostly due to the gracilization of the male which most researchers associate with a reduction in selection for large size due to the advancement of hunting technologies and smaller game species. Female size (and theoretically, activity pattern) did not undergo any major changes at that time. Frayer

(1980) found that the reduction in dimorphism which occurred at the dawn of the Neolithic was more closely associated with changes in the female form rather than the male. While he does not offer an explanation for these results it is reasonable to assume that changes in the female form may be particularly pronounced in populations where females were the primary agriculturalists. Ruff et al. (1984) found that of the biological changes associated with the transition to agriculture (increased periosteal infections, increased frequency of dental caries, and decreased stature and robusticity) the majority were more prevalent in females than males. In the case of the Georgia coastal populations these changes are thought to result from heavier female involvement in agricultural activities and greater female consumption of corn (Ruff, 1987). Analysis of the combined data used in this study could not attribute changes in dimorphism to either sex. Changes in individual studies may be largely male or female, but there is no consistent pattern when studies are compared.

Appropriate Indices of Dimorphism

The data collected for this review consisted of twenty-two different osteological measurement variables from which sexual dimorphism could be calculated. A review of the literature provides many other measurement variables of dimorphism which have been used to compare populations. This presents the researcher with two important questions: 1) is there an appropriate index of dimorphism, and 2) does it depend on the questions which are being asked of the data? A number of studies have used stature, or the sexual dimorphism of stature as an indicator of overall health in a population (Brauer, 1982; Holden and Mace, 1999; Wolanski and Kasprzak, 1976; Wolfe and Gray, 1982a). Unlike many osteometric measurements, stature can be easily measured in extant populations and compared to skeletal populations through a number of available formulae

for the estimation of stature. However, for skeletal populations, stature may not be the most reliable indicator of dimorphism. First, all formulas used to calculate dimorphism assume some amount of error. Second, when available, the femur or tibia is most commonly used to calculate stature due to the fact that the stature calculations for those bones have a smaller error than other long bones. In the analyses conducted for this study, the trend toward a decline in dimorphism was less evident in the femur than it was in measurements of the humerus. Therefore, perhaps stature is not the most sensitive measurement for explaining changes in sexual dimorphism over time.

Of the twelve meta-analyses conducted on the femur, three (25%) had a negative mean effect size indicating that sexual dimorphism increased rather than declined. For the humeral meta-analyses, only one of seven (14%) mean effect sizes was negative. The twelve meta-analyses used to describe the femur were drawn from a total of 35 effect sizes, one for each measurement variable considered in each study. Forty two percent of the femoral effect sizes were negative compared to 17% for the humerus. Ruff et al. (1993) evaluated temporal changes in postcranial robusticity and found that a decline in femoral diaphyseal robusticity was consistent in humans from the early Pleistocene through recent populations whereas trends in upper limb robusticity were more difficult to decipher. While these results may encourage researchers to evaluate the femur when studying temporal changes in robusticity, the same confidence should not be extended to studies of temporal changes in sexual dimorphism.

Measurements of sexual dimorphism on archaeological samples are limited to adults due to the difficulty of sexing juvenile remains. However, studies of extant populations have proven that problems exist in interpreting the remains of adult sex

differences. While juvenile populations may exhibit differential effects of stress, many of these effects may be corrected through “catch-up” growth before reaching adulthood (Stini, 1975). Therefore, adult size may not be the most sensitive indicator of the differential effects of stress.

Ruff (1987; 1984) suggests that the different measurements of sexual dimorphism may be evidence for particular causal factors. He suggests that cross-sectional data reveal more information about the forces acting on bone and, therefore, activity patterns, whereas changes in size or stature, linear data, are more likely to be due to nutritional factors (Ruff et al., 1984). If this is indeed the case, it is important to note that the only significant results in this study were for cross-sectional data.

The Transition to Agriculture

Theories regarding sexual dimorphism and the transition to agriculture are not based solely on the dietary effects of cultigens, but rather on the changes that accompany this subsistence change. Population growth accompanied the transition to agriculture although theories differ as to how these two factors relate to one another. Some believe that the growth in population forced people to adopt an agricultural economy; others think that the surplus food and sedentary nature of agricultural economies allowed for population expansion (Boserup, 1965; Bronson, 1977; Cohen, 1977).

With increased sedentism and population expansion, the rates of infectious diseases also increased after the transition to agriculture. Sedentism is particularly problematic under marginal environmental conditions since mobility can be beneficial in allowing a person to flee the worst circumstances. In the studies compiled by Cohen and Armelagos (1984) there appears to be an overall decline in the quality and length of life with the transition to agriculture. It could be argued that morphological changes associated with

the transition to agriculture are due to population expansion rather than subsistence change. However, these two changes are largely inseparable.

In some areas of the world there were changes that accompanied the transition to agriculture that were not universal and need to be considered as possible moderating factors to any morphological change. For example, Bridges (2000) points out that the atlatl was being replaced by the bow as a hunting tool around the same time that the transition to agriculture was occurring in some areas of North America. These two changes did not occur simultaneously worldwide, but may account for some of the morphological changes seen at the transition to agriculture. Brues' (1959) spearman-archer hypothesis suggested that the mechanical needs of the two weapon types would afford a selective advantage to different body types. While attempts to test this theory have proven it highly suspect, it must be considered that any change to the mechanical loading of bone which accompanied the transition to agriculture may prove to be a moderating variable in studies of morphological change.

The adoption of agriculture has been associated with an increase in infectious diseases due to increased sedentism and a population expansion. Population expansion allowed viral diseases such as measles, mumps and small pox to be more easily communicable than ever before. Malaria, cholera, blastomycosis, and scrub typhus are examples of diseases associated with agriculture due to an increased exposure to zoonoses when turning soil and exposure to contaminated water (Armelagos, 1990; Ortner, 2003).

Similarly, new ideas and technologies, such as those associated with subsistence changes, may be introduced through trade or migration. In many areas of the world, the

transition to agriculture was associated with a colonizing force. None of the populations in this study were subject to the diseases introduced with European contact, but the introduction of disease should be considered as a moderating variable in some areas.

Ruff and Larsen (1990) were able to compare precontact agricultural groups with postcontact agricultural groups on the Georgia coast. On the Georgia coast it appears that sexual dimorphism in femur length increased with the adoption of agriculture but the trend then decreased after contact. The increase in dimorphism that marked the adoption of agriculture along the Georgia coast has been associated with a culture in which the negative effects of corn agriculture appear to have affected females much more so than males. Throughout much of southeastern North America after the adoption of agriculture, females were the farmers while the primary subsistence activity of men remained hunting (Swanton, 1946). Contact with the Spanish brought diseases and a mission system which regimented the lives of both males and females. This example provides valuable information on the effect of culture on morphological changes spanning the transition to agriculture.

In this study, the size of males and females were compared in agricultural and preagricultural populations. However, the dividing line separating these two groups is not always clear. Bronson (1977) argues that cultivation of plant foods began as early as the Paleolithic. By selectively discarding waste from food plants in areas where they wanted plants to grow, people began propagating plant species. In North America, Native Americans cultivated local seed crops before maize (*Zea mays*) was introduced from Mesoamerica. Exposure to agriculture may thus have occurred long before the full adoption of an agricultural economy, and food crops may have been limited to a certain

segment of the population before they became dietary staples among the population at large.

For the purposes of this study, a population had to have a dependency on at least one domesticated carbohydrate crop to be considered agricultural. In Bridges (2000) the Middle Woodland population described had small scale cultivation of food crops. However, this population is considered “preagricultural” in this study because it is believed that agricultural products and activities had not become a significant portion of this population’s diet and lifestyle.

Determining the presence of agriculture in an archaeological site can be based on the identification of plant remains, associated material culture, or through skeletal indicators of agricultural subsistence. It is important to remember that the lack of botanical samples may be the result of poor preservation, or, as Rose et al. (1984) point out, many sites were excavated prior to the adoption of flotation techniques for retrieving paleobotanical remains. Conversely, the presence of plant domesticants does not necessarily indicate that agricultural products were a dietary staple of the population at large. Several skeletal pathologies are associated with agricultural populations, but an increase in the frequency of carious lesions in the dentition is universal and as such they are used as one indicator of the presence of agriculture (Larsen, 1984; Rose et al., 1984). Turner (1979) compared global samples and found that the average frequency of teeth affected by carious lesions in hunting and gathering groups is 1.72%; mixed hunting, gathering and farming groups average 4.37%; and agriculturalists average 8.56%. These rates vary regionally based on the food sources available. Agricultural diets are high in carbohydrates which are the primary cause of dental caries. Chemical analysis of bone

may also be used as a method of deducing paleodiet, particularly in the Americas where corn leaves such a clear chemical signature.

Many studies contain skeletal data from time periods that are considered transitional with regard to agriculture. Martin et al. (1984) found that agricultural intensification, rather than agricultural origins, were accountable for differential patterns of biological response, and, as such, only those groups in which agriculture was fully entrenched are used in this study. Nonetheless, transitional groups can provide information about how changes occurred. Nickens' (1976) study of stature reduction with the adoption of agriculture suggests that body size declined with the adoption of agriculture, but then increased as humans adapted, perhaps learning to compensate for some of the negative effects of agriculture. This suggests that some of the recorded morphological changes observed with the transition to agriculture may represent short-term rather than evolutionary changes. Table 5 provides sexual dimorphism ratios from a study which includes transitional populations. Of particular interest are the cases where Middle Woodland and Mississippian groups have very similar sexual dimorphism ratios, while the intermediate populations differ greatly (for example, see femoral maximum bending strength, humeral cortical area, and humeral minimum bending strength). If the transitional groups were not included, it would appear there was little morphological change with the transition to agriculture. If some morphological changes are only short-term, they may be difficult to detect in the archaeological record, particularly when comparing groups which may be at different stages in the transition to agriculture.

Table 5: Sexual Dimorphism Ratios in Transitional Groups (Bridges 2000)

	Middle Woodland*	Early Late Woodland	Late Late Woodland	Mississippian
Femoral Cross-Sectional Properties				
Cortical Area	0.1700	0.0541	0.0228	0.0675
Min Bending Strength	0.0055	-0.0334	0.0165	0.0847
Max Bending Strength	0.2877	0.0271	0.0990	0.2281
Torsional Strength	0.2665	0.0010	0.0615	0.1674
Shape Index (I_{\max} / I_{\min})	0.0455	0.1008	0.0729	0.1542
Femoral linear data and indices				
Bicondylar Length	0.0733	0.0864	0.0760	0.0760
AP diameter (midshaft)	0.1247	0.1520	0.1514	0.1456
ML diameter (midshaft)	0.0794	0.0551	0.0738	0.0666
Circumference (midshaft)	0.1158	0.1098	0.1088	0.1118
AP diameter (subtroch)	0.1238	0.1163	0.1223	0.1207
ML diameter (subtroch)	0.1007	0.0859	0.1076	0.0924
Circumference (subtroch)	0.1007	0.0949	0.1341	0.1037
Vert Head Diam Subtroch	0.1117	0.1051	0.1265	0.1394
Pilastric Shape Index	0.0461	0.0987	0.0741	0.0793
Platymeric Shape Index	0.0270	0.0270	0.0136	0.0270
Humeral Cross-sectional Properties				
Cortical Area	0.4143	0.1665	0.1032	0.4149
Min Bending Strength	0.3222	-0.1452	0.0440	0.2678
Max Bending Strength	0.2865	-0.2187	-0.1178	0.3005
Torsional Strength	0.2990	-0.1927	-0.0563	0.2900
Shape Index (I_{\max} / I_{\min})	-0.0357	-0.0818	-0.1542	0.0255
Humeral linear data and indices				
Length	0.0854	0.0881	0.0795	0.0734
Max diameter (midshaft)	0.1110	0.0745	0.0612	0.1089
Min diameter (midshaft)	0.1353	0.0831	0.0953	0.1133
Circumference (midshaft)	0.1172	0.0918	0.0712	0.1016
Max diameter (min. shaft)	0.1205	0.1112	0.0905	0.0943
Min diameter (min. shaft)	0.1550	0.0827	0.0927	0.1313
Circumference (min. shaft)	0.1161	0.0927	0.0794	0.1025
Midshaft shape index	0.0267	0.0000	0.0270	0.0132
Min. shaft shape index	0.0290	-0.0296	0.0000	0.0396

*In the meta-analysis, Middle Woodland and Mississippian groups were compared as the preagricultural and agricultural populations. Early late and late late Woodland groups are considered transitional.

Limitations of Meta-Analysis

In using meta-analysis it is important to understand the inherent assumptions and limitations of the technique. First, meta-analysis assumes that all available data is included in the analysis. For the researcher compiling these data, this presents the problem of publication bias or the “file drawer” problem; studies with significant results are more likely to be published than those with insignificant results (Rosenthal, 1984). In this review, the nature of the publication bias was different. Most of the studies used in the meta-analysis were not primarily investigating sexual dimorphism. Therefore, significant results in the original publications were not an issue. Rather, finding sufficient data was a problem due to the standards used for presenting data. The vast majority of publications on the transition to agriculture provided mean values for the populations studied, with no information on the dispersion of the sample. Hence, statistical data could not be gathered from these studies. Situations such as these present a problem for the meta-analyst as well as any reader hoping to critique the results of a study.

In collecting data, the hope was to find archaeological sites worldwide from which information could be drawn. However, the studies which could be included in my sample are affected by publication bias. As an English-speaker, all the journals and resources I collected were from sources written in English; all the studies I collected with data sufficient for a meta-analysis were from sites within the continental United States. Requests for data from international sources went unanswered. Furthermore, differential preservation of skeletal remains in the archaeological record is likely to skew any worldwide study of temporal changes in morphology.

The number of studies which contain data on skeletal morphology spanning the transition to agriculture is far greater than the number that could be included in a meta-analysis. A meta-analysis assumes independent samples. Skeletal remains are culturally sensitive materials and laws limit the access to these remains. As such, the same skeletal materials are often used in a number of different studies. No skeleton could be used more than once without violating the assumptions of meta-analysis.

Due to these problems in data collection, the results of this study are only applicable to the transition to agriculture as it occurred in North America. While a variety of locations and cultures are considered in these North American samples, they are all of similar ancestry and adopted maize as the primary agricultural carbohydrate. To assess the effect of the transition to agriculture on sexual dimorphism worldwide, it would be necessary to include studies from other areas of the globe.

Meta-analysis has been criticized for glossing over the details of individual studies. However, Rosenthal (1984) argues that the same can be said of any traditional review. In fact, a meta-analysis is more likely to reflect the actual results of studies rather than being overly influenced by information included in their abstracts or discussions (Rosenthal, 1984).

Another common criticism of meta-analysis is that comparing different studies, by different researchers, is like comparing apples and oranges. Not only are methods heterogeneous, but the quality of the studies may also vary. To control for heterogeneity, only like measurement variables were compared in twenty-two separate meta-analyses. However, in this study several measurements were combined although the methods of data collection were not identical. For example, measurements of maximum femur

length and bicondylar length were combined for the meta-analysis of femur length. Measurements of bending strength in different studies were collected using similar methods, but then each author used a different formula for standardization. A meta-analysis would not have been possible had these measurements not been compared. To do so did not violate any assumption of independence and provided important information which would have otherwise been unavailable. Glass made an excellent point in defense of such generalizations. “One compares apples and oranges in the study of fruit” (Glass, 1978).

The criticisms of meta-analysis have been addressed by its proponents and the method has proved reliable when used for its intended purpose (Glass et al., 1981; Hunter et al., 1982; Rosenthal, 1984). In this study the technique has been employed to test the theory that sexual dimorphism declined with the transition to agriculture. While this meta-analysis does not directly inform the question of causality, it provides information about patterns of dimorphism which may then serve future studies of sexual dimorphism. The availability of data has restricted the applicability of the results to North American populations but has provided a needed cumulative analysis of how sexual dimorphism may be affected by the transition to agriculture in a large geographic area.

CONCLUSIONS

Meta-analyses were conducted on the postcranial measurements taken in five separate studies. Of the nineteen measurements from which populations were deemed homogeneous, two experienced a significant decline with the transition to agriculture (10.5 %) and a third experienced a near significant decline ($p = 0.0537$). A comparison of the effect sizes found that 79 % of all measurements experienced a decline in dimorphism as opposed to the remaining 21 % in which a negative effect size indicated that the degree of dimorphism increased. None of the increases in dimorphism were found to be significant. The trend towards a decline in dimorphism is more apparent in humeral than in femoral measurements. The non-statistical analysis of agricultural versus preagricultural populations shows similar results. In contrast to the theory that sexual dimorphism declines with the transition to agriculture, in most cases, no significant change occurs.

APPENDIX A
META-ANALYSES OF FEMORAL MEASUREMENTS

Femur Length (based on maximum or bicondylar length measurements)

source	study #	t statistic	r	N	df	Z
Boyd and Boyd (1989)	1	0.2343	0.0103	524	520	0.2343
Bridges (2000)	3	-0.1495	-0.0135	127	123	-0.1495
Brock and Ruff (1988)	4	-1.3684	-0.1173	138	134	-1.3636
Ruff and Larsen (1990)	5	-2.195	-0.3436	40	36	-2.1216

$$\begin{aligned} \bar{r} &= -0.0317 & X_{k-1}^2 &= 5.5141 & (0.5 > p > 0.1) & \text{Homogeneous} \\ S_r^2 &= 0.0071 & S_{er}^2/S_r^2 &= 0.6802 & \text{Moderator Variable Present} \\ S_{er}^2 &= 0.0048 & Z &= -1.7002 & p = 0.9554, \text{N.S.} \end{aligned}$$

Femur Midshaft Circumference

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	-2.156	-0.1786	174	170	-2.1413
Bridges (2000)	3	0	0	126	122	0
Brock and Ruff (1988)	4	-0.4192	-0.0362	138	134	-0.4190

$$\begin{aligned} \bar{r} &= -0.0824 & X_{k-1}^2 &= 2.3564 & (0.5 > p > 0.1) & \text{Homogeneous} \\ S_r^2 &= 0.0063 & S_{er}^2/S_r^2 &= 1.0721 & \text{No moderator variable present} \\ S_{er}^2 &= 0.0068 & Z &= -1.4782 & p = 0.0929, \text{N.S.} \end{aligned}$$

Femoral Cortical Area (size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	-1.4781	-0.2276	44	40	-1.4579
Bridges (2000)	3	1.2617	0.2058	40	36	1.2478
Brock and Ruff (1988)	4	2.3047	0.3424	44	40	2.2282
Ruff and Larsen (1990)	5	-0.2271	-0.0378	40	36	-0.2270

$$\begin{aligned} \bar{r} &= 0.0701 & X_{k-1}^2 &= 9.6710 & (0.01 > p > 0.005) & \text{Heterogeneous} \\ S_r^2 &= 0.0498 & S_{er}^2/S_r^2 &= 0.4736 & \text{Moderator Variable Present} \\ S_{er}^2 &= 0.0236 & Z &= 0.8955 & p = 0.1867, \text{N.S.} \end{aligned}$$

Femur Minimum Bending Strength (size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	-2.0041	-0.3021	44	40	-1.9538
Bridges (2000)	3	-0.6359	-0.1054	40	36	-0.6342
Brock and Ruff (1988)	4	1.1042	0.1720	44	40	1.0958
Ruff and Larsen (1990)	5	-0.3512	-0.0584	40	36	-0.3509

$$\bar{r} = -0.0731 \quad X_{k-1}^2 = 4.3424 \quad (0.5 > p > 0.1) \text{ Homogeneous}$$

$$S_r^2 = 0.0298 \quad S_{er}^2/S_r^2 = 0.7914 \quad \text{No Moderator Variable}$$

$$S_{er}^2 = 0.0236 \quad Z = -0.9215 \quad p = 0.8212, \text{ N.S.}$$

Femur Maximum Bending Strength (size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	-0.4867	-0.0767	44	40	-0.4860
Bridges (2000)	3	0.3108	0.0517	40	36	0.3106
Brock and Ruff (1988)	4	1.5627	0.2399	44	40	1.5389
Ruff and Larsen (1990)	5	0.1877	0.0313	40	36	0.1876

$$\bar{r} = 0.0625 \quad X_{k-1}^2 = 2.5951 \quad (0.5 > p > 0.1) \text{ Homogeneous}$$

$$S_r^2 = 0.0136 \quad S_{er}^2/S_r^2 = 1.7400 \quad \text{No Moderator Variable}$$

$$S_{er}^2 = 0.0236 \quad Z = 0.7756 \quad p = 0.2206, \text{ N.S.}$$

Femoral Shape Index (I_{\max}/I_{\min})

source	study #	t statistic	r	N	df	Z
Bridges (2000)	3	-1.1831	-0.1935	40	36	-1.1716
Brock and Ruff (1988)	4	1.2728	0.1973	44	40	1.2599
Ruff and Larsen (1990)	5	0.7035	0.1165	40	36	0.7011

$$\bar{r} = 0.0452 \quad X_{k-1}^2 = 3.8381 \quad (0.5 > p > 0.1) \text{ Homogeneous}$$

$$S_r^2 = 0.0282 \quad S_{er}^2/S_r^2 = 0.8538 \quad \text{No Moderator Variable}$$

$$S_{er}^2 = 0.0241 \quad Z = 0.4558 \quad p = 0.3300, \text{ N.S.}$$

Femoral J ($J=I_{ap} + I_{ml}$, polar second moment of area, size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (2000)	3	-0.2930	-0.0488	40	36	-0.2928
Brock and Ruff (1988)	4	1.7651	0.2688	44	40	1.7307
Ruff and Larsen (1990)	5	-0.7420	-0.1227	40	36	-0.7391

rbar = 0.0401 $\mathbf{X}_{k-1}^2 =$ 3.9915 $(0.5 > p > 0.1)$ Homogeneous
 $S_r^2 =$ 0.0297 $S_{er}^2/S_r^2 =$ 0.8130 No Moderator Variable
 $S_{er}^2 =$ 0.0241 $Z =$ 0.4034 $p = 0.3446$, N.S.

Subtrochanteric Cortical Area (size standardized)

source	study #	t statistic	r	N	df	Z
Brock and Ruff (1988)	4	2.3822	0.3647	41	37	1.2589
Ruff and Larsen (1990)	5	0.1767	0.0294	40	36	0.7011

rbar = 0.1991 $\mathbf{X}_{k-1}^2 =$ 3.5471 $(0.5 > p > 0.1)$ Homogeneous
 $S_r^2 =$ 0.0281 $S_{er}^2/S_r^2 =$ 0.8107 No Moderator Variable
 $S_{er}^2 =$ 0.0228 $Z =$ 1.3859 $p = 0.0838$, N.S.

Subtrochanteric Minimum Bending Strength (size standardized)

source	study #	t statistic	r	N	df	Z
Brock and Ruff (1988)	4	1.4423	0.2307	41	37	1.4221
Ruff and Larsen (1990)	5	0.2916	0.0485	40	36	0.2914

rbar = 0.1408 $\mathbf{X}_{k-1}^2 =$ 0.9102 $(0.5 > p > 0.1)$ Homogeneous
 $S_r^2 =$ 0.0083 $S_{er}^2/S_r^2 =$ 2.8595 No Moderator Variable
 $S_{er}^2 =$ 0.0237 $Z =$ 1.2116 $p = 0.1131$, N.S.

Subtrochanteric Maximum Bending Strength (size standardized)

source	study #	t statistic	r	N	df	Z
Brock and Ruff (1988)	4	1.0468	0.1696	41	37	1.0391
Ruff and Larsen (1990)	5	1.2519	0.2042	40	36	1.2382

rbar = 0.1867 $\mathbf{X}_{k-1}^2 =$ 0.0367 $(0.9 > p > 0.5)$ Homogeneous
 $S_r^2 =$ 0.0003 $S_{er}^2/S_r^2 =$ 76.6613 No Moderator Variable
 $S_{er}^2 =$ 0.0230 $Z =$ 1.6103 $p = 0.0537$, Near Significant

Subtrochanteric Femoral Shape Index (I_{\max}/I_{\min})

source	study #	t statistic	r	N	df	Z
Brock and Ruff (1988)	4	-0.6500	0.1063	41	37	-0.6481
Ruff and Larsen (1990)	5	1.2510	0.2041	40	36	1.2374

$$\begin{array}{lll}
 \mathbf{rbar} = 0.1546 & \mathbf{X_{k-1}^2} = 0.2713 & (0.9 > p > 0.5) \text{ Homogeneous} \\
 \mathbf{S_r^2} = 0.0024 & \mathbf{S_{er}^2/S_r^2} = 9.8274 & \text{No Moderator Variable} \\
 \mathbf{S_{er}^2} = 0.0235 & \mathbf{Z} = 0.4167 & p = 0.3409, \text{N.S.}
 \end{array}$$

Subtrochanteric J ($J=I_{ap} + I_{ml}$, polar second moment of area, size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Brock and Ruff (1988)	4	1.4423	0.2307	41	37	1.4221
Ruff and Larsen (1990)	5	0.2916	0.0485	40	36	0.2914

$$\begin{array}{lll}
 \mathbf{rbar} = 0.2010 & \mathbf{X_{k-1}^2} = 0.1569 & (0.9 > p > 0.5) \text{ Homogeneous} \\
 \mathbf{S_r^2} = 0.0012 & \mathbf{S_{er}^2/S_r^2} = 18.3894 & \text{No Moderator Variable} \\
 \mathbf{S_{er}^2} = 0.0227 & \mathbf{Z} = 1.7342 & p = 0.0418, \text{SIGNIFICANT}
 \end{array}$$

APPENDIX B
META-ANALYSES OF HUMERAL MEASUREMENTS

Humerus Length

source	study #	t statistic	r	N	df	Z
Ruff and Larsen (1990)	5	-0.9413	-0.1294	56	52	-0.9373
Bridges (2000)	3	0.7501	0.0710	115	111	0.7491

$$\begin{aligned} \bar{r}_{\text{bar}} &= 0.0054 & X_{k-1}^2 &= 1.4492 & (0.5 > p > 0.1) & \text{Homogeneous} \\ S_r^2 &= 0.0084 & S_{\text{er}}^2/S_r^2 &= 1.3949 & \text{No Moderator Variable} \\ S_{\text{er}}^2 &= 0.0117 & Z &= -0.0941 & p = 0.5359, \text{N.S.} \end{aligned}$$

Humerus Midshaft Circumference

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	2.2074	0.1453	220	216	2.1949
Bridges (2000)	3	0.4943	0.0467	116	112	0.4941

$$\begin{aligned} \bar{r}_{\text{bar}} &= 0.1112 & X_{k-1}^2 &= 6.4901 & (0.025 > p > 0.01) & \text{Heterogeneous} \\ S_r^2 &= 0.0153 & S_{\text{er}}^2/S_r^2 &= 0.3805 & \text{Moderator Variable Present} \\ S_{\text{er}}^2 &= 0.0058 & Z &= 1.3445 & p = 0.090, \text{N.S.} \end{aligned}$$

Humerus Cortical Area (size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	0.2326	0.0347	49	45	0.2325
Bridges (2000)	3	0.2995	0.0623	40	36	0.2993
Ruff and Larsen(1990)	5	0.4068	0.0563	56	52	0.4065

$$\begin{aligned} \bar{r}_{\text{bar}} &= 0.0507 & X_{k-1}^2 &= 0.0220 & (0.975 > p > 0.9) & \text{Homogeneous} \\ S_r^2 &= 0.0001 & S_{\text{er}}^2/S_r^2 &= 150.7371 & \text{No Moderator Variable} \\ S_{\text{er}}^2 &= 0.0206 & Z &= 0.4692 & p = 0.3228, \text{N.S.} \end{aligned}$$

Humerus Minimum Bending Strength (size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	1.8729	0.2689	49	45	1.8364
Bridges (2000)	3	-0.6359	-0.1054	40	36	-0.6342
Ruff and Larsen(1990)	5	1.4135	0.1924	56	52	1.3999

$$\begin{array}{lll} \mathbf{rbar} = & 0.1361 & \mathbf{X_{k-1}^2} = & 4.5214 & (0.5 > p > 0.1) \text{ Homogeneous} \\ \mathbf{S_r^2} = & 0.0233 & \mathbf{S_{er}^2/S_r^2} = & 0.8564 & \text{No Moderator Variable} \\ \mathbf{S_{er}^2} = & 0.0199 & \mathbf{Z} = & 1.3011 & p = 0.0968, \text{N.S.} \end{array}$$

Humerus Maximum Bending Strength (size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	1.9915	0.2846	49	45	1.9476
Bridges (2000)	3	0.3108	0.0517	40	36	0.3106
Ruff and Larsen(1990)	5	1.0010	0.1375	56	52	0.9962

$$\begin{array}{lll} \mathbf{rbar} = & 0.1635 & \mathbf{X_{k-1}^2} = & 1.7955 & (0.5 > p > 0.1) \text{ Homogeneous} \\ \mathbf{S_r^2} = & 0.0087 & \mathbf{S_{er}^2/S_r^2} = & 2.2621 & \text{No Moderator Variable} \\ \mathbf{S_{er}^2} = & 0.0196 & \mathbf{Z} = & 1.8789 & p = 0.0307, \text{SIGNIFICANT} \end{array}$$

Humeral Shape Index (I_{\max}/I_{\min})

source	study #	t statistic	r	N	df	Z
Bridges (2000)	3	-0.9142	-0.1873	27	23	-0.9059
Ruff and Larsen(1990)	5	-0.8729	-0.1202	56	52	-0.8697

$$\begin{array}{lll} \mathbf{rbar} = & -0.1420 & \mathbf{X_{k-1}^2} = & 0.0629 & (0.9 > p > 0.5) \text{ Homogeneous} \\ \mathbf{S_r^2} = & 0.0010 & \mathbf{S_{er}^2/S_r^2} = & 23.4217 & \text{No Moderator Variable} \\ \mathbf{S_{er}^2} = & 0.0231 & \mathbf{Z} = & -0.8878 & p = 0.8106, \text{N.S.} \end{array}$$

Humeral J (J=I_{ap} + I_{ml}, polar second moment of area, size standardized at midshaft)

source	study #	t statistic	r	N	df	Z
Bridges (2000)	3	-0.3942	0.0819	27	23	-0.3935
Ruff and Larsen(1990)	5	1.2280	0.1679	56	52	1.0368

$\bar{r} = 0.1399$ $\bar{X}_{k-1}^2 = 0.1819$ $(0.9 > p > 0.5)$ Homogeneous
 $S_r^2 = 0.0016$ $S_{er}^2/S_r^2 = 14.2832$ No Moderator Variable
 $S_{er}^2 = 0.0232$ $Z = 0.5838$ $p = 0.2810$, N.S.

APPENDIX C
META-ANALYSES OF OTHER LONG BONE MEASUREMENTS

Tibia Midshaft Circumference

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	0	0	121	117	0
Bridges (2000)	3	0.3914	0.0461	76	72	0.3912

rbar = 0.0178 $X_{k-1}^2 =$ 0.0631 ($0.9 > p > 0.5$) Homogeneous
S_r² = 0.0003 $S_{er}^2/S_r^2 =$ 32.8342 No Moderator Variable
S_{er}² = 0.0101 **Z =** 0.1956 p = 0.4247, N.S.

Ulna Midshaft Circumference

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	-0.0910	-0.0082	140	136	-0.0910
Bridges (2000)	3	0.4406	0.0505	80	76	0.4403

rbar = 0.0131 $X_{k-1}^2 =$ 0.1244 ($0.9 > p > 0.5$) Homogeneous
S_r² = 0.0006 $S_{er}^2/S_r^2 =$ 16.4999 No Moderator Variable
S_{er}² = 0.0091 **Z =** 0.1747 p = 0.4325, N.S.

Radius Midshaft Circumference

source	study #	t statistic	r	N	df	Z
Bridges (1989)	2	2.9719	0.2513	142	138	2.9243
Bridges (2000)	3	0.9075	0.0947	95	91	0.9054

rbar = 0.1885 $X_{k-1}^2 =$ 14.8913 (p < 0.01) Heterogeneous
S_r² = 0.0414 $S_{er}^2/S_r^2 =$ 0.1897 Moderator Variable Present
S_{er}² = 0.0078 **Z =** 1.9149 p = 0.0281, Significant, but not relevant due to the presence of moderator variable

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