CHAPTER 7

DISCUSSION

Forensic anthropology uses comprehensive methods to recognize certain skeletal traits in the determination of sex. Quantitative analyses are the examination of measurements to illuminate information on sex or stature (Holman and Bennet 1991; Richman *et al.* 1979; Rother *et al.* 1977; Stewart 1954; Tagaya 1989; Wescott and Moore-Jansen 2001), and visual traits give information on the observed morphology and anatomy of the human skeleton (Donlon 2000; Hill 2000; van Dongen 1963; Ubelaker and Volk 2002; Walrath *et al.* 2003). Combined, these methods have proven quite effective in their accuracy rates for the determination of sex, in particular. In addition, geometric morphometrics provides a new way for anthropologists to quantify the shapes they visualize (Adams 1999; Bookstein 1982, 1986; Holliday and Falsetti 1999; Pretorius *et al.* 1994; Richtsmeier *et al.* 2002; Siegal and Benson 1982). All three methods are valuable tools by which analysts conduct research and identify skeletal remains in a medico-legal aspect.

However, modification in bone through degenerative processes may cause ambiguity in the expression of a trait or traits used for sex determination. The effect of age advancement on the human skeleton has been researched extensively with regard to living people and how these changes affect fracture patterns, healing, bone mineral density and general wellbeing (e.g., Bilezikian 1999; Dickenson *et al.* 1981; Heaney *et al.* 1989; Nordin 1966; Scientific Advisory Board 1988, 1996). As of yet, the effect of age on the human skeleton has not been studied to such a degree that we can understand its consequences on the successful establishment of skeletal sex in an unknown individual. Degenerative processes occur in a dynamic environment, with bone gain and loss occurring simultaneously to provide a complex picture of hard tissue morphology as humans age (Ebeling *et al.* 1998; Herd *et al.* 1992; Kolbe-Alexander *et al.* 2004; Leiel *et al.* 1988; Micklesfield *et al.* 2003; Riggs *et al.* 1982;

Steiger *et al.* 1992). These processes required further study in order to determine how they influence the way forensic anthropologists draw conclusions about sex with regard to aged human remains.

The aim of this study was to determine if sexual dimorphism changed with age in the human skeleton. If changes in the human skeleton with age are great enough to visualize, quantify, and ultimately are deemed significant through statistical analysis, then forensic anthropologists would have reason to be more cautious and prudent in their determination of sex based on these facts.

The goal to determine if sexual dimorphism changed with age was accomplished on three distinct levels. Using measurements and subsequent statistical analyses on 23 postcranial measurement sites, information was gained on patterns of metric increase or decrease at each skeletal site. These sites included articular joint ends of all six major long bones (both proximal and distal), shaft diameters and circumferences of these bones, and measurements of the pelvis. Biological populations were separated in order to take into account size discrepancies. When analyzing the size differences between young and old individuals, evidence was gained on where these changes were occurring and to what degree these changes were taking place. The magnitude of metric changes was important because of the potential misclassification of females if these bones metrically increased to such a degree that females may be misclassified as males, or if these bones decreased in size such that males were incorrectly classified as females. Changes in all dimensions were assessed between young and old individuals, and if the difference between the two were significant, they were compared to their male or female counterpart to reveal the possibility of metric overlap.

Secondly, non-metric traits of the pelvis and the distal humerus were employed to gain knowledge as to whether or not these visual indicators of sex changed with the onset of age. Four traits of the pelvis and four traits of the humerus were used to determine sex. The classification accuracies for both young and old individuals of each biological affiliation were compared to determine if misclassification increased or decreased with advancing age.

Finally, geometric morphometric analysis was used on four 2-dimensional perspectives from the pelvis and the humerus to "quantify" the shape and form of each feature. These 2-dimensional views of the pelvis and humerus were directly correlated to those features used in the non-metric visual assessment of sex. In each perspective (especially the distal humerus) it was first attempted to prove that each view was sexually dimorphic. Subsequently, the geometric shape equivalent of young and old individuals from each group were calculated and compared to determine if any quantifiable changes in form took place with the onset of age. Geometric morphometric analysis achieved results that illuminated several issues with regard to the quantification of shape and form in anthropology. This visual and statistical tool is a powerful resource and produced interesting, highly accurate results on most occasions. However, drawbacks to the method will be discussed, as well as the future applicability of geometric morphometrics in forensic casework.

7.1

Research sample

The sample should ideally have included an equal number of females and males from all age groups and both population affiliations. Because the Pretoria Bone collection does not include a large number of young white individuals (both male and female), every effort was made to create a comprehensive sample that would include as many males and females in each population and age group as possible, and therefore specimens from the Raymond Dart collection (University of Witwatersrand) were added where possible.

Although this study does not focus on biological affinity, it was difficult not to note the abundance of young black male specimens in the collection, and the conspicuous absence of young black females and young whites (L'Abbe *et al.* 2005). The sample of young white specimens was not ideal, but every effort was made to acquire as much information as possible.

The Pretoria Bone and the Raymond Dart Skeletal Collections cannot be studied without addressing the issue of possible secular trends in the size of individuals throughout time. A secular trend is the tendency for each succeeding generation to mature earlier and become, on the average, larger (Kieser *et. al.* 1987). Slow but persistent alteration over a period of time in the mean shape or size of individuals in a population is referred to as a secular trend in human biological terms. A positive secular trend is one that demonstrates an increase in the dimensions under consideration, while a negative trend relates to a diminution of the structure (Cameron *et al.* 1989; Tobias 1975, 1985; Tobias and Netscher 1977).

This pattern of development towards an increase in size has numerous variables attributed to it. Factors include better nutrition and health care options which may allow for an increase in the stature of individuals in a healthier environment. The amount and quality of nutrition have increased, which allowed for more energy to be exerted in growth and development (Henneberg and George 1993; Jantz 2001). These factors may very well hold true with South African people. Sexual selection of taller individuals, decreased mortality rates and phenotypic adaptation to particular environmental conditions may also be mechanisms that drive secular trends towards an increase in size. However, studies focused on secular trends in humans concentrate largely on stature and cranial measurements (Henneberg and Louw 1997; Jantz 2001; Kelpinger 2001; Malina and Zavaleta 1980; Malena 1979; Susann 1985; Tanner 1994), which were not the focus of this study. However, these types of quantitative comparisons of past era samples to contemporary samples have provided data that support a general increase in stature in recent generations. Research in South Africa has also shown certain positive secular trends, especially in cranial dimensions and the dentition of black South Africans, although the mid-20th century has shown an absence of a positive secular trend, which seemed to denote that environmental factors believed to produce a positive trend were absent in this time frame (Cameron *et al.* 1989; Kieser *et al.* 1987). Studies on the magnitude of secular trend in stature among South Africans found a weak positive trend (Henneberg and van den Berg 1990; Steyn and Smith 2007) but Tobias and Netscher (1977) and Ulijaszek (1996) found evidence of a reversal of this positive trend in the cranium and femur. Later, Tobias (1985) documented the reversal of a secular trend change in South Africans. Thus, it is difficult to determine what the effect of secular trend would be in this study, if any. Long bone length measurements were purposefully not included in this study because stature was not a priority for this particular research. Articular joint ends (such as those studied) were analyzed because they had unique properties in a degenerative sense that may illuminate differences with the onset of age. The possible addition of bone in old age (and subsequent degeneration) may be present regardless of whether a population was well or poorly nourished, as evidenced in Katzmarzyk and Leonard (1998) and Susann (1985). Long bone lengths, and thus secular trend in stature, would most likely not have influenced this study. The birth and death dates of each individual in the study were not recorded, eliminating the possibility of studying the mean birth dates for each group to see if a difference occurred between size and the era in which the individual was born. It should be mentioned that the Pretoria bone collection is the most contemporary sample in South Africa, with dates of birth ranging from 1863 to 1996.

This study was conducted with ideal parameters in mind. Every effort was made to collect data that was comprehensive, comparable, and that reflected the contemporary questions that were posed. Thus although the sample for each group was not ideal, it was considered sufficient for research purposes.

7.2

Metric analysis

The statistically significant size difference between males and females was initially apparent when comparing metric results, and continued to be the principle component of sexual dimorphism based on metric analysis as seen in other works (Bass 1995; White 2000; Steele and Bramblett 1988). The size (and size differences) in South Africans specifically have been well-documented by Asala (2001), Asala *et al.* (1998), Bidmos (2006), and Patriquin *et al.* (2005). All males were observed to be larger than their female counterparts in proximal and distal articular surfaces, midshaft diameters and circumferences, as well as most pelvic measurements; the only exception was the pubis length (males=73.2mm, females=76.6mm). The calculated ischio-pubic index of females presented a larger value than that of the male sample, based on the ratio of longer pubic lengths to shorter ischium lengths in females. These results correspond to all past research that detail South African osteometry.

7.2.1

Metric changes in females with the onset of age

In regard to the female specimens studied, metric differences between black and white female long bone dimensions were observed in several midshaft measurements and the head diameters of both the humerus and femur, among others. White female specimens have been shown to have larger skeletal measurements than their black counterparts (Steyn and Iscan 1999). Through analysis of the measurements, the degree of difference between the two populations was statistically significant in a majority of all variables. Thus, although there were some similarities in size between the two female groups, the groupings by population were made so as not to obscure small metric changes with age.

Clear size differences existed in pelvic dimensions between black and white females as well. All measurements of the pelvis and the ischio-pubic index calculation were greater in white females on a statistically significant level. This simply revalidates the results of the postcranial long bone measurement means indicating that white females are larger in size than their black counterparts.

Black females did not change much in their long bone dimensions with the onset of age. The absence of any size change showed that black females continued to exhibit the same level of sexual dimorphism (based on size) throughout life. Only one measurement changed on a statistically significant level with the onset of age in the black female, namely the circumference of the humerus at midshaft, which decreased with age. This decrease in the diaphyseal value of the upper arm bone is in general congruence with previous studies that showed both the addition and involution of bone within the cortical/ endosteal surface (Ericksen 1976; Evers *et al.* 1985; Garn *et al.* 1969; Garn 1970; Heaney *et al.* 1982; Nilas *et al.* 1988; Thompson 1980; Woddard 1962). Specifically, Heaney *et al.* (1989) found an increase in medullary cavity size does not always lead to the increase in midshaft circumference, especially if bone density is greater in cortical bone to begin with. Because bone density was found to be predominantly greater in black populations (Orwoll *et al.* 1996; Garn *et al.* 1969, 1972), a general loss of bone within the cortical/ endosteal surface of long bones in South African females seemed logical when viewing the results from both Heaney *et al.*'s and Orwoll *et al.*'s work. Thus, a net loss in the circumference of the humerus for black females with the onset of age appeared to be in conjunction within the framework of normal degenerative processes documented by Cummings *et al.* (1990), Herd *et al.* (1992) and Herrin (2001), and paralleled the findings of past research.

In addition, the high bone mineral content of black South African females may account for the lack of change with the onset of age in this sample. Numerous studies prove unequivocally that the population of black females in Africa inherently have a greater bone density than white individuals. Adebajo *et al.* (1990) specifically saw less femoral fractures in black West African females than in European samples. Aspray *et al.* (1996) found even with a lower bone mineral content after menopause, Gambian females were less prone to osteoporotic fractures based on their elevated bone density. Schnitzler *et al.* (1990) attributed the lack of fragility in Black South African females as a combination of thicker and better connected trabeculae, even with the onset of age. Grynpas (1993) conclusion was the same; Black South African females were less likely to suffer from fragility fractures than others based on their bone mineral content. Black South African females commence with greater bone density, and thus theoretically have less bone density loss with the onset of age. In addition, pathological changes such as microfractures along muscle attachment sites and articular surfaces in black females during the 7th, 8th, and 9th decades of life would be less prevalent than in white females of the same age category. All past studies concluded the lack of fragility in black South African female bone with the onset of age, and this current study corresponds to those conclusions. Black South African females change very little in their dimensions with the onset of age, because they do not lose as much bone tissue nor do they suffer as much from osteoporotic fractures and healing as white South African females.

Metric values from the pelvis for black South African females also remained static and largely unchanged with advanced age, much like they did in the other postcranial measurements. This indicated the absence of osteophytic changes that occur with decreased bone mineral density and the presence of robust bone tissue resilient to degenerative changes. Female pelvic morphology throughout life was maintained for this group, and the continuation of distinct sexual dimorphism with the onset of age was seen.

White females increased in all long bone metric dimensions with the onset of age. This result corresponded to the original notion that females may very well *decrease* in sexual dimorphism by *increasing* in size, thus making them more difficult to categorize correctly. As found in Smith (1964), midshaft diameters of long bones did increase as age increased. Rother *et al.'s* research (1977) found 16% of female specimens overlapped metrically into the male mean when measuring older specimens. In addition, Walker (1995) found an increase in skeletal robusticity in white females 45 years old and older. Walker's results directly correspond to the metric increase in long bone articular ends and midshafts seen here.

White females in our study came metrically close to the white male mean with the humeral head diameter, the distal diameter of the ulna, the radial head, the femur diameter at midshaft, the bicondylar breadth of the distal femur, the bicondylar breadth of the proximal tibia, and the tibia diameter at midshaft. The mean of old white females through their 7th, 8th, and 9th decades of life came quite close to overlapping the mean of young white males. This raised a serious concern for the possible misidentification of an isolated bone shaft or fragment, if recovered in the field and only measurements were used to assess skeletal sex. Young white males in practice may rarely be misclassified as old white females for a number of reasons (visual techniques, bone density assessment, the presence of possible degenerative changes). However, misclassification may occur in instances of fragmentation and if other indicators of sex are absent.

One metric dimension of old white females crossed over into the metric dimension for black males; namely the humeral head diameter, which increased significantly in the white female population with the advance of age. The mean for black males and white females for this measurement not only converged as age progressed, but the female mean exceeded that of the males in the 6th decade of life. This result, again, was cause for concern based on the fact that many times measurements are often used exclusively to determine skeletal sex when remains are fragmented or incomplete, and ancestry of the individual cannot be determined from a fragmented bone.

The reasons for these changes are multi-faceted and may include normal degenerative factors as well as disease, e.g., osteoporosis (Aloia *et al.* 1985; Cummings *et al.* 2000; Dickenson *et al.* 1981; Frost 1963; Herd *et al.* 1992; Herrin 2001; Hurxthal *et al.* 1969; Jowsey 1960; Nilas *et al.* 1988; Orwoll *et al.* 1996; Riggs *et al.* 1982; Steiger 1992). White South African females commenced with less bone mineral density, and thus were more subject to degenerative processes as age progressed (Chavassieux *et al.* 2007; Cummings and Black 1995; Cummings *et al.* 1985; Evers *et al.* 1985). These degenerative processes include osteoporotic bone remodeling and the repair of possible microfractures at articular joint surfaces (Jowsey 1960; Kanis and McCloskey 1993; Martin and Atkinson 1977). Osteon count increases with age, which in turn allows for more potential microfracture points along the osteon margins. Also, bone mineral density has been directly correlated to the size of Haversian canals, and their increase in dimension with the onset of age (Thompson 1980). Thompson found that females tend to have significantly larger Haversian canal areas compared with males of the same advanced age, thus their bone mineral density values are smaller. Larger Haversian canals equate to larger expanses within osteons, thus less density in bone is seen in females than males. Because females of non-African origin have a lower bone mineral density with the onset of age (as seen in studies by Trotter *et al.* 1960, Ericksen 1976, and Martin *et al.* 1985), fractures are more likely to occur because the tensile strength of white female bone is not as substantial. As more bone is formed at these fracture sites due to hard tissue fracture response, metrically larger articular sites could occur.

The increase in long bone midshaft diameters with the onset of age in white females may also follow mechanisms found in past studies of cortical bone change with time. Endosteal bone loss and periosteal bone gain in long bones is characteristic of aging populations. As seen in the study by Nilas *et al.* (1988), an unexpected increase in bone width at two forearm sites was the result of research originally designed to observe bone loss over time. Smith and Walker (1964) showed that in white females, the diameter of the midshaft periosteum increased as cortical thickness declined. Both processes worked together to increase the diameter of a long bone shaft. Since periosteal diameter increased and cortical thickness decreased, the endosteal diameter of long bones in white females were seen to expand when comparing the young and old groups. The same results were apparent in this current research as well, with an increase in dimensions of four skeletal sites (among others) of the arm in the white female sample when comparing young to old. The combined processes of an increase in the medullary cavity of long bones and the net bone gain at the periosteal surface with age, acts in tandem with osteophytic fracturing in less-dense bone to create a dual-process addition (thus net bone gain) in the white female skeleton.

Studies by Martin and Atkinson 1977, Leiel *et al.* 1988, and Heaney *et al.* 1989 showed the results of the complex process of addition and subtraction of bone on the periosteal surface and within the endosteal envelope. These changes can have an ultimate net bone gain or loss in regard to measurements such as midshaft diameters, cross-sectional periosteal widths, and circumferences. As seen in this current study, the female skeleton can show both bone loss (as in the black South African sample) and bone gain (white South African females), which directly correspond to the findings in past studies.

No measurements of the pelvis or the ischio-pubic index changed on a statistically significant level with the onset of age in either black or white females. This indicated the static nature of female pelvic morphology throughout life, and showed that cortical bone thinning and bone mineral density decline was not necessarily affecting white females in the os coxae as it was affecting them in their long bone measurements. Both white and black females appeared to maintain a relative stasis in their pelvic measurements, which indicated a lack of pelvic modification with the onset of age in both female groups. Although the size component between black South African females and white South African females continued to be apparent (as seen in Patriquin *et al.* 2002), no dimension changes that may influence sexual dimorphism were observed with either group.

The possibility of misclassification from long bone measurements of white South African females was present. In addition, pelvic metric data from all white females, both young and old, were larger than pelvic metric data from all males, young and old. If size is truly the principle component for sex determination, then larger metric values in white females indicated the possible misclassification of females. However, sexual dimorphism in the pelvis can be seen as the amalgamation of many factors, only one of which is size. Visual characteristics may be the best predictor of sex from the pelvis (Bruzek and Soustal 1984; Krogman 1962; Moerman 1981; Stewart 1954), and measurements in this study do not indicate a change in sexual dimorphism in the female pelvis with the onset of advanced age.

Thus, the changes with age observed in white South African females and the lack of change in the black South African females can be attributed, in part, to original bone mineral density. Sexual dimorphism remained unchanged in black female long bones, while sexual dimorphism decreased in the form of increased metric dimensions of long bones in white South African females.

7.2.2

Metric changes in males with the onset of age

As in the white female sample, white males were observed to be markedly larger than black males. This discrepancy in the principle component of size was more discernible in males than in females, and the difference in size was significantly larger in 18 out of 23 postcranial measurements (Table 4.9).

Black males metrically increased significantly in seven long bone locations with the onset of age (Table 4.10). These statistically significant sites where metric increases took place were the midshaft diameters of the appendicular skeleton and the elbow and knee joint locations. Based on research indicating the increase in medullary cavity dimensions with age (Garn et al. 1969; Garn 1970, 1972; Martin and Atkinson 1977; Rogers 1982; Thompson 1980), midshaft diameters may very well increase with the onset of age. The midshaft diameters of the black male humerus, ulna, and femur increased significantly with the onset of advanced age. These changes showed the where degenerative changes with age may occur; as stated and discussed earlier, black females showed a statistically significant *decrease* in the diameter of the humerus with the onset of age, a contrast to what was observed in their black male counterparts.

Elbow locations that increased in size included the distal epicondylar breadth of the humerus and the superior diameter of the head of the ulna. Additionally, the distal femur, being an integral component of the knee joint, increased in size when young were compared to their older counterparts. Black males became larger with age at these specific skeletal sites, and because sexual dimorphism in males may be categorized by size, the increase can be considered a trend towards more marked sexual dimorphism. These articular joint measurements increased to where they did not overlap any of the female measurements (of both populations) with the onset of age.

Based on the size increase of black males throughout the incremental age groups (and their distinct separation from black females with regard to size), sexual dimorphism can be said to "metrically" increase in this population with the onset of age. In addition to this, the metrics of black males tended to increase later in life, much later than the age category where epiphyseal closure occurs. This indicated that males continue to grow and show metric increases later in life, which subsequently separates them farther from black females with the onset of age.

White males increased in size significantly at three locations (Table 4.11). Interestingly, these three sites paralleled the results documented with the black male population; articular joint surfaces of the elbow and knee were exhibiting degenerative changes in which metric values were shown to increase. These skeletal sites increased in size with the onset of age, and did not become more diminutive. This would indicate that white males (as with black males) are becoming "metrically" more sexually dimorphic based on their size attributes. White males are by far the biggest sample, size-wise, in the study population, and their increase in dimensions with the onset of advanced age only secures their position more definitively as the most robust sample in this study.

Also seen in the white male sample (and illustrated in part by Figures 4.2-4.19) most of the changes in size in young males could be seen shortly after epiphyseal closure, i.e. in the 2^{nd} and 3^{rd} decades of life. This meant that even though the epiphyses are closed, some form of "growth" or bone gain is taking place. This interesting result indicated that this population undergoes a type of increase in robusticity after the onset of puberty, which in some ways contrasts the notion that puberty provides the majority of bone growth and gain in the developing male skeleton, and after puberty metric gain appears nonexistent and size maintains a certain stasis (Bonjour *et al.* 1991; Sun *et al.* 2004; Tanner 1994). White males appear to not adhere to this pattern, and in fact show most of their size increase in robusticity after the fusion of most epiphyseal ends. Walker (1995) illustrated the residual feminine characteristics of male skeletons after maturation, and in part those results correspond to these measurement increases into the 3^{rd} decade of life in white males.

Are the mechanisms for changes with age in male skeletons different than those for metric changes in females? Most often in past research including males and females, the net increase in size regarding midshaft diameters is correlated to thinning cortical bone and an increase in medullary cavity diameter in the aged, and not necessarily an increase in the thickness of cortical bone (Martin and Atkinson 1977; Leiel *et al.* 1988; Heaney *et al.* 1989). This increase in medullary cavity space might possibly be a mechanism for size increase in the both the black and white male population of this study. In addition, as stated above, net bone gain in males was observed to increase fairly late in life, where they reached their final robusticity. This could not be due to degeneration. Males appear to become even more robust after the epiphyses have fused, thus implying some appositional "growth" in adult males. The cause of this is unknown, but the influence of testosterone in males may be a factor based hormonal influences already seen on hard tissue. Research from Jee *et al.* (1970) and Young and Heath (2000) emphasize the role hormones may have on the long term development and possible degenerative changes found in human bone. As seen in this current research, hormones may very well play a role in male skeletal modification.

Bones of the elbow joint in both black and white South Africans increased metrically with age. The epicondylar breadth of the humerus, being the main junction and stabilizing bone for the proximal ulna and radius, exhibits numerous muscle, ligament, and cartilage attachment sites along its borders (Amis *et al.* 1989; Fuss 1991; Grabiner 1989). These sites may become compromised due to the loss of cartilage normally covering the central areas of bone ends, and may compensate for this loss by net bone gain in the form of calcified cartilage or bone remodelling into additional bone or "osteophytes" as documented by Aufderheide and Rodriguez-Martin (1998).

Bones of the knee joint in the male skeleton exhibited increased metric dimensions in both black and white South African males. The knee joint is an extremely robust weight-bearing joint in humans, and past research has shown marked sexual dimorphism and changes with age in this location. Iscan and Steyn (1997) confirmed the sexually dimorphic nature of the knee joint (with research aimed at the femur and tibia of South African whites). Sakaue (2004), although studying a Japanese population, noted that elbow and knee joint measurements increased with age in females, "narrowing the gap" between male and female metric analysis. This result was in direct correlation to the metric increase in elbow and knee joint measurements with age found in three out of four populations studied here (black males, white males, and white females). Finally, Ruff (1982) showed an increase in dimensions where bending and torsional rigidity are at their greatest in males and females, namely the knee joint. Ruff's findings are mirrored here, as metric dimensions also increased in the distal femur and proximal tibia. An increase in size with the onset of age may also signify signs of degenerative changes and progressive pathological conditions characterized by the loss of joint cartilage and the production of bony lesions for strength compensation. Both Compston *et al.* (2007) and Chavassieux *et al.* (2007) document remodeling patterns that increase size; this type of remodeling pattern may very well be present when observing the results from this current research as well.

Because white males, black males, and even white females show statistically significant metric increases in at least one of the three bones that comprise the knee joint, this area can be considered one of considerable modification with the onset of age in its bony components. Changes in these locations may be due not only to degenerative changes, but may also be attributed to reaching maximum levels of robusticity in middle age. As the size of males increased with age, it was observed that these increases did not occur late in life, but in mid-life constituting a sort of "late maturation" after puberty in adult males.

When black males were compared to white males with regard to pelvic measurements and the calculated ischio-pubic index, the common trend was extended in that white males were seen to present larger metric values in all measurements. However, the calculated difference with the ischio-pubic index was statistically insignificant between black and white males. This result should be considered a direct correlate to male morphology as it exists in both populations (and numerous others) as seen in research by Krogman (1962), Meindl *et al.* (1985), Patriquin *et al.* (2003), Phenice (1969), Richman *et al.* (1979), Rissech and Malgosa (1997), Ubelaker (2002), Walker (2005) and Washburn (1948). Males were considered the same statistically (regardless of their ancestry) in their ischio-pubic index, even though white males were seen to be metrically larger on a statistically significant level.

Change in black male pelvic measurements when comparing young and old was only present in the ischio-pubic index. This indicated that a modification of the two measurements used to calculate the index, although not statistically significant in isolation, when combined altered the index to the point of increasing it with significance (82.1 in young black males to 83.3 in old black males). The length of the pubis was observed to increase with the onset of age. This increase in the ischio-pubic index brought the value closer to that of black females when viewing the incremental increase through the various age categories (Figure 4.30). However, old black males and their ischio-pubic index did not come close to converging with the female mean at any point. There appeared to be little possibility of metrically misclassifying black male pelves based on the ischio-pubic index.

Black male pelvic measurements, however, continued to be smaller than any of the white female pelvic measurements throughout the onset of age. This fact may still be considered a challenge where pelvic remains are incomplete and fragmented, because the determination of sex from metric analysis relies largely on the size of the bony element to correctly categorize the specimen as male or female. There is always the danger of misclassifying sex directly based on measurements of black males if these measurements were used in isolation and morphology was not considered. However, anthropologists tend to use a suite of techniques to come to an ultimate determination of sex, and the presence of additional remains and their subsequent morphology could provide insight into an ultimate establishment of sex.

Comparison of young and old white males in the metric values of the pelvis yielded two statistically significant differences. Pubis length and the ischio-pubic index both decreased significantly with the onset of age. The decrease in the pubis length could alter the visual characteristics of the pelvis. A shortening of the pubis would indicate a modification towards male morphology, based on the fact that visually the male pubis is short, compact, stout and compressed. If the white male pubis became shorter with the onset of age, this would indicate that male pelves in this population exhibit more male morphology as they advance in age. To this end, the white male pelvis may very well become more sexually dimorphic in its metric values.

Length of the pubis increased in black males, and decreased in white males. Studies in pelvic morphology largely focus on sexual dimorphism in general, as with Bass (1995), Camacho *et al.* (1993), Steele and Bramblett (1988), and White (2000). Walker (2005) does illustrate the greater tendency for male pelves to shift in a masculine direction with increased age, resulting in greater sexual dimorphism with that particular study sample. However, the lengthening or shortening of the male pubis with age has not been extensively studied; Walker focused primarily on the greater sciatic notch. Reasons for the increased length of the black male pubis may include the ossification of pubic symphyseal cartilage with the onset of age. In addition, reasons for the decreased length of the white male pubis may include degenerative bone loss with age or the erosion of the pubic symphyseal borders that created length in a younger pubic bone.

7.3

Non-metric Analysis

In this study, traits from the distal and posterior humerus and the pelvis were used to determine sex; a comparison was then performed between young and old groups by population to determine if classification accuracies decreased with the onset of age. This analysis showed that different population groups had varying degrees of accuracy with each suite of traits. However, similarities in morphology between populations were noted as well.

Morphology of the elbow joint is known to be sexually dimorphic by observing the carrying angle of the articulated humerus and ulna (Amis 1989; Grabiner 1989; Fuss 1991; Wanek 2002). The lateral deviation of the human forearm from the axis of the humerus is distinctive between males and females, and each sex forms deviating angles that can be construed as sexually dimorphic (10 to 15 degrees in males, 20 to 25 degrees in females, Rogers 1999). The soft tissue anatomy of the ulnar collateral ligament (which originates on the medial epicondyle and inserts on the medial aspect of the coronoid process of the ulna) as well as the skeletal structure of the trochlear spool changes this carrying angle during elbow flexion. Grabiner (1989) also showed that the elbow and radioulnar joints are sexually dimorphic. Hard tissue morphology relating to the ulnar collateral ligament and the trochlear spool should therefore exhibit differences between males and females which have been shown in this research. The medial epicondyle is obviously the origin of ligaments that preserve the carrying angle; the olecranon fossa shape is the receptacle for the olecranon process superiorly, and is connected to the coronoid process inferiorly; and trochlear extension is an expansion of the trochlear spool and the articulation between the trochlea and the coronoid process. Anatomical soft tissue characteristics should influence the hard tissue sexual dimorphism of the bone at that location as well, and in fact have been documented as sexually dimorphic on a statistically significant level (Rogers 1999; Wanek 2002).

Examination of features from the distal and posterior humerus resulted in reasonably accurate classification rates with both males and females when utilizing a suite of three visual traits (trochlear extension, olecranon fossa shape, and the angle of the medial epicondyle). A fourth characteristic (medial epicondylar symmetry) was determined to be highly inaccurate, and was abandoned due to the increase in classification accuracy when it was excluded from the analysis. Each of these three characteristics in isolation were not particularly accurate in predicting sex on their own. However, when used in conjunction with each other as an amalgamated recognition of sex, all males were classified with a 74% accuracy rate, while all females were classified accurately 77% of the time. This was accurate enough to deem these characteristics sexually dimorphic and moderately successful in predicting sex. These traits were also observed to be sexually dimorphic when utilizing geometric morphometrics, which confirmed the validity and efficacy of these traits by quantifying the form and shape of each characteristic.

Classic non-metric techniques based on the pelvic morphology of males and females has been used extensively to predict sex (Bass 1995; Krogman 1962; Steele and Bramblett 1988; White 200). Four characteristics of the pelvis were utilized to determine sex, then young and old determinations were compared to observe any changes in classification accuracy. Visual pelvic morphology remained unchanged in females with the onset of age, and exhibited differences with age in both the black and white South African males. These differences are discussed below.

7.3.1

Non-metric changes in females with the onset of age

Classification accuracy differed when comparing black to white females. When estimating sex from the distal humerus, black females performed better or exhibited more "female" morphological traits than did their white counterparts. Sex was estimated correctly in 84% of all black females, and 68% in all white females (Figure 5.7). This discrepancy in accuracy rates indicated that not only did black females exhibit "classic" female morphology of the distal and posterior humerus (as defined by Rogers 1999 and Wanek 2002) but exhibited a minimal amount of overlap into the male realm of morphological traits (black females were misclassified as males 11% of the time). In contrast, white females were misclassified as males 26% of the time. This is a significant amount of overlap into male morphology, and indicated that sexual dimorphism in this bony element is less apparent in white than black South Africans. If increased sexual dimorphism is based, in part, by socioeconomic variables and nutritional factors, this suite of traits from the bony element of the elbow does not appear to be influenced by it. White females may simply exhibit less sexual dimorphism than their black female counterparts, or they may just appear more robust in their morphology than black females. Additionally, because of the abundance of old white females in the sample, the possibility that many were misclassified or ambiguous due to increased robusticity with age at the distal humerus site was apparent. White females would probably continue to look more female when compared to white males, but in isolation may cause confusion with their robusticity.

Black females and their classification accuracy in the determination of sex from the distal humerus decreased from 88% in young to 78% in old. This was not a significant drop in accuracy according to Pearson's chi square analysis, and simply indicated that there was a small amount of variation between young and old individuals of this population group. Black females continued to exhibit female morphology through the onset of advanced age, and results indicated that morphology was static with black females in this location.

This maintenance of sexual dimorphism in the humerus of black females may be due to several factors. As discussed previously, bone density indices are larger for black females as seen in past studies (Katzmarzyk and Leonard 1998; Kieser *et al.* 1987; Orwoll *et al.* 1996; Trotter *et al.* 1960). Degenerative processes that effect bone when it becomes structurally unsound may not necessarily affect black females, based on the higher bone density they exhibit.

It is important to note that virtually no metric changes occurred with the black female skeleton as well. Black females stayed approximately the same size throughout the onset of advanced age. These metric results correspond quite accurately with the non-metric results of the visual techniques employed in this study. Because no physiological changes appeared to be occurring (such as bone gain through osteoporosis or microfracture healing), no visual changes were observed.

Similar changes in classification accuracy were seen in the white female sample when comparing the young and old samples. The percentage of white females correctly classified by distal humeral traits decreased significantly from 93% to 63% with the onset of age, which indicated a marked decrease in the classification accuracy of the suite of characteristics. Thus, there is an apparent change of morphology between young and old white female specimens.

Specifically, two features exhibited marked, statistically significant changes in visual morphology which would either increase or decrease the predictive value of the trait. The olecranon fossa shape appeared to change visually with age, as young white females were classified with 79% accuracy and old white females with 38%. Results such as these indicated that a distinct change in the shape of this bony fossa was influencing the ability for to correctly determine sex using this trait. An oval shape is indicative of female morphology, with no upward projection of the fossa towards the shaft of the humerus to modify the shape into roughly triangular. The misclassification of 38% of old white females as males, in addition to the poor classification accuracy of 38% for this older group, gave two-fold evidence that old white females were exhibiting more triangular-shaped olecranon fossae than their young counterparts, and more than their black female counterparts as well.

The angle of the medial epicondyle increased in its predictive value as age increased in the white female sample. This change was in direct contrast to the modification of the olecranon fossa shape; classification accuracy in white females increased with age when viewing the medial epicondylar angle, from 36% (young white females) to 56% (old white females). An equal percentage of young and old white females were misclassified as males (43% in both groups). However, ambiguous cases in young white females were much greater (21%) than in old white females. This result indicated that old white females exhibited an array of distinct morphology that did not necessarily allow them to be correctly classified, but did allow for less ambiguous determinations. Although the sample size was small, young white females did not appear to exhibit clear, definable female morphology *regarding the angle of the medial epicondyle* as their older counterparts, or as much as their black equivalents. A larger sample size of young white females may have allowed for different results.

The ultimate result of "estimated sex" was similar in both black and white females. Changes in non-metric morphology were occurring that decreased the classification accuracy of the sex determination in all females with the onset of age. Thus, young females were classified more accurately than older females when utilizing characteristics from the distal humerus. In general, therefore, the results of the black and white females were congruent, as accuracies of both decreased (although not significantly) with age.

Why morphology changes when viewing young and old white females may be, in part, a mechanism of the aging process. A decrease in elasticity of the joint's connective tissue structures may perhaps cause morphological modification to compensate for decreased range of motion, as documented in Aufderheide and Rodriguez-Martin (1998) as pathological conditions. In addition, bone density loss over time and with age (especially in white females) may cause the olecranon fossa to take on an alternate appearance, perhaps in an effort to combat simultaneous breakdown or osteophytosis of the olecranon process of the ulna, its main partner in the humero-ulnar junction (Grabiner 1989).

Metric increases of the elbow joint were seen on a statistically significant level in white females with the onset of age. These metric increases could very well be the result of early osteophytosis and its subsequent degenerative bone addition to the articular joint surface of the distal humerus. As osteoporotic bone gain increased, it was quite possible that non-metric visual characteristics within this bony element of the forearm changed as well. Even though the sample size of young white females was quite small, the fact remains that morphology with all traits combined was unambiguous in this sample group, estimating sex accurately 93% of the time. The well-visualized female morphology in young white specimens declined dramatically with the onset of age within the population group. This can again be attributed directly to the degenerative processes with the onset of age, the decline of bone mineral density, and the propensity to incur microfractures at skeletal location most susceptible to stress, strain, and tensile strength reduction.

It may also be possible that the white population in this sample were considerably older than the black population, and that old age with degenerative changes masked the sexually dimorphic traits. Classification accuracy from the distal humerus decreased slightly in the black female sample with age, and the sample size was adequate. White females may perform better in these non-metric characteristics if the sample size of younger individuals was greater.

Classic non-metric morphology characteristics from the os coxae (the subpubic concavity, subpubic angle, ischio-pubic ramus width and the width of the greater sciatic notch) produced a 94% accuracy rate in the female sample, regardless of biological affiliation and the onset of age. Females provided a higher rate of classification accuracy than did males (83% accuracy) when combining the traits.

Both biological groups in the female sample appeared consistent in their pelvic morphology and had similar classification accuracies (93% black females, 96% white females). The biological affiliation of the specimen was not needed in order to successfully predict skeletal sex. This result was indicative of a highly sexually dimorphic skeletal trait that is may not be influenced as strongly by external factors such as socio-economic status, occupational stressors, dietary deficiencies, weight-bearing activities or childbirth statistics. Internal factors such as bone density measurements appeared not play a significant part in the sexually dimorphic nature of the female pelvis.

Although not statistically significant, a result of interest was the fact that more black females (young and old) were misclassified as male than were deemed having ambiguous morphology. These numbers were not large, but indicated that when variation occurred, it occurred as an explicit departure in morphology for black females to male morphology, and not just to an "ambiguous" type.

The onset of advanced age did not appear to influence the distinct and unambiguous female pelvic morphology of either black females or white females. Pelvic non-metric traits in both black females and white females were highly predictive of sex with both age groups and neither group's classification accuracies decreased with statistical significance with the onset of age. Age was thus determined to not play a role in the successful determination of skeletal sex in the female skeleton, regardless of population group.

7.3.2

Non-metric changes in males with the onset of age

Examination of the two male population groups studied showed congruence in morphology between them. Only the classification accuracy of the olecranon fossa shape was significantly different between black males and white males when determining sex from that particular feature. Specifically, the black group had a varying morphology within the framework of the olecranon fossa shape, and a large percentage of black males would be considered "female" in their shape. Black males, however, were still classified at a relatively high rate of accuracy, along with their white male counterparts. These similarities between the two populations show that the technique is not population specific. Changes with age, however, were still viewed separately to determine possible trends.

Black males exhibited a slight increase in their classification accuracy when comparing the young (50 years of age or younger, 71% accurate) to the old sample (over 50 years of age, 74% accurate). Thus, the morphology of the black male distal humerus can be thought of as static with the onset of advanced age. As described above, this result is congruent with the black female sample in which no statistically significant change in the classification accuracy was observed with the onset of age. The onset of advanced age in the black male skeleton appeared to not affect the bone of the distal and posterior humerus, thus indicating that degenerative changes were minimal in this location.

As a reference (and as exhibited by Figure 4.35), metric increases were seen in two locations of the elbow joint of black males with the onset of advanced age, one site being the distal epicondylar breadth of the humerus. These metric changes exhibited an increase in size; in conjunction, black males exhibited an increase in classification accuracy with the non-metric/ visual technique with the onset of age. Changes in *metric size*, then, appear to be linked to visual changes that increase the presence of *male morphology*.

White males exhibited little change with the onset of age from the distal humerus, as well. High classification accuracies for both age categories were seen and the difference between the young and old groups was statistically insignificant, although declining (86% vs.75% respectively). Both males in each population group appeared to remain static in their male morphology with the onset of advanced age, and in this fact can be considered quite similar.

Trochlear extension is the inferior projection of the trochlear edge past the inferior edge of the capitulum's border, and decreased in classification accuracy with statistical significance with the white male sample. There could be several reasons for this extension to become visually less pronounced with the onset of age. Most probable would be the induction of osteoporotic lesions along the lateral edge of the distal humerus, creating a more robust profile on that side and "evening out" the extension of the trochlea on the medial side. In addition, the loss of elasticity in the soft tissue anatomy of the elbow joint with age (Aufderheide and Rodriquez-Martin 1998) may cause a loss of movement in the joint. This, in turn, could cause degeneration of the junction of the coronoid process and the trochlear-capitulum surface, creating a certain amount of constriction within the space between the posterior capitulum and the trochlea. Visually, this may cause the inferior edge of the trochlea to appear more congruent or equal to that of the capitulum. Regardless, this visual characteristic was seen as being the only statistically significant change with the onset of age in the white male distal humerus, and did not apparently affect the ultimate estimation of sex for the specimens over 50 years of age.

For comparison, no metric increase with age occurred at the distal humerus in white males. This result may indicate that *no metric increase* would equate to no definitive modification of visual characteristics, thus *no change in sexual dimorphism*. Size and shape, then, appear to go hand-in-hand with one another. If a metric increase occurred, visual male morphology would have appeared to change. Because a metric increase did not occur in the white male distal humerus, visual male morphology did not appear to increase.

Black and white males differed in their classification accuracy when assessing overall skeletal sex (85% accurate for black males, 79% accurate for white males). The discrepancy in these percentages were deemed non-significant, but black male pelvic morphology did appear different than white male pelvic morphology when observing the distribution of classification; black males exhibited a greater amount of "classic" male sexual traits.

Visually, results indicated that variation in the greater sciatic notch width for white males may lead the observer to misclassify the sex of the pelvis based largely on this feature. In this (and with results observed from geometric morphometrics), white male greater sciatic notch widths may very well be misleading in their visual morphology, and should be considered a tentatively reliable trait. Challenges in the visual determination of sex from the greater sciatic notch in this study paralleled past research in which male morphology in this region was surprisingly variable (Patriquin *et al.* 2003; Steyn *et al.* 2004; Walker 2005). White males in this study exhibited both wide and narrow sciatic notches, and were visually ambiguous with this isolated trait on many occasions.

With the onset of age, accuracies in black males increased as age increased. The older the individuals in the sample, the more accurate the prediction rates were for black male pelvic morphology. The subpubic angle specifically increased in its "classic" male visual morphology with age. The differences that make this characteristic statistically different from the young to old group was in how many are *misclassified* as females. More young black males were misclassified as females (12%) than their older black male counterparts (7%). These results show that it may not be the presence of male morphology that allows for the correct classification, but rather the presence of female morphology that allows for the incorrect classification. The misclassification of black males as females in the subpubic angle would indicate the presence of an elongated and more rectangular pubic region in young males, which subsequently changes into a more "male" appearing short and stout pubis. Black males, then, may follow the same trajectory observed by Walker (2005), in which male pelvic sexual dimorphism increased as age increased. This may be attributed to a type of maturation process (as seen in long bone measurements for black males as well), where full robusticity in the form of dimensions (or full sexually dimorphic characteristics) are not observed until middle or advanced age.

This same observation holds true with the other isolated trait that appeared significantly different in classification accuracy between young and old black males. There was little discrepancy between the predictive values of the width of the greater sciatic notch in young and old black males (73% accurate and 74% accurate, respectively). However, the number of young black males misclassified as females was more (20%) than those of old black males misclassified as females (12%). Black males, with the onset of age, appeared to exhibit more male morphology (and less female morphology) than their younger counterparts, making them essentially more sexually dimorphic. Again, this may very well be due to the presence of lingering female morphology from early adulthood, and the development of more observable male traits in middle age.

The results of white male pelvic morphology were contrary to the results of their black male counterparts. White males were correctly classified less often with old specimens than they were with young specimens (93% accuracy for young, 74% accuracy for old), and seemed to decrease in sexual dimorphism with age. The white male pelvis continued to be a challenge with morphological features providing a large amount of variation in this study sample. Specifically, the greater sciatic notch was markedly wider and more "female-looking" in young white males (30% were deemed ambiguous in their morphology as compared to 13% in the older sample), but characteristics such as the ischio-pubic ramus width appeared decidedly thin and gracile in the older male sample. These changes in the white male pelvis (that do not appear to occur in the black male pelvis) may be due to degenerative changes brought on by decreasing bone density. Specifically, Heaney *et al.* (1982) found that the average 30-40 year old white male has reached maximum bone density. The average elderly male is in negative calcium balance, and accordingly is losing bone mass. Decreased mechanical loading (which would increase structural integrity) was not seen in this population according to Heaney *et al.*'s study; visual characteristics of the white male pelvis, which include the thickness of the ischio-pubic ramus and the stout nature of the subpubic concavity, may very well be affected by cortical and endosteal bone loss in the os coxae. This, in turn, would create a more gracile visual description of the older male specimens.

7.4

Geometric Morphometric Analysis

Geometric morphometrics provided information that directly correlated to results found in the non-metric visual portion of this study in the fact that it "quantified" what the visual traits reportedly depicted. This union between a visual technique (which could be considered a qualitative technique) and a quantitative technique has many promising aspects, several of which were apparent in this research. To be able to "test" a visual technique with a very robust secondary quantitative technique had several advantages and disadvantages.

Because aspects of the distal humerus have not been used extensively as sexually dimorphic features, geometric morphometrics provided definitive proof that there were, indeed, sexually dimorphic attributes of this skeletal feature that could be used with a fairly high degree of accuracy to determine sex. Visual techniques had already provided accurate determinations of sex from the features the distal humerus exhibited; geometric morphometrics provided additional verification that features researched in the past (Rogers 1999; Wanek 2002) were indeed accurate and reproducible. Two characteristics, namely the shape of the olecranon fossa and the angle of the medial epicondyle, were assessed with this method. An extensive discussion of the morphology related to both aspects follows, in order to illuminate the strong correlation between the distal humerus and its sexually dimorphic features.

Analysis of the pelvis and features relating to the sexual dimorphic nature of this pair of bones could be quantified in a way done only recently. This study employed four features of the pelvis, and quantified these existing highly accurate features and determined whether they changed with the onset of age. In addition, past geometric morphometrics research on the greater sciatic notch by Steyn *et al.* (2004) confirmed that this pelvic feature was sexually dimorphic, but also determined distinct differences in the white South African male population that appealed for more study. This current research confirmed the variable nature of the greater sciatic notch in the white South African male population.

7.4.1

Sexual dimorphism of the EPI perspective

In general, the EPI view (which depicted the angle of the medial epicondyle of the distal humerus) provided a unique and quantifiable way in which to accurately designate sex. The sexual dimorphism of the element was illuminated with the relative warp analysis first of the EPI perspective (Figure 6.1). This showed that males and females were divergent by grouping all females below the x-axis, while all males grouped above the x-axis. White males and females were seen at quite a distance from each other in this perspective, while black males and females were seen to be closer to each other within the grid than their white counterparts. This may indicate the fact that the black South African population is less sexually dimorphic in this feature. Statistical analysis confirmed this fact. However, males were always seen quite separate from their female equivalents and exhibited features of the medial epicondylar angle that were observed in visual assessment.

The medial epicondyle itself exhibited the most discrepancy between males and females, which was expected. First, when the medial epicondyle sits more centrally within the profile of the trochlea, there was more trochlear surface area surrounding the medial epicondyle. This, in turn, positioned the entire medial epicondyle further into an anterior position, thus closer to the tabletop on which the bone actually rested. This was the pattern most commonly seen in males. The amount of trochlear area between the posterior and anterior portion of the medial epicondyle allowed the male trochlea to project directly outward, parallel to the tabletop. With the lack of posterior surface area in the female trochlea surrounding the medial epicondyle, there was more possibility to angle away from the tabletop based on less physical bone for ligament and tendon insertion. The female medial epicondyle, in turn, appeared more elevated along the surface of the bone and provided for a large amount of deviation between the male and female form. These skeletal features most probably correspond to soft tissue features that act upon the distal humerus, and these medial epicondylar angle differences were thought to be directly related to 1) the carrying angle of the arm, 2) where the ulnar collateral ligament actually originates on the female medial epicondyle as opposed to the male epicondyle, and 3) how this difference in tension, torsion, extension and flexion would affect the hard tissue anatomy of the elbow joint. This joint has been proven to be sexually dimorphic (Grabiner 1989) and thus the variation between males and females in this particular element can also be seen in hard tissue morphology.

Males and females were classified on a fairly accurate level with geometric morphometrics, and morphometrics could categorize males and females from each other more accurately than visual techniques. This skeletal feature was deemed sexually dimorphic, and geometric morphometrics increased the classification accuracy by observing differences in form that the human eye could not necessarily discern.

Male-female differences in black South Africans were different in the points assigned to the lateral margin of the distal humerus. These landmarks deviated downwards in the black male humerus, and surprisingly, the angle of the medial epicondyle appeared largely unchanged based on the vector mode arrows depicting shape variation between females and males (Figure 6.6). When viewing the relative warp analysis in Figure 6.1, black males and black females were quite close on the graph depicting the distance between shape configurations. This indicated a sexually dimorphic component between black females and males, although the distance between the two was not substantial.

White females and males were markedly sexually dimorphic in the EPI perspective, as seen in the relative warp analysis grid comparing all four population groups (Figure 6.1). The distance between the two groups proved that a distinct morphological difference existed between the two, and this was confirmed by viewing the vector mode thin plate spline that differentiated between female and male form from the EPI perspective (Figure 6.8). The raised nature of the female medial epicondyle can be clearly delineated as the originating point in the vector mode thin plate spline, as shown in Figure 6.8. This positioned the female medial epicondyle in a more prominently angled perspective, much different than the male perspective which exhibited a flat and parallel profile. These characteristics were "classic" in the fact that they aligned clearly with the defined morphology attributes. The more posteriorly-placed landmarks assigned to features on the lateral surface of the distal humerus appeared in the same location as those seen in black males vs. black females, which indicated a common morphology throughout populations between both males and females, with the white South African population exhibiting a more marked degree of differentiation between the sexes.

The only discrepancy in this result was the apparent common morphology between young white females and males with the EPI perspective. Young white males and females did not produce statistical results when young females were compared to young males, indicating that they were virtually the same in form and shape. The CVA analysis was unable to divide specimens successfully into two distinct morphological groups, which implied that young white South Africans exhibited the same medial epicondylar angle and distal humeral attributes between males and females. These results may be due, in part, to the low sample number of young white female group. If the sample was larger, perhaps different results would have been observed. In addition, white male morphology may not exhibit marked sexual dimorphism in this location until later in life, as documented by research on gracile male specimens by Coleman (1969) and Walker (2005), who both noted lingering juvenile characteristics in the male pelvis, and Walker (1995), who documented gracile male crania in an adult sample from a historical collection.

Quantification of the sexually dimorphic features in the EPI perspective was, by in large, successful with geometric morphometrics, and correctly classified males and females at a high rate of accuracy. These morphometric results directly correspond to those results found in Rogers (1999) and illuminate a different perspective when taking the hard tissue attributes of the radioulnar joint into account with sexual dimorphism, as outlined by Grabiner (1989). Steyn and Iscan (1999) concluded that the osteometrics of the humerus were sexually dimorphic; geometric morphometrics can now play a role in providing more information regarding the sexually dimorphic aspects of the distal end of this bone.

7.4.2

The EPI perspective: changes in females with the onset of age

The shape of the EPI perspective appeared almost the same with young black females as it did with old black females. This corresponds directly with both the metric analysis of black females as well as the non-metric visual analysis of black females with the onset of age.

Measurements of the distal humerus did not change on a statistically significant level (Table 4.6). This indicated the size component of black females remained static, even as this population group got older. In addition, the classification accuracy of the non-metric visual traits between young black females and old black females did not change on a statistically significant level (Tab le 5.10). Geometric morphometrics showed the lack of anatomical differences in the specific feature of the medial epicondyle and its angulation between young black females black females with advanced age. This feature was sexually dimorphic, was accurate in distinguishing black females from black males, and did not modify its shape in females with the onset of age.

These results indicated that the higher bone density in the South African black female skeleton found in studies by Micklesfield *et al.* (2003) Kolbe-Alexander *et al.* (2004) and Taitz (1998) very well “shielded” skeletal anatomy from degenerative changes, microfractures, and other possibly detrimental modification that may manifest themselves in the skeleton.

Determination of whether white females exhibited morphology change with the onset of age was depicted in the vector thin plate spline mode of Figure 6.12. Results showed a change in the location of virtually all landmarks assigned to the medial epicondyle (Landmarks 5-14), with the changes tilting the medial epicondyle into a more angled position. When evaluating the differences in change depicted in Figure 6.12, it was clear that morphological changes with age were occurring in the white female population. Landmarks in the white female EPI perspective were observed to migrate into different positions and forms, which apparently increased the degree of sexual dimorphism exhibited in this group. In addition, young white females could not be successfully separated from young white males in the EPI perspective, which indicated a lack of sexual dimorphism between males and females of the young white population. Old white females in the EPI perspective, however, were categorized successfully, which indicated a distinct change in morphology between the young population and the old population.

This morphometric result was in direct correlation to the non-metric visual results that were obtained when attempting to designate sex from the angle of the medial epicondyle and paralleled the visual classification accuracies. Young white females were highly variable in this feature, and the angle of the medial epicondyle only predicted sex in young white females a dismal 36% of the time. In contrast, old white females were correctly classified at a higher rate of accuracy, at 56% (Table 5.11). This indicated that as the white female population aged, the angle of the medial epicondyle began to exhibit the more "classic" form of female morphology as defined in this study.

White females were indeed changing in size at the distal humerus, as well as in shape and form as indicated from visual analysis and geometric morphometrics. The angle of the medial epicondyle moving from variable morphology in young white females to definitively angled in old white females may be caused by bone density loss (Aloia *et al.* 1985; Aspray *et al.* 1996; Cummings *et al.* 1990; Cummings and

Black 1995; Schnitzler and Mesquita 1998) or the effect of soft tissue degradation in the joint, with subsequent addition or loss of bone around the medial epicondyle for structural integrity (France 1998; Garn 1972; Seeman 2003). Regardless, a relationship between a *size change in the element* with the onset of age and the *morphology of the element* with the onset of age was seen.

7.4.3

The EPI perspective: changes in males with the onset of age

Black males were also compared in both age groups to observe discrepancies in shape with the onset of age. Young black males exhibited a distinctly different morphology mainly within the points assigned to the lateral surface of the humeral element, as well as aspects of anterior features of the bone (which are seen as landmarks 15, 16, 17 and 18, Figure 6.11). The way these landmarks migrate to a more posterior position in older black males may indicate a morphology change that may be correlated with increased torsion on the existing ligaments (Fuss 1991), degenerative changes at the lateral aspect of the distal humerus, or compensatory factors related with age as documented by Aufderheide and Rodriguez-Martin, 1998 (i.e., motion change with osteoarthritis).

However, the onset of age in the black male South African sample did not change the degree of accuracy obtained when assigning sex to specimens via canonical variates analysis. In fact, the older black individuals were placed correctly in their “male” or “female” category with more accuracy than their younger counterparts. The degree of classification accuracy increase in black males with the onset of age indicated that perhaps the sexually dimorphic traits that were visibly apparent were also becoming quantifiably more apparent.

In direct correlation with morphometric results are the results from the non-metric visual technique performed when observing sexually dimorphic features of the distal humerus. In general, classification accuracy increased with the onset of age in the black male skeleton, very similarly to the geometric morphometric results. Even more comparable were the accuracy rates of the specific visual assessment of the angle of the medial epicondyle in comparison to the EPI view, which quantifies exactly that- the angle of the medial epicondyle. Just as the EPI perspective and its classification accuracy increased with the onset of age in black males, the classification accuracy for the visual trait in isolation increased with the onset of age. Geometric morphometrics quantified the visual characteristics of the angle of the medial epicondyle.

Finally, metric values for black males increased significantly with age at the site of the distal humerus (Figure 4.35). In black South African males, then, changes were occurring that not only increased the size of the element being studied, but morphology was modified to the point in which it became more sexually dimorphic, meaning more in congruence to “classic” male morphology as defined in this study. As stated before, an increase in *size* at a given element or feature appears to influence the *amount of sexual dimorphism* exhibited.

Shape change between young and old white males did not appear to be extensive as seen in the small amount of landmark movement depicted in Figure 6.13. Males appeared to stay the same in geometric morphometric analysis, as they did in both metric analysis and non-metric visual analysis. The distal epicondylar breadth measurement of white males did not increase nor decrease on a statistically significant level with the onset of age (Table 4.11). In addition, the difference in classification accuracy when observing the medial epicondylar angle in isolation as a visual trait was non-significant between young white males and old white. The absence of a size change in metric values equated to stasis in the classification accuracy and quantifiable morphology of the white male distal humerus.

The limitation to geometric morphometric analysis in this particular analysis was the perception of distance shown in the relative warp graph for the EPI perspective (Figure 6.9). Although statistical analysis proved that young white females and males exhibited similar morphology (by being unsuccessful in dividing males from females in the young white population), the relative warp analysis, by viewing the graph, indicated a much larger distance in form between these two groups. In addition, old white males and females were successfully separated when subjected to CV analysis; however, these two groups and their consensus form appeared quite close on the relative warp analysis graph. This may very well be an unfortunate artefact of the sample size of the young white population.

7.4.4

Sexual dimorphism of the OL perspective

The olecranon fossa shape and trochlear extension was considered accurate predictors of sex when non-metric visual analysis was performed on each in isolation (Table 5.6). Analysis of the OL perspective, specifically the relative warp analysis of each population group divided by sex ("black female", "black male", "white female", "white male") indicated a distinct separation of males and females which signified that the male and female forms of these traits were in fact sexually dimorphic. This is important to note, based on the fact that features of the distal humerus have not been consistently utilized for sex determination. The olecranon fossa shape appears to be an accurate predictor of sex based on geometric morphometric analysis. Both features exhibited differences between males and females.

The most important feature to observe when viewing the olecranon fossa shape is the upward projection of the fossa towards the shaft, producing a superior "point" at the apex of the fossa. This made the fossa appear more triangular, which was considered a classic male trait. As seen in Figure 6.17 this point is located far more superiorly in males (the arrow of landmark 5) than in females (the point). In addition, trochlear extension clarifies male from female morphology by positioning the inferior margin of the trochlea farther downward (inferiorly) to that of females, which would form the visual equivalent of "extension" in this region.

Sexual dimorphism was evident in the OL perspective. Again, the morphology of the olecranon fossa and the trochlea most probably correspond to soft tissue features that act upon the distal humerus. These include the junction of the humerus to the ulna, which forms an articular surface between the two as described by Fuss (1991). Grabiner (1989) also documented the articulation between the distal humerus and the ulna within the olecranon fossa, and saw differences between males and females in the carrying angle of the arm at this location. Thus the variation between males and females in this particular element can also be seen in hard tissue morphology.

7.4.5

The OL perspective: changes in females with the onset of age

Young and old black South African females were observed to be close in morphology based on the relative warp consensus for the OL perspective (Figure 6.22). This indicated that morphology did not change drastically between the young and old samples of this population. In fact, black female South Africans were classified accurately in both young and old categories, confirming the clustering of both groups with the relative warp analysis. The majority of morphological changes with age occurred along the periphery of the feature, and not with the olecranon fossa shape itself or with the extension of the trochlea. The extension of the trochlea did appear to migrate superiorly in the older black female sample, which would indicate a less extended trochlea and a more equal margin with the edge of the capitulum. This change would theoretically make the OL feature more sexually dimorphic in this location than their younger counterparts. Although slight, the classification accuracy for young black females was better than that of their older counterparts.

Non-metric analysis of the distal humerus (specifically the olecranon fossa and trochlear extension) corresponded with the results found here in geometric morphometrics in that the classification accuracy of both methods decreased non-significantly with the onset of age. However, both analyses appeared to show morphology change in the black female that, over time, made sex determination from this element slightly more difficult. The decrease in both the geometric morphometric accuracy and the non-metric accuracy may be attributed to a change in morphology due to compensatory actions or some sort of other physiological change. Regardless, geometric morphometrics confirmed that the black female olecranon fossa shape and trochlear extension stayed relatively static through time in its morphology.

Based again on the relative warp analysis (Figure 6.22), the fact that young and old consensus groups for white females clustered together in the same quadrant indicated that this feature changed little with age. This result was confirmed with the additional information from Figure 6.25, which indicated virtually no morphology change between young and old white females from the OL perspective. In fact, young whit females and old white females were categorized with an extremely high rate of accuracy, indicating that olecranon fossa morphology was easily quantified and again, quite sexually dimorphic regardless of the age of the white female specimen. Obviously, degenerative changes in the distal humerus of the white female did not affect the classification accuracy of geometric morphometrics.

When compared to the results from the non-metric visual analysis performed on the same features that comprise the OL perspective (olecranon fossa shape, trochlear extension), geometric morphometrics performed better than the non-metric visual analysis. Accuracy decreased from the young sample to the old in the visual technique, but geometric morphometrics correctly categorized both young and old white female specimens. Regardless, the sexually dimorphic features of an oval olecranon fossa shape and the lack of extension through the trochlea were seen to persist in the white female skeleton with the onset of age.

7.4.6

The OL perspective: changes in males with the onset of age

Black South African males (young and old) clustered closely together when viewing the consensus relative warp analysis for the OL perspective (Figure 6.22). The subsequent thin-plate spline graph (Figure 6.24) showed little difference between the morphological features of young black males and old black males, and in fact both were classified with a high rate of accuracy. The morphology of the male olecranon fossa and the extension of the trochlea in black South Africans was different than that of females, and continued to be different from females with the onset of age. Classic morphology defined in this study was maintained with the onset of age, and this feature provided a robust and discernable method of determining sex when utilizing geometric morphometrics.

Comparison of geometric morphometrics and the non-metric visual analysis of the same features in young and old black males (olecranon fossa shape, trochlear extension) showed similar results in that young and old black males were ultimately categorized correctly with a certain level of accuracy with the OL perspective. Non-metric techniques did show an increase in ambiguity of the olecranon fossa shape with the onset of age in black males (see Table 5.13). This would indicate a change of shape from distinctly triangular (a male characteristic) to a form that does not appear so triangular. Geometric morphometrics, however, does not show such a modification when viewing the comparison between the young and old black male forms in the OL perspective in vector mode (Figure 6.24). Geometric morphometrics confirmed the idea that many factors may play a role in the modification of bone throughout time, but a lack of morphology change found in geometric morphometrics may not correspond directly with the visual techniques employed for sex determination. Human error in the visual non-metric technique of observing olecranon fossa shape could have very well played a role in the significant classification accuracy change with this trait, but geometric morphometric analysis continued to categorize both young and old black male specimens accurately with the OL perspective.

The same can be said for white male specimens with the OL perspective in that geometric morphometrics "quantified" what was seen visually with non-metric techniques, and performed better in the correct assignment of sex. Once again, the consensus shapes from the OL perspective for young and old white males were viewed near each other in the relative warp analysis graph, and again the corresponding thin-plate spline (Figure 6.26) showed no apparent morphological change between the young and the old white male samples. This lack of quantifiable physical changes in the olecranon fossa shape and trochlear extension allowed for the accurate classification of both young and old white males (92% and 90%, respectively), indicating that morphology in the OL perspective is static with the onset of age in white males.

Comparison of geometric morphometrics to non-metric visual techniques showed that the olecranon fossa shape was easily visualized as male in both young and old specimens and categorized with the same level of accuracy in young and old white males. Visualization of trochlear extension did not appear as distinctly with older white males as it did with younger ones, however. Trochlear extension with the non-metric technique misclassified old males as female (or deemed the trait ambiguous) more often than in young white males. This again illustrates the fact the geometric morphometrics may "visualize" the congruency of a trait more effectively than when employing the non-metric visual technique of sex determination. Morphometrics performed well in that it did not "observe" potential degenerative changes that may have influenced the correct categorization of old white male specimens.

All visual characteristics performed relatively well in the assignment of sex, while geometric morphometrics increased the classification accuracy on several occasions of both young and old samples in the OL perspective. This indicated that what was observed in the anatomy of the distal humerus by physical characteristics was substantiated with the quantification method of landmark assignment and statistical testing in morphometrics. Again, this perspective did not appear to change with the onset of age, and thus can be considered a good representation of sexual dimorphism in the distal humerus for all young and old black and white South African males.

7.4.7

Sexual dimorphism of the SUB perspective

The SUB perspective quantified characteristics of the subpubic concavity and the subpubic angle (as well as the obturator foramen) through landmark data analysis. This perspective provided information that complemented the non-metric visual traits of the same characteristics used in this study which have been documented extensively in the past (Bass 1995; Bruzek and Soustal 1984; Humphrey 1998; Krogman 1962; Moerman 1982; Patriquin *et al.* 2003; Steele and Bramblett 1988). Geometric morphometrics confirmed that when utilized together, the subpubic concavity and subpubic angle were highly accurate in determining the sex of the human pelvic bone. Sexual dimorphism was marked and apparent, as shown in Figure 6.27 where males and females cluster separately from each other, and appear to span a large distance on the consensus relative warp graph. Dramatic differences in male and female pelvic morphology could also be seen in Figure 6.30, which demonstrates the magnitude and direction of change from male pelvic morphology to female morphology. Males were observed to have shorter and stouter pubic regions and thicker ischial surfaces than their female counterparts. Females had a more elongated pubis, thinner superior pubic profiles, and thinner inferior ischial profiles. This indicated that in general, this portion of the pelvis remained a highly sexually dimorphic skeletal element in which sex determination was quantifiably apparent.

Black males and females specifically were also observed to be highly sexually dimorphic in their pelvic characteristics. Black females exhibited a thinner pubis and more elongated superior ischial region, which corresponds directly to the subpubic angle and subpubic cavity visual traits observed (Figure 6.32). White males and females exhibited a different and more subtle variation in traits when utilizing the SUB perspective for geometric morphometrics, with white females and males exhibiting much the same thickness in the pubic region, while the male ischial region appeared slightly more broad and robust. In addition, the male pubic symphyseal region was shorter and more truncated, possibly decreasing the visual aspect of the subpubic concavity (Figure 6.34).

However, when divided into age groups, geometric morphometrics had a difficult time discerning young white males from young white females. Statistically, the difference in morphology between young white males and females is not significant (Table 6.23) and in fact a CVA could not discern a difference between the two; statistics were not generated when this analysis was performed, indicating that morphology between the two were so close no meaningful statistics could be generated (Table 6.24). These results indicated variability in morphology of the young white male pelvis as seen in a previous study by Steyn *et al.* (2004). Male os coxae appeared to exhibit morphology that could be either considered distinctly male, variable, or female.

7.4.8

The SUB perspective: changes in females with the onset of age

In Figure 6.35, young females (of both populations) clustered together, while old females did the same above the x-axis of the graph. Thus, females separated out on the relative warp consensus graph into distinct age clusters, and not necessarily by population. Old black females were the closest to the young contingency, which indicated that the morphology of this group of black females continued to maintain the skeletal structure of classic "young" morphology, while old white females deviated from this morphology by appearing farther apart on the graph. However, black females showed a progression with age that looked quite similar to the progression seen in the sexual dimorphism between females and males when viewing thin-plate spline data (Figure 6.36). The landmarks on the old black female pubis appeared to migrate laterally and superiorly, making this region appear thicker and broader (as in male morphology). In addition, landmarks placed on the ischium appeared to migrate inferiorly, allowing a thicker ischial region in the old black female pelvis to be present.

Despite this apparent trend towards possible robust "male" morphology, old black female classification accuracy was high at 93% (Table 6.22). In contrast, young black females were classified correctly by CVA 96% of the time, an even higher percentage. This result indicated the same point that was viewed in the non-metric visual portion of this study; if sexually dimorphic modification was to take place in the human skeleton, it apparently takes place in the form of *black females exhibiting more male morphology* with the onset of advanced age.

When compared to the visual techniques employed in this study to determine sex, virtually the same results were found in the black population sample as were found in geometric morphometrics. Young black females were categorized with more accuracy (94%) than old black females (92%), but both were highly sexually dimorphic. Specifically, the subpubic angle (directly correlated with the SUB perspective) in young black females provided an 87% accuracy rate, while old black females fared slightly better with an 89% accuracy rate. In addition, subpubic angle determination (a trait directly correlated with the SUB perspective) in young black females was 91% accurate, while old black females were 94% accurate. The change between young and old black female pelvic morphology was negligible. Even though geometric morphometrics showed changes in morphology with the onset of age in the black female pelvis, this morphology change did not prevent the SUB perspective from being highly accurate as a sex predictor.

As stated above, young white females clustered with their young black female counterparts, exhibiting a morphology that was more related to age than to population affinity. In addition, young and old white females did not appear to change with the onset of age; Figure 6.38 illustrated migrating landmarks between young and old white females with this perspective. When viewing the small changes in morphology, it was observed that the changes that did occur were similar to the differences between females and males in general, just as observed with the black female population. When points did migrate with age, they migrated to create a thicker, broader pubis and a wider ischial region. Again, when female morphology changes, it was in the direction towards male morphology and not in the direction of becoming more sexually dimorphic, i.e., more "female". This is direct correlation with the metric and non-metric portions of this study. White females increased in metric dimensions with the onset of age, migrating towards male morphology in measurements, while classification accuracy in both the humeral and pelvic non-metric traits decreased with age, indicating that morphology of the white female is becoming, in the very least, more ambiguous and less sexually dimorphic.

7.4.9

The SUB perspective: changes in males with the onset of age

In the SUB perspective, males appeared to separate (to a point) into population groups, and appeared not to diverge too greatly with the onset of age (Figure 6.35). This result was different from that of females in the same perspective, where females were seen to cluster in age-specific groupings to the right of the y-axis. Male morphology in the SUB perspective also did not appear to change with age across both population groups.

When observing the respective results of geometric morphometrics and the non-metric techniques employed, young black males exhibited less sexually dimorphic features visually than they did with morphometrics; classification accuracy increased as black males got older when determining sex from the visual indicators of the subpubic angle and the subpubic concavity. Specifically, the subpubic concavity provided a 70% classification accuracy rate for young black males, and a 78% classification accuracy rate for old black males (Table 5.27). These statistics were less accurate than the morphometric results.

White males (young and old) clustered together as a population on the relative warp consensus graph. However, young white males were observed close to the x-axis, similar to old black females and young white females. Young white males were also closest in distance to all the female consensus shapes when comparing all male consensus shapes. Past research showed that white male pelves were different morphologically from other male populations (Patriquin *et al.* 2003). These results indicated that portions of the male pelvic structure may be similar to female morphology.

Old white males exhibited a thicker, stouter pubis and a more inferiorly blunted ischial region indicating a decrease in the subpubic angle from young specimens to old specimens (Figure 6.39). This suggested that as white males became older, their morphology began to modify to the point where it looked more classically “male”. Young white males were quite variable in their morphology, but the SUB perspective indicated that with age, white males exhibited a more male structure and thus could be classified with more accuracy.

In comparison to the non-metric visual techniques that included the subpubic angle and the subpubic concavity, geometric morphometrics performed differently than the visual techniques normally used to determine sex. White males decreased in their classification accuracy with visual techniques when comparing the young populations to the old populations. This was the opposite result of geometric morphometrics, which increased clearly in assignment accuracy from the young white population to the old white population. This inconsistency between the visual technique and the geometric morphometrics analysis was unusual to observe, based on the fact that the two, being complimentary to each other, should provide similar results. This may be attributed to the human factor in visual analysis; visual determination of sex from the pelvis is more of a holistic approach, where the observer cannot help but be influenced by not only the specific features observed, but other variables such as size, bone density, corresponding characteristics, robustness or gracility. Geometric morphometrics with the SUB perspective only focused on roughly a third of the entire pelvic bone, meaning it was a much more refined and concentrated endeavour to determine sex from a limited number of homologous landmarks placed on skeletal features.

7.4.10

Sexual dimorphism of the SCI perspective

The SCI perspective quantified one of the most well-known and accurate pelvic traits in which to discern sexual dimorphism, the greater sciatic notch. When viewing the relative warp analysis graph of the four-group consensus shapes (Figure 6.40), males and females were seen immediately to separate, indicating their marked sexual dimorphism in this feature. In addition, the sexual dimorphism of the greater sciatic notch was easily illustrated when observing Figure 6.43, the consensus thin-plate spline that demonstrated the differences in the placement of landmarks between all males and females. In general, female notches appeared wider and shallower than their male counterparts. Male notches tended to be more constricted with a shorter superior margin or “leg”.

However, what was also clearly discernable from the consensus relative warp graph was the closeness of the black female consensus shape and the white male consensus shape, indicating a similarity in morphology that needed further investigation. Because black females grouped in the same grid quadrant as their white female counterparts, the deviation in SCI morphology was thought to not be attributed to the black females; they clustered in a classic sense with other females. The white male consensus shape, however, did not group in the same grid quadrant as the black male consensus shape. This indicated that if one of the two groups were exhibiting a deviation from the “classic” morphology of the greater sciatic notch in males and females, it was the white male sample.

Through the analysis of the vector mode thin-plate spline, it was obvious that black females and males exhibited what was considered classic sexually dimorphic anatomy of the greater sciatic notch (Figure 6.45). Black females exhibited the same landmark locations, in general, as the larger population of all pooled females in the sample. Males, in turn, exhibited the same migration of points as the pooled male sample, in that black male notches appeared more constricted with a shorter superior margin.

When comparing white female greater sciatic notch morphology to the same characteristic in males, a contrasting set of differences in landmark distribution than that of the black population was observed (Figure 6.47). In other words, the differences between white male and female greater sciatic notch shape were unlike the differences between black male and female greater sciatic notch shape. Males in the white population did not exhibit the characteristic shorter superior margin. In white males compared to white females, each point migrates in a different direction creating a much different notch profile than that of black males compared to black females. The ischial spine is projected posteriorly in white males. Black male morphology also projects the ischial spine posteriorly, but also migrates more towards the inferior margin or “leg”, constricting the two points towards each other, which may cause a narrower notch. This does not occur in white males. The white male inferior ischial spine “flares” more anteriorly as opposed to the female ischial spine position.

Differences continued when observing the relative warp consensus graph for all eight groups of males and females with the SCI perspective (Figure 6.48). Young white males clustered most closely with young black females and not another male group at all. In fact, the young white male consensus shape was the only male group that clusters closely to all the other female groups. Young white males clearly have different greater sciatic notch morphology than their other male counterparts. Statistical analysis showed that young white males were not markedly distinguishable from young white females, as seen by the barely significant p-value (0.043, Table 6.31).

This lack of sexual dimorphism in the white male greater sciatic notch has been recognized in past research (Patriquin 2003; Steyn *et al.* 2004) and illustrates the variability in the young white male pelvis. In particular, Walker (2005) found that younger individuals (males and females) exhibited more feminine morphology in the pelvis, and sexual dimorphism was strongly affected by age in males, especially in greater sciatic notch width. In Walker's study, greater sciatic notch width in an English sample shifted in a masculine direction with increasing longevity, which increased sexual dimorphism of the male sample. Walker also found that the sciatic notch width tended to decrease with increasing age at death, creating a more masculine notch in older individuals. The results of this current research in geometric morphometrics quantified this phenomenon by showing the wider, more feminine notch in young white males, which modified with age to become more sexually dimorphic in older males.

7.4.11

The SCI perspective: changes in females with the onset of age

Black females were seen to change morphologically with time through the greater sciatic notch when comparing the young population to the old population. However, the migration of landmarks between the young sample and the old sample appeared to “cancel” each other, meaning movement from a wide position to a more narrow position was observed on the inferior margin, while movement from a narrow position to a wider position was observed on the superior margin. This signified change, but not necessarily change that would influence the classification accuracy of the sample when comparing young to old. In fact, young black females and old black females were classified with nearly the same accuracy rate when compared to their male counterparts (80% accurate and 81% accurate, respectively). Age did not greatly influence the shape of the greater sciatic notch in the black female, and the SCI perspective continued to provide acceptable levels of classification accuracy even with the onset of age.

When comparing geometric morphometric results from the quantification of the greater sciatic notch to the visual technique used to determine sex from the greater sciatic notch, similar results were observed. Young black females were extremely sexually dimorphic in this feature when used as a visual indicator of sex. In addition, old black females were sexually dimorphic in their greater sciatic notches as well and were actually classified correctly more often than their younger counterparts (89% and 84%, respectively). These visual results were very closely correlated to the morphometrics results in which the classification accuracy rate increased slightly with the onset of age in black females.

Young and old white females are seen clustered together in the relative warp analysis graph (Figure 6.48), which indicated that this feature, in addition to being sexually dimorphic in females, was also static and unchanging in the white female population with the onset of age. The consensus thin-plate spline that demonstrated differences between young white females and old white females confirmed that if changes occurred in morphology with the white female sample, they were minimal (Figure 6.51). The changes that did occur appear to create an even wider notch profile in old females as in their younger counterparts, which in turn indicated that sexual dimorphism was marked and quite apparent in both the young and old sample. However, when compared to their male counterparts, females were distinguished from males at a much higher rate of accuracy in the old white population than in the young population. All data indicated that the greater sciatic notch was quite variable in the young sample, and then modified through age into a type of morphology that was better suited to the "classic" definition of sexual dimorphism with this population.

When comparing techniques, visual determination of sex and the classification accuracy for white females decreased with the onset of age; young white females were categorized more accurately (100%) with visual techniques than old females were (94%). Geometric morphometrics, on the other hand, saw an increase in statistical classification accuracy with the onset of age. One similar result between the two analyses was the fact that white females changed little with the onset of age, and the classification accuracies remained high for this female population, even over the age of 50.

7.4.12

The SCI perspective: changes in males with the onset of age

Black males exhibited a similar pattern as black females with the onset of age. Based on the vector mode thin-plate spline comparing the differences between young black males and old black males, morphology of the greater sciatic notch continued to be sexually dimorphic in advanced age (Figure 6.50). The migration of landmarks indicated that old black males exhibited an even shorter superior margin than the young sample, and changes appeared to create a notch that would be seen as more constricted. The combination of these modifications would indicate that the black male pelvis was getting even more sexually dimorphic with age, meaning the greater sciatic notch of old black males exhibited even more classic male morphology than the young sample. In fact, old black males were ultimately categorized with slightly less accuracy than the young black males based on the CVA (Table 6.30).

Ultimately, the classification accuracies of black males in the SCI perspective stayed relatively static through comparisons of the young and old samples. Sexual dimorphism was apparent even with advanced age from the SCI perspective.

The visual and geometric morphometric greater sciatic notch assessments gave the same results. The classification accuracy of the visual technique increased with the onset of age with black males (73% to 74%). These results, when combined with those from geometric morphometric analysis, indicated that the black South African male population was sexually dimorphic in this feature, and that these features of the pelvis did not change in a sexually dimorphic nature with the onset of age.

When viewing the relative warp consensus graph comparing age groups for the SCI perspective, it is easy to see the discrepancy between young and old white male morphology in the greater sciatic notch (Figure 6.48). The consensus thin plate spline in vector mode comparing young and old white males details the reason young white males appear morphologically similar to their female counterparts (and most closely to black females). The margins of the young white male greater sciatic notch were positioned wide and make the appearance of each margin to be roughly equal. The point of the most curvature in the notch was placed centrally and more forward, which produced a more “open” notch. The old white male greater sciatic notch, in contrast, has unequal margins with the inferior “leg” constricting inward and the superior “leg” extending outward, and the notch curvature is placed deeper within the pelvis. This constriction and inequality in margins seen with the old white male greater sciatic notch allowed this group to be categorized as male with more accuracy than their younger male counterparts (89% and 74%, respectively). Classification accuracy improved with the onset of age, and young white males may exhibit residual female pelvic characteristics through skeletal maturation and into the 3rd and 4th decades.

When comparing the visual technique of sex determination from the greater sciatic notch to the morphometric analysis of the greater sciatic notch, a divergent pattern emerged. Visual determination of sex and the classification accuracy for males decreased with the onset of age; geometric morphometrics saw an increase in statistical classification accuracy with the onset of age. With non-metric visual assessment, white males appeared to *visually* migrate towards a more "female" like morphology, with ambiguous cases increasing in the old age group, and more old white males being misclassified as females than their younger white male counterparts. Geometric morphometrics did not show this. In fact, geometric morphometrics did much better in correctly classifying old white males than it did classifying young white males. This indicated that sexual dimorphism in the SCI perspective increased with the onset of age in the white male pelvis, and features deemed classically "male" were more often viewed in the pelvic bones of older males. Young white males continued to be variable in their morphology, and geometric morphometrics quantified the young white male sciatic notch shape as more similar to female morphology than to male morphology.

7.4.13

Geometric morphometric analysis: summary

Geometric morphometrics complemented visual techniques in sex determination from the distal humerus and pelvis. This quantitative analysis provided generally accurate classification results in all four 2-dimensional perspectives studied. Males and females were markedly sexually dimorphic in both humerus views (EPI and OL) and both views of the pelvis (SUB and SCI). Each one of these perspectives can be considered a good indicator of sex in the human skeleton.

The EPI perspective showed age-related differences between white females and males. Young white females and males appeared so morphologically similar that neither could be successfully categorized with CVA analysis. Old white females and males, on the other hand, were classified quite accurately when compared to each other. Both young and old black males and females were classified with significant accuracy in the EPI perspective. Therefore, age appeared to play a role in the white population with classification accuracy, but did not appear to affect the classification accuracy of blacks.

The OL perspective exhibited sexual dimorphism between all males and females in both population groups. These marked differences between males and females did not appear to statistically diminish with the onset of age.

The SUB perspective exhibited sexual dimorphism between all black South African males and females. When comparing young and old groups, age did not appear to affect the morphology of the subpubic angle and subpubic concavity of the black males and females; they remained sexually dimorphic from young age ranges to old age ranges. Differences in the morphology of white SUB perspective, however, were observed when comparing young and old samples. Young white females and males appeared so morphologically similar in this perspective that they could not be classified correctly with any amount of accuracy. Old white females and males were classified accurately, indicating a distinct age component to this view. Older white individuals were more sexually dimorphic than young individuals.

The SCI perspective exhibited sexual dimorphism between all black South African males and females, and age did not appear to diminish the classification accuracy for this group. The young white population was classified at a much lower accuracy than their old counterparts when comparing males and females. This indicated (again) that older white individuals were more sexually dimorphic than young individuals in the pelvis. In general, young white males exhibited more classically "female" morphology in the pelvis.

Based on classification accuracies between males and females, females presented male morphology on more occasions with all four perspectives, as seen by the female group's lower classification accuracies (in general). This was a good indication that if age did play a role in morphology change, that role was to make females appear more "male". Males rarely appeared more "female" in their morphology, especially with the onset of age.

7.4.14

Geometric morphometric analysis: advantages and disadvantages

As seen in other published research, geometric morphometric analysis can be helpful in the determination of sexual dimorphism in the human skeleton (Pretorius *et al.* 2006; Pretorius and Steyn 2005). These studies successfully assess differences in the shape of several different skeletal elements, one of which is the greater sciatic notch also studied in this research. Pretorius *et al.* (2006) found a distinct separation between males and females in the greater sciatic notch width, but did not view changes with age as a parameter for the study. Results from this current research showed that homologous landmark analysis in geometric morphometrics successfully reflected the shape of each structure studied, and provided useful classification accuracies for each trait. In addition, geometric morphometric analysis, by and large, complemented the visual techniques utilized in this study to determine sex from postcranial skeletal remains. Results from the three perspectives used in this morphometric analysis (EPI, OL, SUB) showed results that appeared to be congruent with visual analysis. The SCI perspective did exhibit contradictory results in that its statistical analysis performed better on older individuals, while visual techniques were better at categorizing younger individuals.

Geometric morphometric results from the distal humerus (that confirmed visual results) implied that other features of the skeleton not normally explored could be considered sexually dimorphic as well. Specifically, other features of the elbow joint that contribute to the carrying angle of the arm may provide accurate results in sex determination if utilizing geometric morphometrics. The analysis provided interesting results that were note-worthy and significant, especially in the fact that the distal humerus performed so well as a sexually dimorphic element.

In addition, geometric morphometrics quite often provided a higher accuracy rate in classification than the visual techniques alone did with regard to the distal humerus. This showed that as an observer, features were seen, but not to the extent or to the degree in which the computer-generated thin-plate spline could "see" them. This exposed advantages and disadvantages of a robust and complex shape-quantification package such as seen in geometric morphometrics.

Advantages to performing geometric morphometrics were clear. Visualization of a quantified shape allowed for explicit, defined analysis of the form (or aspects of the form) that were being modified with age. In many cases, subtle changes in form were observed with age, but ultimately did not alter the classification accuracy of designating one form "female" and the other form "male". Siegel and Benson (1982) viewed the complexities of interpreting small changes in form and determined that continuous research must be undertaken in order to correctly classify biological shapes. Geometric morphometrics also provided answers to questions posed regarding the efficacy of distal humeral traits as sex indicators. Because these features were not well-known and not yet well-established, morphometrics supplied the quantification of past visual techniques to solidify these physical features as sexually dimorphic. Just as Richtsmeier *et al.* (2002) used geometric morphometrics to quantify the description of characteristic traits in the identification of species, so can geometric morphometrics be used to characterize sexually dimorphic forms of a known species.

Geometric morphometrics provided answers to the specific question of sexual dimorphism changing with the onset of age. Visual sex determination techniques simply would not have been able to discern the subtle modifications in shape that were occurring in several locations. This analysis was compelling based on the fact that the human eye (and human bias) will always play a role in the visual determination of sex from the skeleton. Geometric morphometrics attempts to eliminate all size bias so that only forms and shapes can be analyzed and compared. Finally, the fact that geometric morphometric statistical packages provided clear and concise accuracy rates and p-values (in most cases) made interpretation straightforward.

Disadvantages of geometric morphometric analysis became apparent during this study. Positioning of skeletal elements for correct image capture required an explicit research protocol that was comprehensive and clear. Little room for error was found in the digital image capture methods for morphometrics. These precise protocols made the analysis a robust one, but also hindered the analysis in the fact that image capture was extremely labour intensive. Digital image file storing, appropriate file names and the need to enhance photographs were consistent concerns that were addressed again and again. With such a large sample size for a geometric morphometric study, image files were in jeopardy of being renamed or stored incorrectly simply due to human error. Care was always taken to maintain digital image file integrity, but it must be noted that analysts not familiar with the effort in creating image files for morphometric analysis may find the procedure daunting. In addition, a small sample size in the young white female population was attributed to the lack of some statistical output. Better results may have been obtained if the sample size had been larger, but the lack of statistics made some interpretation difficult in these instances.

As shown, geometric morphometrics generally provided the same answers that visual techniques did. Where geometric morphometrics excelled was in the small morphological changes not discernable by the human eye; however, if those changes are, in fact, not easily discernable by visual techniques, would they ultimately play a role in the misclassification of sex of unidentified remains? This question could not be immediately answered.

CHAPTER 8

CONCLUSIONS

The results of this study answered several queries posed in an effort to determine if sexual dimorphism changed with age. These conclusions included the following:

- The human skeleton is not static in its modification through time. Changes in shape and size throughout a person's lifetime can be observed. However, changes in sexual dimorphism are limited.
- Size differences between the South African black and white populations were once again confirmed. Whites, in general, were larger, but the morphology of black and white South Africans was similar.
- Those more prone to osteoporotic modification (i.e., white females) increased metrically with the onset of age. This increase in size may indicate an increase in male morphology, and a subsequent decrease in sexual dimorphism. It also may indicate the possibility of misclassification of sex based on measurements.
- Those with higher bone densities in younger years (i.e., black females) had less osteoporotic modification in later years, and did not exhibit significant changes in size with the onset of age. Thus, sexual dimorphism stayed consistently marked.
- Males, in general, increased metrically at knee and elbow joint locations with the onset of age.
- Sexual dimorphism in non-metric traits of the humerus changed in females with the onset of age, but not with males. Females became more ambiguous in their morphology as age increased. Males exhibited distinct sexual dimorphism with classic "male" characteristics even with the onset of age.

♦ A relationship between a size change in the skeletal element and the morphology of that element with the onset of age was seen. If a feature was seen to increase metrically, it was more likely to exhibit male visual morphology in both females and males.

♦ The pelvic morphology of females stayed the same with the onset of age; sexual dimorphism was marked and apparent even in the aged individuals.

♦ The pelvic morphology of males became either more sexually dimorphic with age (as seen in black males) or less sexually dimorphic with age (as seen in white males). White South African male pelves showed the most variation with age, and continued to exhibit varying degrees of sexual dimorphism throughout age categories.

♦ Geometric morphometrics accurately quantified visually sexually dimorphic features of the distal humerus and the pelvis. Morphometrics rarely found a significant difference in sexual dimorphism between young and old males and females. The SCI perspective (which quantified the greater sciatic notch) increased in sexual dimorphism with the onset of age only in white males.

♦ A "late" maturation or increase in robusticity was observed in the male sample. This indicated that males apparently only reach their full adult, robust status (and thus their full set of sexually dimorphic characteristics) well after puberty (30's, 40's, and 50's). This held true in both long bone sexually dimorphic morphology and pelvic morphology.

The human skeleton does appear to change with age, but sexual dimorphism does not increase or decrease dramatically in the elements chosen for this research. An increase in size with age indicated an increase in male morphology, which again may pose some classification difficulty with older females. These changes, however, would rarely influence an anthropologist's ability to determine sex from an unknown individual.

The methods used by anthropologists to determine sex should not be modified at this time, but the knowledge of possible changes in sexual dimorphism with the onset of age in the postcranial skeleton should be considered when observing individuals of differing ages. The presence of these changes should be taken into account by any anthropologist while attempting to sex specimens of unknown age, and great care should be used in the determination of sex with these changes in mind.

This research appeared to coincide with the findings of decreased sexual dimorphism/ increased robusticity in females with age as seen in past research on cranial morphology. More research is necessary to determine whether metric and visual changes in the long bones occur in conjunction with specific cranial robusticity as age increases, and if there is a correlation between populations and the differing levels of sexual dimorphism with age. Research on the increase in female cranial robusticity has only included populations of European origin. Interesting findings may be encountered when examining South African whites and blacks in this area of study.

Ultimately, the implications of this research rest with the anthropologist and their knowledge of the changes that occur with the onset of age. Sexual dimorphism does not change greatly in the long bones or the pelvis with the onset of age; however, changes do occur that make sex determination more challenging. Dynamic changes in bone with age were important to examine more closely and with a variety of sex determination methods. These modifications in bone must be understood and appreciated as anthropologists examine unknown specimens in forensic and paleodemographic fields.