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A Comparative Analysis of Differences in the Pelves of South African blacks and whites

by

Michelle Lyn Patriquin

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Declaration:

I declare that this thesis is my own, unaided work, and is being submitted in fulfillment of the requirements for the degree of Master of Science (Anatomy) to the University of Pretoria, Pretoria. It has not been submitted for any other degree or examination at any other University.

Signed

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______ day of ______________ 2001

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ABSTRACT

Correct race and sex determination of unknown skeletal material is an important aspect of forensic anthropology. Numerous studies have focused on the differences, both osteometric and morphological, between the sexes of a particular racial phenotype, between race groups, and populations. From previous work by a variety of researchers, the necessity of population specific standards for identification has been demonstrated. The purpose of this research was to examine the metric and morphological differences in the pelvis between the sexes and races of South African whites and blacks. Results will be used in developing standards of identification tailored to this population. A sample of 400 known sex/race os coxae were examined. Skeletal material was obtained from the Pretoria collection housed at the University of Pretoria, Department of Anatomy and the Dart collection located at the University of Witwatersrand, Department of Anatomical Sciences. A series of thirteen measurements and five morphological characteristics were examined. Indices were calculated from data obtained from the metric analysis. Left and right sides were examined and those bones visibly pathologically deformed were excluded from the study. Data were subjected to SPSS stepwise and direct discriminant analysis. Results showed ischial length as the most sexually dimorphic characteristic in whites, while acetabulum diameter was best in blacks. Four functions (using pelvic dimensions) were developed for determining sex. Highest accuracies were achieved from function 1 (including all dimensions) which correctly classified 92-96% of individuals. Race differences were also investigated. Pubic length was chosen as best for discriminating between races for males and iliac breadth as best in females. Accuracies were 86-89% for males and 82-88% for females. Accuracies for sex discrimination were consistent with earlier studies. Morphological results yielded >80% accuracy for all traits in white males except greater sciatic notch shape where only 33% were correctly classified. A population specific variation in sciatic notch shape was observed where >50% of the white males had a wide sciatic notch previously thought to be a female expression. Black males recorded 81% correct classification for pubic shape and >90% for the remaining characteristics. Greater sciatic notch and pubic bone shape achieved highest accuracies with 96% for both traits in white females, and 84% and 88% in black females respectively. In conclusion, this study conclusively demonstrates that race and population differences affect the expression of sexual dimorphism and must be accounted for to develop the most effective methods of analysis.

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Chapter I

Introduction

Factors of skeletal identification such as age, sex, race and time since death have become ever more important as the number of skeletal remains that need to be identified increase [1-5]. The role of the forensic anthropologist is changing and becoming an integral part of the law enforcement process [6,7]. New and more accurate means of identification of human remains are needed to keep up with the increasing demands due to higher crime rates, which has become a worldwide phenomenon [8].

The determination of sex from the skeleton is of the utmost importance to anthropologists working in the forensic and archaeological fields. Techniques for accurate sex determination are invaluable to investigators. Sex can be determined by using a wide variety of bones in the skeleton (e.g., femur, crania, vertebra, mandible, skull, pelvis) with varying levels of accuracy [9-29].

A number of both metric and morphological traits appear in the literature for determining sex from the pelvis [e.g., 30-34]. Osteometric analysis entails measuring bones. To use this method one must choose appropriate dimensions and landmarks and take one, or a series of measurements, with the appropriate measuring devices. Metric data are useful for comparing different racial phenotypes and populations and analyzing differences between the sexes using various statistical approaches.

Morphological analysis does not require equipment and depends on clearly defined shape configurations or merely determining the absence or presence of the trait then quantifying the results. Experience on the part of the observer is a plus, allowing a better understanding of the skeleton and the degree of variability that can be found within most morphological traits.

Sex differences in the adult as well as the subadult, have been investigated using the os coxae [35-39]. Most of the observed skeletal differences between sexes, however, occur only after puberty.

To date, the best results for accurate sex assessment have been obtained from the mandible and pelvis [16,40]. According to Krogman and İşcan [41] 95 percent sexing accuracy can be expected from a complete pelvis, making this one of the most effective bones to use for determination of sex. The os coxa which is composed of the ilium, ischium and pubis, is widely accepted as the most sexually dimorphic bone in the human skeleton. Publications from different regions are available throughout the literature [e.g., 42-46]. Sex differences in morphological and metric characteristics of the pelvis have been attributed primarily to modifications in females for childbirth [45,47-50].

There are differences between the races throughout the whole skeleton [48,51,52]. Research revealed race differences between North American white and black population from postcranial measurements [53]. Sex and race differences between North American and European populations and South Africans have also been noted [54-56]. Few studies have focused on the South African populations specifically and fewer still on the sex and race differences in the os coxa [57-61].

It is necessary for each population to have its own standards tailored to the metric and morphological characteristics of the population. Until recently, most research has been based on North American and European populations and the data were adapted as international standards. Standards, especially metric ones, from other populations can often result in incorrect sex diagnosis due to the regional variation of populations. To avoid this problem, population specific standards should be devised and used strictly on the population from which they have been derived [9-11,15-17,25,62,63].

The pelvic girdle is composed of the sacrum, coccyx and a pair of os coxae uniting at the pubic symphysis. The os coxae, or hipbone, is large and irregular in shape and is composed of three bones the ilium, ischium and pubis. In youth, these bones are connected by cartilage and unite in adolescence. On the lateral surface, there is a deep spherical shaped hollow, acetabulum, which articulates with the head of the femur (Figure 1). The ilium is the blade shaped supero-lateral portion of the hipbone, which includes the upper part of the acetabulum and serves a weight bearing function. The ischium is the postero-inferior portion of the os coxae and contributes the inferior third of the acetabulum. It is comprised of a body and an ischial ramus which runs superiorly fuse with the descending ramus of the pubis. The pubis comprises the anterior portion of the acetabulum and meets the opposite pubis medially to form a synchondrosis, the pubic symphysis. The obturator foramen is a large foramen in the hip bone located anteroinferiorly to the acetabulum (Figure 2) [64,65].

There are numerous known differences between the male and female pelvis. The female pelvis appears broader yet more gracile with

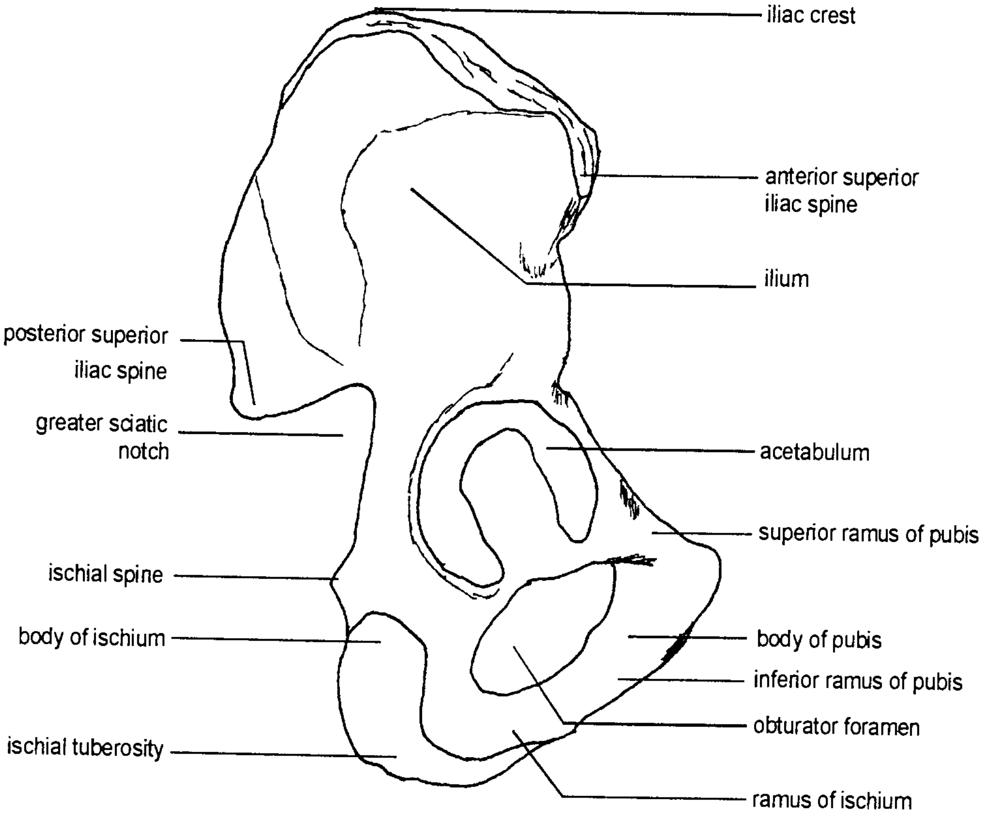

Figure 1. Lateral view of os coxae

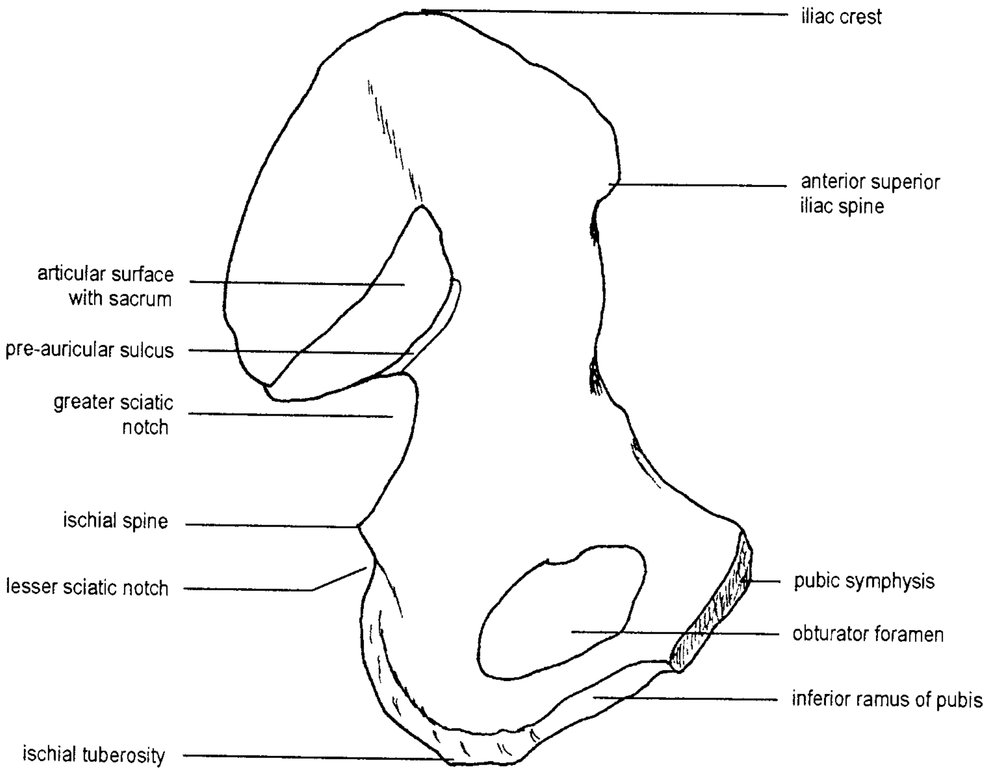

Figure 2. Medial view of os coxae

lighter more slender bones while that of the male is more robust with more prominent muscle attachments. The lesser pelvis of the female is wider and shallower than that of the male. The pelvic cavity is longer and more conical in the male as opposed to more cylindrical configuration in the female. The pelvic inlet of the male is heart-shaped whereas the female inlet is kidney shaped.

The pre-auricular groove, which has been associated with pelvic expansion during childbirth, is larger and more pronounced in females. In males the iliac crest is more rugged and curves medially at its anterior end more acutely than in females. The iliac blades are more vertical in the female, but do not extend as far upwards. The acetabulum is normally larger in the male, and its diameter is about equal to the distance of its anterior rim from the pubic symphysis. In the female, however, the acetabular diameter is usually distinctly less than this distance. The subpubic angle formed below the pubic symphysis is smaller in males than in the females. The ischiopubic ramus of the female is more lightly built and narrower near the symphysis whereas those of males are rough and everted in this area stemming from the attachment of the crus penis. The greater sciatic notch is wider and shallower in females than males. Pubic bone length is most often found to be larger in females than in males, but the reverse is true for the ischial length. The general anatomy, and well-documented sex differences of the os coxae can be found in a variety of forensic and anatomy texts [41,64,66-68].

The database for this project consisted of skeletons of whites and blacks from the Pretoria Collection housed at the University of Pretoria

Department of Anatomy and the Raymond Dart Collection housed at the University of Witwaterstrand. The white South African population used in this work is of European descent originating from the Netherlands, France, Germany, Great Britain and Portugal. However, due to the changes over time and admixture the South African whites have become osteologically distinguishable from both the European and North American populations.

There are several different tribes found within the South African black population- Zulu, Xhosa, Sotho, Swazi, Venda and Tsonga to name a few. In this research the various tribes of black South Africans were not differentiated. The blacks sampled were regarded as a homogenous population [69].

South Africa has a real need for more precise methods of identification in forensic anthropology because of the increasing number of unidentified and decomposed human remains that confront law enforcement agencies [7]. Since the determination of sex is essential, it is important to obtain the highest possible accuracy. The purpose of this research is to first learn what problems exist in sexing pelvic remains of South African whites and blacks and then determine the most effective criteria for sexing South African black and white pelves. Therefore, the purpose of this study is also to determine if population specific metric standards can improve sexing from South African pelves. These findings can then be compared to the standards for other populations. The same metric data will also be tested to determine if it is possible to distinguish between whites from blacks.

Chapter II

Literature Review

Sex differences in the pelvis

Sex differences in the pelvis have been examined using various dimensions and developmental aspects by numerous authors [31,32,44-46,49,50,58,59,70-72,72-82]. There are many features of the pelvis, both metric and morphological, that have been found to be sexually dimorphic: pubic length, ischial length, width and depth of the greater sciatic notch much of which has been summarized by Krogman and İşcan [41]. The evidence of metric and morphological differences found in the pelvis is prevalent throughout the literature. In this chapter several of those sexually, and some racially, dimorphic features will be discussed.

Metric sex differences in the pelvis

Sexually dimorphic traits in the pelvis have been demonstrated metrically. Various populations have been examined using metric characters for sex determination, for example, Bantu and Bushman [57], American whites and blacks [23,47,83,84], Australian Aborigines [85], Nigerians [86], Europeans [87] and Eskimos [88]. In general, the female has a longer pubis [50,57,84,88] and shorter ischium than males [57,84,88,89]. The ischiopubic index used to eliminate differences due to absolute size is used to compare the ischial and pubic proportions [90]. As expected, the index was found to be greater in females than in males since females have a larger pubis relative to the ischium [50,57,84,88].

Other pubic bone measurements tested were the height taken at the symphyseal surface and pubic width measured from the posterior surface

Indian sample and 34.2 mm in females. Width averaged 20.4 mm and 23.3 mm in males and females respectively. The pubic bone proved useful as an indicator of sex from this study.

Several authors have found the acetabulum to be sexually dimorphic [49,92,93]. Results showed that males have a greater acetabular diameter than that of females. Kelley [92] found the mean acetabular diameter of a white sample to be 56.3 mm in males and 48.4 mm in females. This is not surprising in light of significant metric dimorphism in the head of the femur. Steyn and İşcan [54] observed a South African white population, and found femur head diameter averaged 48.4 mm in males and 43.0 mm in females.

Sex differences in the sciatic notch have been examined in a number of populations including Asian Indians [94], Bantu and Bushman [57], American whites and blacks. Overall the mean greatest width of the notch was larger in females than males and the depth for both races was greater in the males than the females [83]. Similar results were found by Akpan *et al* [86] in a Nigerian sample of 150 known sex X-rays. A sample of Australian Aborigines also showed the greatest width in females, but in this group the greatest depth was also observed in the females instead of in the males as previously found and these differences were statistically significant between the sexes [85]. The Belgian and French population examined by Segebarth-Orban [87] found the greatest width in females, but the sex difference was not significant. The greater sciatic notch has even been found to be usable in sex identification in a pathologically deformed hipbone [95]. The depth of the notch was greater in males than females in North American black and whites [83].

Sciatic notch anterior and posterior widths have not been addressed in the literature as extensively as those previously mentioned [32,83,85]. Posterior width has, however, been though of as a good indicator of sex with small overlap between the sexes [47].

What are referred to in this thesis as the total bone measurements (iliac breadth and total height of the os coxae) have been examined metrically for sex differences [59,85,87,96]. Davivongs [85] found total height of the os coxae and iliac breadth to be greater in males than females in an Aboriginal sample. Kimura [96] examining a Japanese and American white and black sample found iliac breadth larger in males for all three race groups and overall largest in American white males. Segebarth-Orban [87] found mean breadth and total height larger in males than females for the French and Belgians examined.

The height and width of the obturator foramen has not been investigated as often metrically as it has been morphologically. In females the foramen is smaller and triangular while males it is larger and ovoid in shape [33]. Rogers *et al* [33] recorded accuracies for different age groups. The age interval less than 25 and 45 plus achieved 100 percent from obturator foramen morphology while accuracy for the 25 to 44 year olds was 87.5 percent. Day and Pitcher-Wilmott [97] metrically examined an English sample and in their series of seventeen measurements obturator foramen width and height were examined. Mean female values for height and width were 47.6 mm and 35.4 mm. Male means were 50.8 mm and 33 .6 mm for height and width respectively.

Morphological sex differences in the pelvis

Considerable research has been done to assess sexually dimorphic morphological characteristics in the pelvis [30,33,34,76,91,98-104]. Tables compiled from numerous research studies on visually assessing sex from the pelvis can be found in larger texts [e.g., 41]. Phenice [102] produced one of the better-known studies on morphological characters of the adult pelvis. This author used the ventral arc, subpubic concavity and medial aspect of the ischiopubic ramus and attained 95 percent accuracy for sex determination. Several authors after have tested this visual technique on other samples [34,99,101]. MacLaughlin and Bruce [101] using Phenice's [102] variables yielded 83 percent accuracy for English and 68 percent and 59 percent for the Dutch and Scottish. Highest individual accuracies were achieved by observing the subpubic concavity with greater than 72 percent accuracy for all groups. Lovell [34] recorded approximately 83 percent accuracy for a white sample testing Phenice characters while Kelley [99] using Californian Indians, also found this method reliable in sexing.

Inferior to the pubic symphysis on the female pubis and ischiopubic ramus, the subpubic concavity can be observed. The concavity is a modification in the female pelvis to childbearing, which makes the pelvic cavity larger to facilitate delivery of the neonate. Rogers and Saunders [33] found that concavity correctly sexed 83.8 percent of individuals and ranked 9th overall for the 17 pelvic traits observed.

The body of the pubic bone shows considerable sexual dimorphism not only in its dimensions, but also in its shape. The male pubis has been described as triangular and narrow while the female pubis is broad and rectangular in shape [33,66]. Changes in pubic bone morphology are in response to varying hormone levels in the female during adolescence.

The ischiopubic ramus form has been described as rough and slightly everted in the male, but less rough with more eversion in the female. Differences in the rami between males and females are in response to differences in secondary sex characteristics and muscle attachment corresponding to them [41,64].

The ischial tuberosity is the rough elevation where the body and ramus of the ischium join. The orientation of this tuberosity varies between males and females. The tuberosities in males are closer together and orientated posteriorly while the female ischial tuberosity is more laterally orientated [105].

The greater sciatic notch is frequently utilized for sex determination. The female sciatic notches of modern humans have been described as being wide and shallow, while the male counterparts are deeper and narrower [21,83,86,94,95,106-108]. Verneau [109] was the first to notice these characteristics. The arc, or shape, of the notch is influenced both by its width and total angle. The total angle has been found to be larger in females than males [94,110]. The shape of the notch can be observed to find common patterns between the sexes [94].

To better understand the nature of sexual dimorphism in the greater sciatic notch, a study was conducted to compare great apes and modern humans [108]. Hager [108]attributes sciatic notch morphology to changes in the posterior ilium and ischium needed for bipedalism. In humans the posterior ilium is extended and pulled downward. The ilium is reduced in total height and broadened most likely to enable it to serve its weight bearing function.

Race differences in the pelvis

Knowing the racial affinity of the skeletal material with which one is working is of the utmost importance for the highest sexing accuracy to be achieved. It is also important to reiterate that populations within race groups also exhibit statistically significant metric differences.

The literature contains conclusive evidence that there are biological differences among the three major racial phenotypes, Caucasoid, Mongoloid and Negroid [23,53,111-114]. Considerable variation has also been demonstrated in the pelves of various populations, for example, American blacks and African blacks [11,48,83,85,115]. Significant metric variation in the skeleton has been published on many populations [21,22,35,50,79,84,116]. Morphological differences between race groups are also readily observable especially in the skull [18,20,25,51]. The skulls of Negroids are commonly dolichocephalic as opposed to the rounder, broader heads of whites and Mongoloids. Since the skull must pass through the pelvis, cranial shape differences have also been proven to affect pelvic configuration [48,117].

Chapter III

Materials and Methods

The human skeletal material used in this research consisted of 400 pairs of adult os coxae evenly distributed between whites and blacks, males and females (Table 1). The known race, sex, and age skeletons for this project were derived from anatomical dissecting room samples housed in the Pretoria Collection (Department of Anatomy, Faculty of Medicine, University of Pretoria) and the Raymond Dart Collection (Department of Anatomical Sciences, University of the Witwatersrand, Johannesburg).

Skeletal material was examined both metrically and morphologically. Three factors influenced the choice of measurements, 1) expression of most dimorphism 2) landmarks that can be consistently identified for repeatability 3) less perishable portions of the pelvis. This series of measurements should, therefore, be applicable to both archaeological and forensic specimens.

Cadavers arrive at the Medical school as donated or unclaimed bodies. In most instances the cost of burial necessitates donation. It can then be said, that the skeletal material may be representative of a lower socio-economic group. Bodies are embalmed and kept for one year, afterwards, cadavers are then utilized as teaching specimens in the medical school. The skeletons then become part of the Pretoria Collection. It should be mentioned that the skeletal material used in this research is composed of individuals who died in Gauteng area. However, the present sample included several black South African groups.

Table 1

Age distribution of known age/sex skeletons.

		N	Mean	Min	Max
White	Male	100	62	28	88
	Female	100	64	21	88
Black	Male	100	52	22	86
	Female	100	42	19	82

Both sides of each pelvis were examined for asymmetries and to determine if consistent side differences existed. Pathologically deformed pelves were excluded from the study. The metric characteristics also include those traditionally used for sex determination, thus making results comparable to international standards. Some new measurements were also introduced. These innovative measurements allowed for data collection from different parts, or segments, of the bone and inclusion of highly dimorphic sites not used before. In addition, some traditional measurements were modified to insure consistent replicability. This was particularly necessary to eliminate problems locating the exact point in the acetabulum where the three elements of the os coxae meet.

Metric

The following measurements were taken:

Pubic height: (Pubic Ht) (sliding calipers) measured from the most superior to the most inferior point on the pubic symphysis (Figure 3) [85,91,118].

Pubic width: (Pubic Wdt) (sliding calipers) measured on the dorsal aspect of the bone from the inferior most point on the face of the pubic symphysis, horizontally to the medial aspect in the obturator foramen. The literature gives variations of this measurement of pubic width, for example, using the midway point of the pubic symphysis, but the inferior point on the symphysis was used in this project (Figure 3).

Obturator foramen height: (Obt For Ht) (sliding calipers) measured by positioning the bone with the pubic symphysis in a vertical plane.

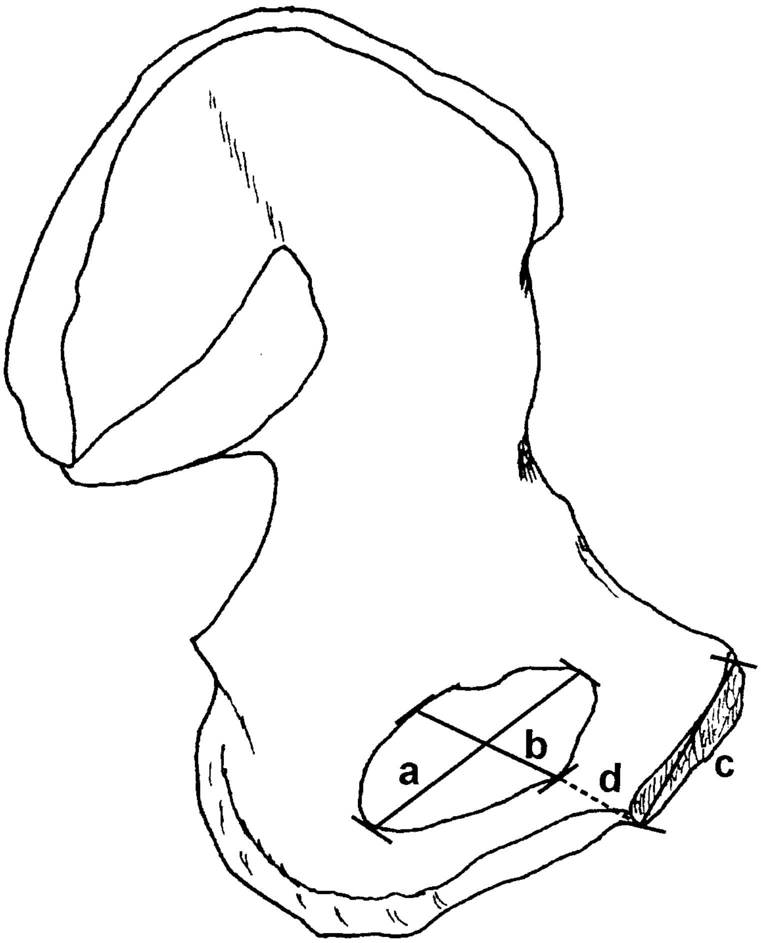

Figure 3. Measurements of os coxae. a= Obturator Foramen Height; b= Obturator Foramen Width; c= Pubic Height; d= Pubic Width.

One arm of the sliding caliper was placed at the most inferior point within the foramen from the dorsal aspect while the other extended upwards to the most superior point meeting the superior ramus of the pubic bone (Figure 3) [97].

Obturator foramen width: (Obt For Wdt) (sliding calipers) measured on dorsal aspect, perpendicular to height from the posterior to the anterior borders of the foramen (Figure 3) [118].

Acetabulum diameter: (Ace Dia) (sliding calipers) measured from the middle of the ridge on the superior border to the inferior border. This was a superior-inferior, thus a vertical dimension. Orientation of the bone is the same as in measurements of the obturator foramen (Figure 4) [92].

Pubic length: (Pubic Lng) (sliding calipers) measured from the point on the superior border of the acetabulum representative of the centre of origin of the iliac blade to the most superior and medial point on the pubic crest. This is a new measurement (Figure 5).

Ischial length: (Ischial Lng) (sliding calipers) measured from the point on the superior ridge of the acetabulum mentioned above to the deepest point on the ischial tuberosity. This is a new measurement (Figure 5).

Iliac breadth: (Iliac Br) (osteometric board) the greatest distance from the anterior superior to the posterior superior iliac spines (Figure 6) [41,85,87,118-121].

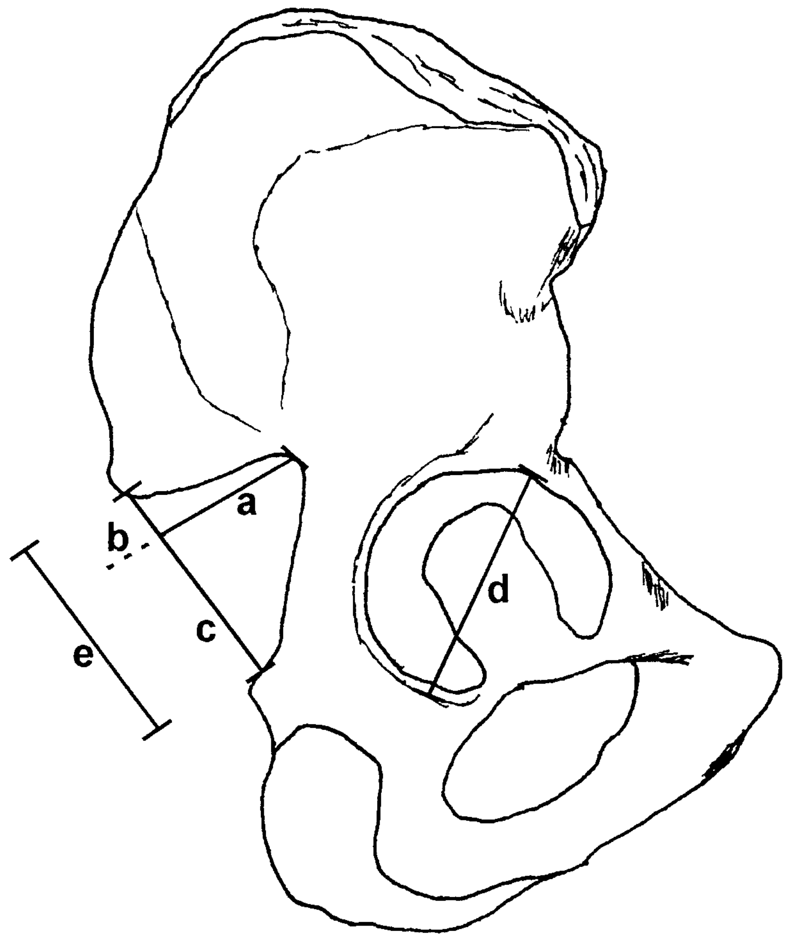

Figure 4. Measurements of os coxae. a= Maximum Depth of Greater Sciatic Notch; b= Posterior Width of Greater Sciatic Notch; c= Anterior Width of Greater Sciatic Notch; d= Acetabulum Diameter; e= Width of Greater Sciatic Notch.

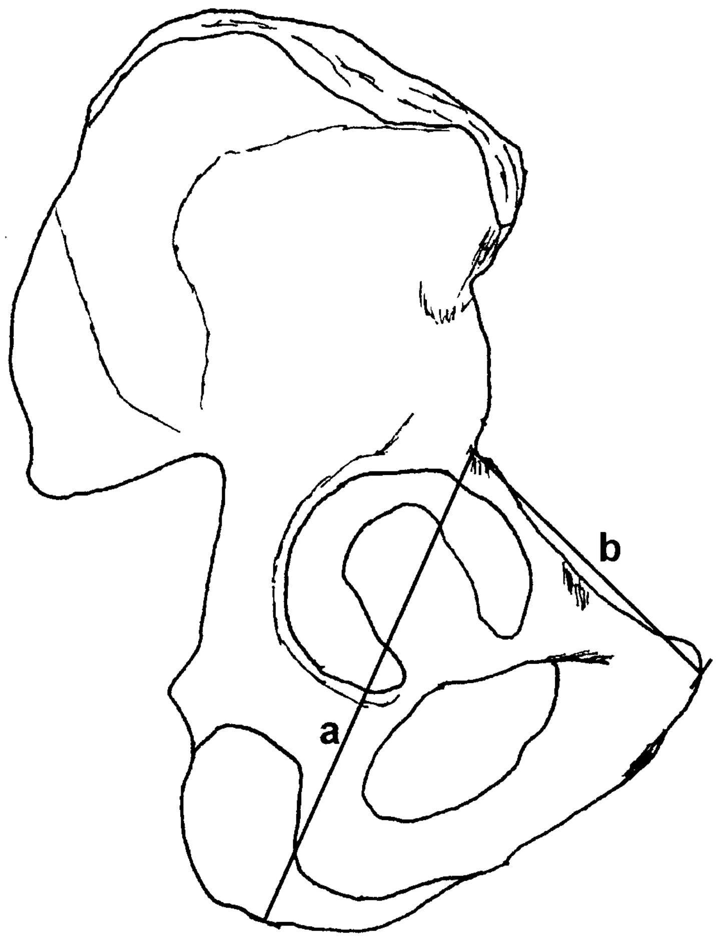

Figure 5. Measurements of os coxae. a= Ischial Length; b= Pubic Length.

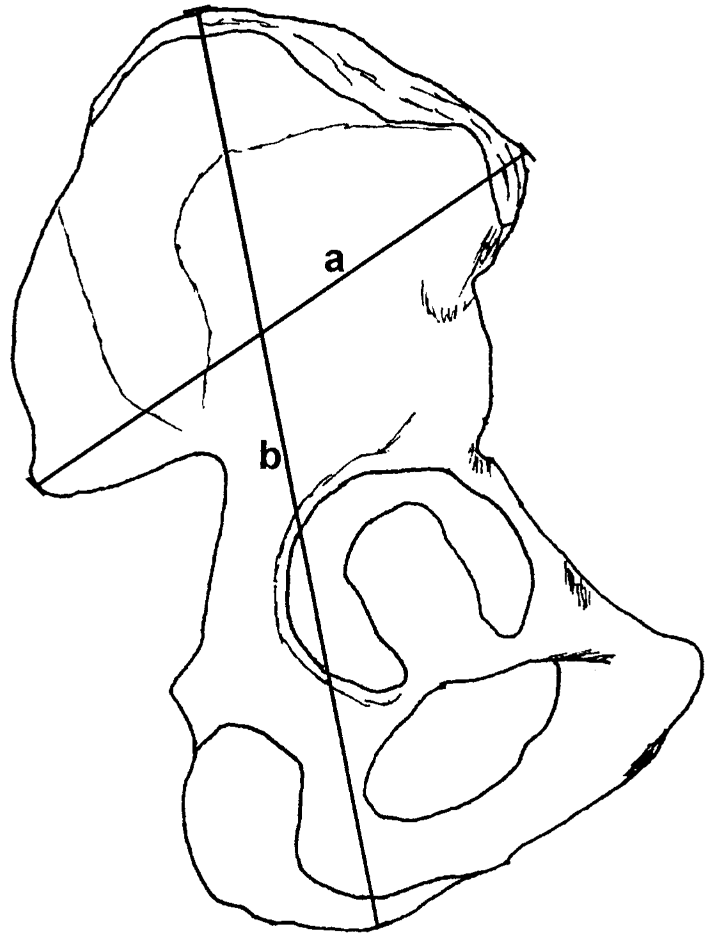

Figure 6. Measurements of os coxae. a= Iliac Breadth; b= Total Height.

Total height: (Total Ht) (osteometric board) greatest distance from the most superior point on the iliac crest to the most inferior point of the ischial tuberosity (Figure 6) [85,87,118-121].

Width of Greater Sciatic Notch: (GSN Wdt) (sliding calipers) measured from the base of the ischial spine to the posterior inferior iliac spine stopping at a point before the curvature of the spine angles to the posterior. Measured from the lateral aspect of the bone (Figure 4) [92,107].

Maximum depth of Greater Sciatic Notch: (GSN Dpth) (sliding calipers) the set arm of the calipers recreates the line measuring width of the notch while the other arm is adjusted to intersect the notch at the greatest depth. Orientating the calipers in this way gives the maximum depth perpendicular to the line of the width of the notch. This measurement was carried out on the lateral aspect of the bone (Figure 4) [32,83,85,86,94,106,108].

Anterior width of greater sciatic notch: (GSN Ant Wdt) the distance from the base of the ischial spine to the point where the maximum depth line intersects the line measuring the width of the notch. Due to the lack of an adequate instrument for measuring anterior and posterior width of the notch, an easy, yet effective, method was devised. A piece of graph paper, cut to a manageable size and graded in millimeters, was numbered in intervals of 5 from 0 to 80. The paper was covered with transparent tape for durability. The graph paper was attached to the centre of a skull pillow for the duration of data collection. Using this setup the os coxae can be orientated in such a way that the numbered line mimics that of the width of the notch. Having previously measured the width with calipers this step served as a good control for accuracy. The notch was positioned horizontally over the graph paper while observing the lateral aspect. The point where the maximum depth of the notch intersects the line on the graph paper can be observed. The anterior width of the notch can now be read from the graph paper (Figure 4) [32].

Posterior width of Greater Sciatic Notch: (GSN Post Wdt) the measurement from the point where the maximum depth line intersects the width of the notch to the posterior inferior iliac spine stopping at a point before the curvature of the spine angles to the posterior. Having the bone orientated properly on the skull pillow allows the observer to take both measurements for anterior and posterior width of the notch at the same time (Figure 4) [83,86,94].

The instruments used for measuring remained the same throughout data collection. All readings for measurements were taken to the nearest millimeter.

Morphology

Five morphological characteristics were considered on each os coxa:

Shape of pubic bone: determined during observation of the pubic bone, from the ventral aspect. Its shape was found to be either characteristic of a rectangle, a triangle or indeterminate (Figure 7A and 7B) [33].

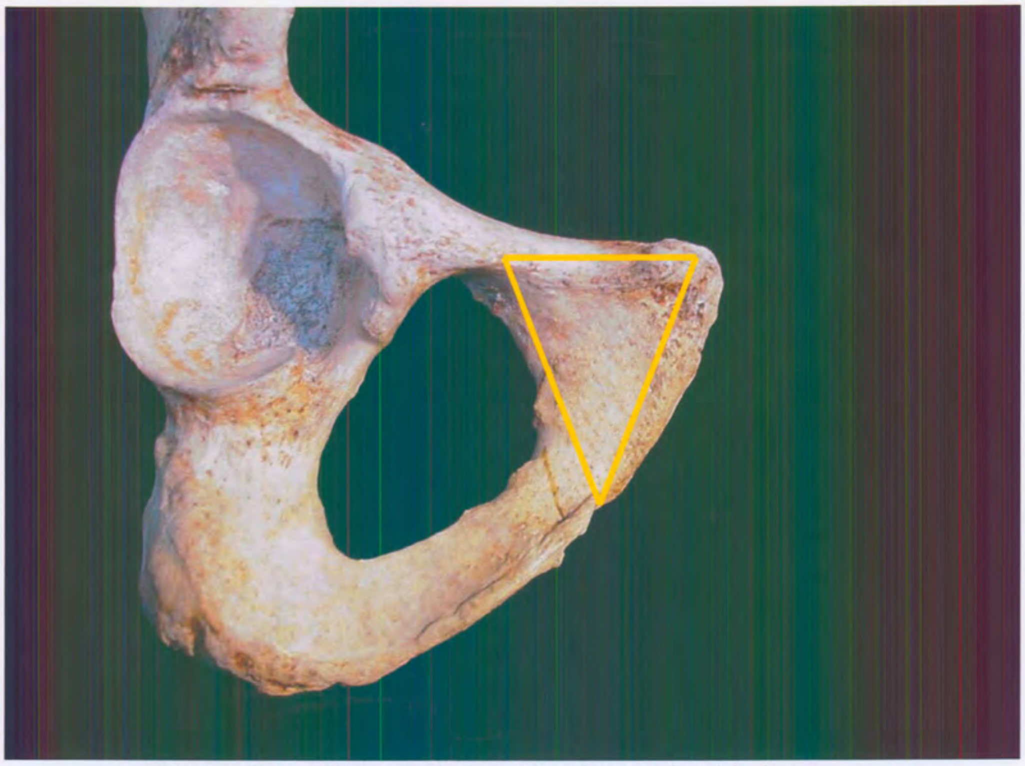

Figure 7A. Characteristic male shape of pubic bone.

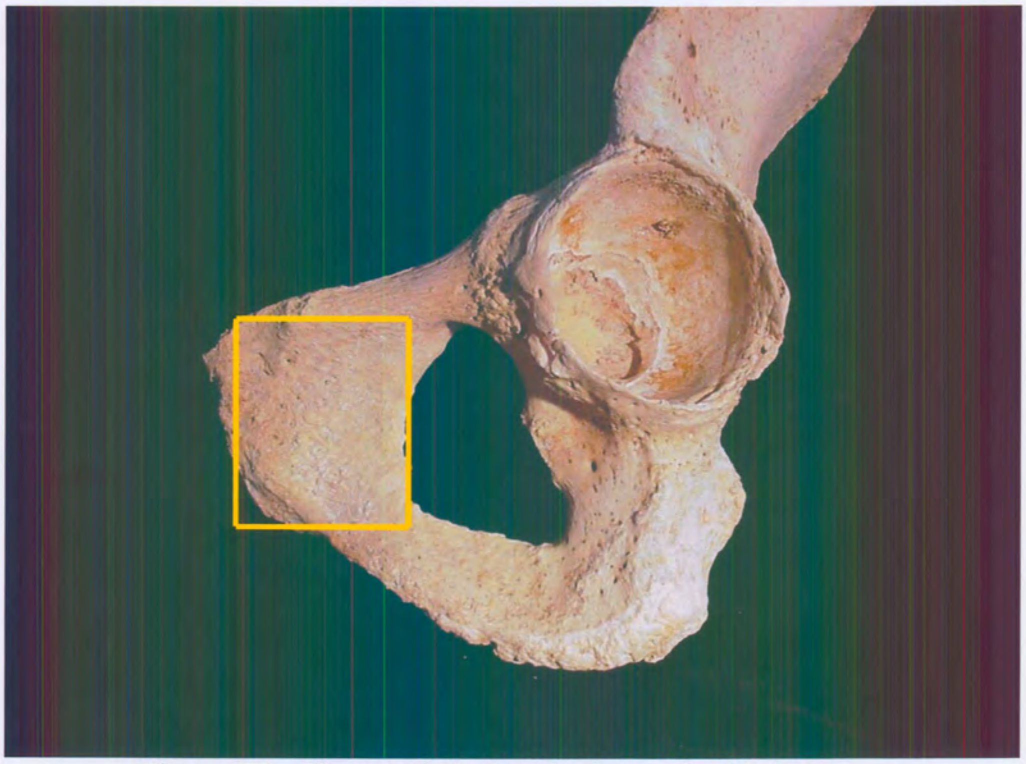

Figure 7B. Characteristic female shape of pubic bone.

Subpubic concavity: determined by observing the ventral aspect of the bone. It is often helpful to simulate an articulated pelvis in examination. In observing the region inferior to the pubic bone, the two bones reveal the subpubic angle. This angle can be concave or convex in shape or neither. In this study, the presence of subpubic concavity was being observed. Its presence (P), absence (A), or indeterminate (I) expression was recorded (Figure 8A and 8B) [33,101,102].

Ischiopubic ramus form: examined for the presence (P), absence (A), or indeterminate (I) expression of roughness and eversion associated with muscle attachment (Figure 9A and 9B) [33,101].

Orientation of the ischial tuberosity: positioning the thumb in the centre of the ischial tuberosity on the lateral side of the bone and orientating the bone directly in front of the observer with the pubic symphysis in a vertical plane, the orientation of the ischial tuberosity can be observed. If ¾ of the thumbnail or more was visible, the ischial tuberosity was rated as visible (V) from the anterior. If only ½ or less of the nail was visible then the orientation was rated as little or not visible from the anterior (L). An indeterminate (I) value could also be awarded (Figure 10A and 10B).

Shape of greater sciatic notch: observed on the lateral aspect there are five ways to describe the shape of the notch namely, wide and asymmetrical (WA), wide and symmetrical (WS), narrow and asymmetrical (NA), narrow and symmetrical (NS), or indeterminate

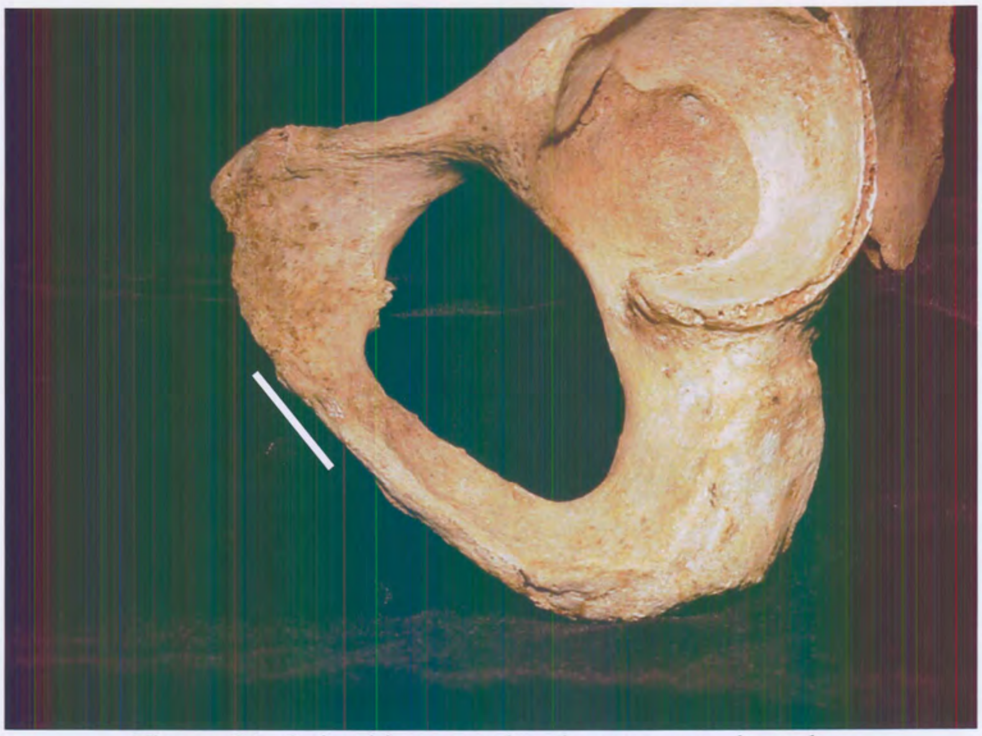

Figure 8A. Subpubic concavity absent as seen in males.

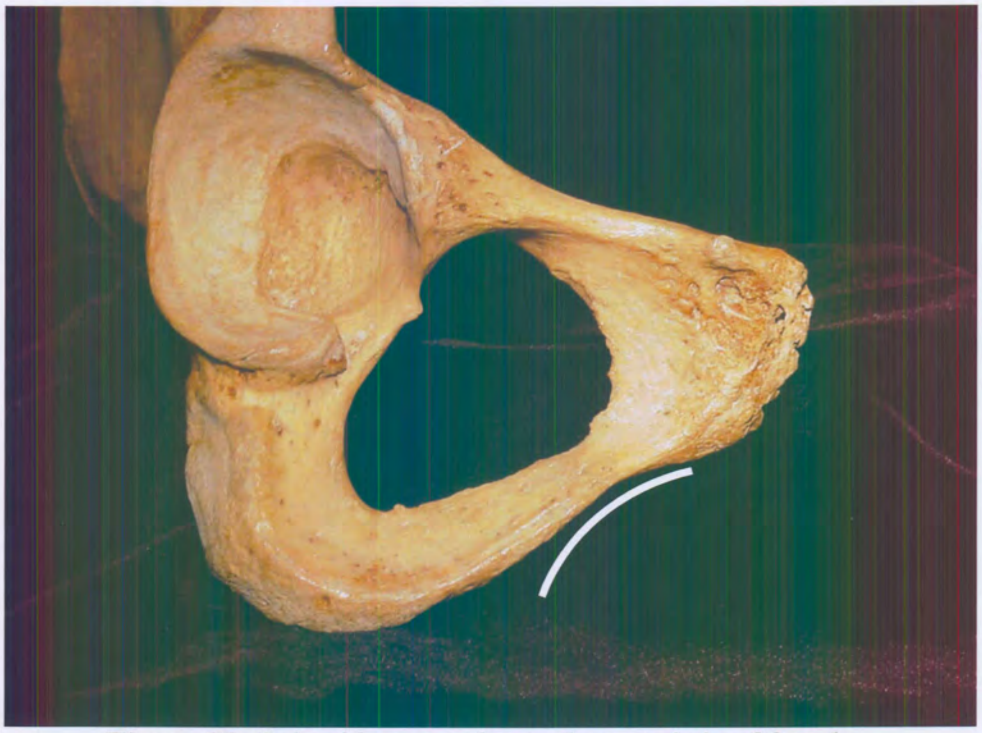

Figure 8B. Subpubic concavity as characteristic of females.

Figure 9A. Ischiopubic ramus form expression in males.

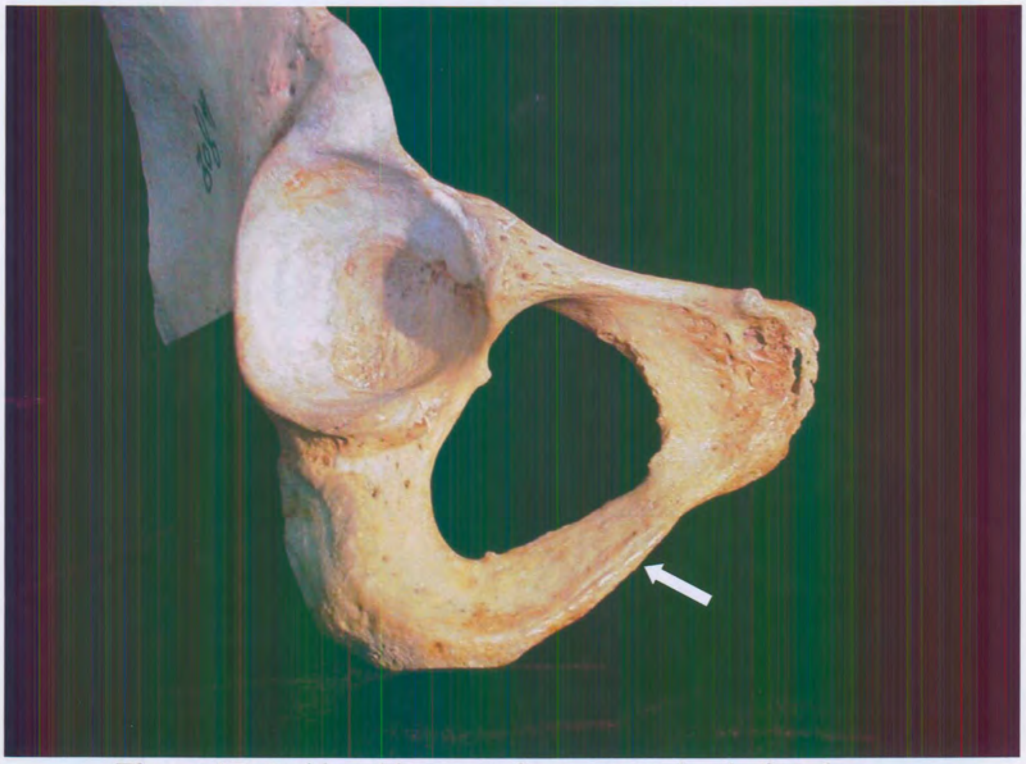

Figure 9B. Ischiopubic ramus form expression in females.

Figure 10A. Orientation of ischial tuberosity in males.

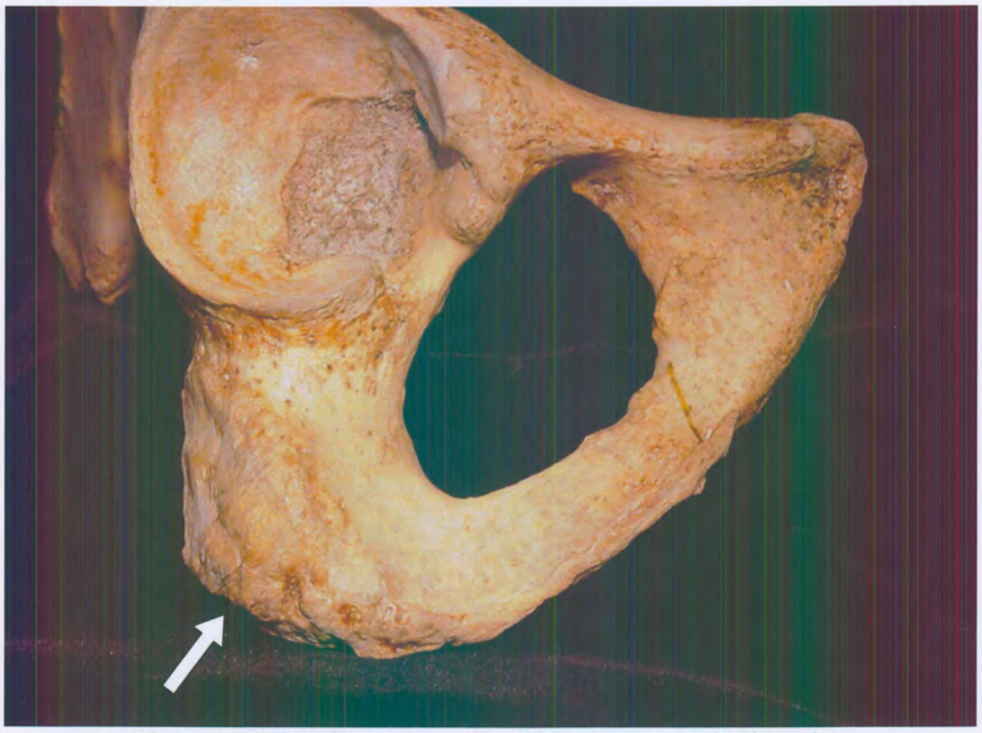

Figure 10B. Orientation of ischial tuberosity in females.

(I) (Figure 11A, 11B and 12A, 12B). In deciding whether or not a notch was wide or narrow two things were considered – 1) the line visualized by the width of the notch as determined metrically and 2) the 'rule of thumb'. When inserting a thumb into the notch, it was considered whether or not it is a tight fit (narrow) or whether there was substantial room on either side (wide). The symmetry of the notch was determined by visualizing the point of greatest depth and deciding whether or not the distance on either side was approximately equal (symmetrical) or unequal (asymmetrical).

Indices and Calculated Variables

Indices are calculated to eliminate the effects of absolute size. The following indices and variables were calculated.

Obturator foramen index: (Obt For Index) calculated using the measurements of height and width of the obturator foramen.

The equation used:

Obt For Index = Obt For Wth x 100/ Obt For Ht

Ischiopubic index: (I/P Index) calculated using measurements of pubic and ischial lengths, with the following equation:

I/P Index = Pubic Lng x 100/ Ischial Lng

Although, the ischiopubic index has been used extensively in the literature, results achieved here can not correlate directly, as the landmarks have been changed for the measurements of ischial and pubic lengths [50,57,71,84,96,122].

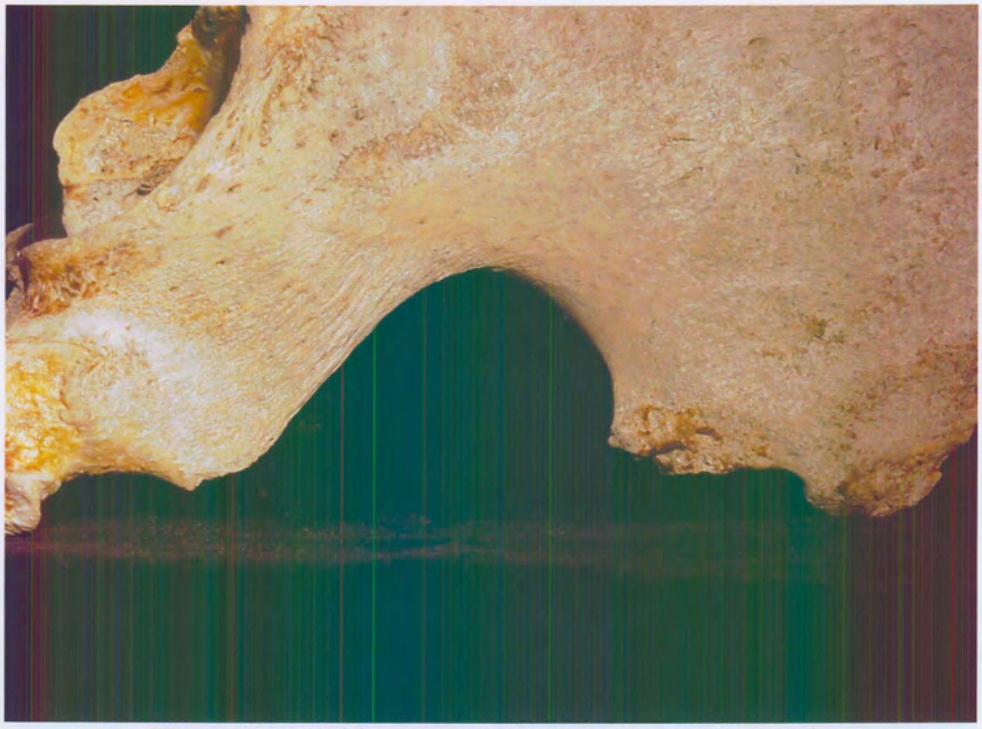

Figure11A. Wide asymmetrical greater sciatic notch.

Figure 11B. Wide symmetrical greater sciatic notch.

Figure 12A. Narrow asymmetrical greater sciatic notch.

Figure 12B. Narrow symmetrical greater sciatic notch.

Anterior diagonal: (Ant Diag) Using the Pythagorean theorem of right angle triangles the anterior diagonal of the greater sciatic notch can be calculated using the equation

$$(\text{Diagonal})^2 = A^2 + B^2$$

where, 'A' represents the anterior width of the greater sciatic notch and 'B' represents the greatest depth of the notch (Figure 13).

Posterior Diagonal: (Post Diag) using the equation described above, the posterior diagonal 'A' represents the posterior width of the greater sciatic notch and 'B' represents the greatest depth of the notch (Figure 13).

Statistical Analysis

All data produced by the analysis of metric and morphological characteristics, and indices will be subjected to statistical analysis using SPSS computer software. The mean, standard deviation, and range for each set of measurements and calculations will be performed for each group (white/black, male/female). Student's t-Tests were used to determine if significant differences in metric data are present between sexes and races. The ranges of values for each sex and race for the two indices will be determined by observing the maximum and minimum values and the region of overlap determined for the sexes. Next the percentage correctly classified individuals (using these sectioning points) will be determined. Stepwise and direct discriminant function analysis of the data were carried out to produce discriminant function formulae, in which data could be entered to determine the sex and race of individuals. A full explanation of the discriminant function analysis appears in Chapter five.

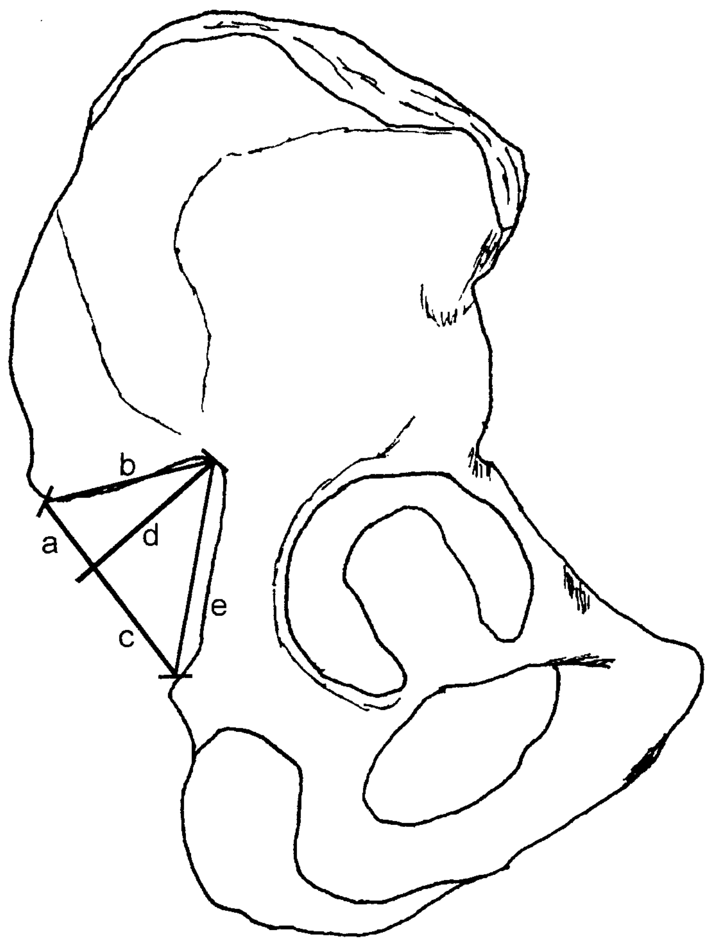

Figure 13. a= Posterior width of greater sciatic notch; Calculated variable of greater sciatic notch b= Posterior Diagonal; c= Anterior width of greater sciatic notch; d= Depth of greater sciatic notch; Calculated variable of greater sciatic notch e= Anterior Diagonal

Chapter IV

Results

Metric

Table 2 contains descriptive statistics of pelvic measurements of white and black males. Mean values for white males are overall greater than those of the black males. This is also the case for white females, who have greater mean values than black females for all measurements (Table 3). White males exceeded white females in mean measurements in all but width of sciatic notch, posterior width of notch, pubic length and width and the width of the obturator foramen. The same dimensions were found to be larger in black males then females.

Table 4 contains univariate F-ratios for pelvic measurements in whites. F-ratios indicate that statistically significant differences ($p \leq 0.001$, or $p \leq 0.05$) between the sexes were found between all measurements for whites except obturator foramen width (L/R), pubic length (L/R) and the iliac breadth (L). F-ratios for blacks showed fewer statistically significant differences between males and females (Table 5). Depth of greater sciatic notch (L/R), anterior width of notch (R), pubic length (L/R), and obturator foramen width (L/R) were not significantly different.

Asymmetries

Paired t-tests for determining significant asymmetries were preformed for white males and white females (Table 6). Six of the 13 measurements were significant in whites: width of sciatic notch, anterior/posterior width of sciatic notch, pubic height and width and

Table 2

Descriptive statistics of pelvic dimensions for white and black males.
N=100 all groups.

Variable (mm)	White Males			Black Males		
	Mean	Range	SD	Mean	Range	SD
GSN Wdt L	43.03	30-56	4.99	36.96	28-49	4.62
GSN Wdt R	43.95	31-62	4.92	37.70	26-52	4.87
GSN Dpth L	26.55	18-33	2.99	22.68	12-39	3.66
GSN Dpth R	26.16	19-35	3.06	22.46	16-38	3.66
GSN Post Wdt L	15.56	6-25	4.24	9.31	1-23	3.90
GSN Post Wdt R	14.61	3-27	4.07	8.80	0-27	3.95
GSN Ant Wdt L	27.39	15-15	3.71	27.63	20-36	3.89
GSN Ant Wdt R	29.55	20-46	4.17	28.91	18-40	3.94
Iliac Br L	163.15	145-185	8.67	150.10	131-168	7.29
Iliac Br R	163.55	144-185	8.39	150.78	131-167	7.69
Total Ht L	220.43	194-252	10.83	203.93	179-221	9.64
Total Ht R	220.15	195-249	11.11	203.60	181-221	9.67
Pubic Lng L	101.65	91-119	5.52	93.26	84-105	4.69
Pubic Lng R	102.00	92-116	5.38	93.63	81-104	4.87
Pubic Ht L	42.18	32-52	4.21	38.98	29-50	3.48
Pubic Ht R	41.67	31-52	4.15	38.68	29-50	3.28
Pubic Wdt L	23.91	18-33	2.73	20.92	12-29	3.04
Pubic Wdt R	23.03	15-29	2.79	20.74	12-27	2.87
Ischial Lng L	111.05	96-124	5.66	104.36	89-116	4.78
Ischial Lng R	110.99	95-124	5.71	104.20	92-115	4.57
Obt For Ht L	54.26	42-65	4.04	51.46	39-60	3.87
Obt For Ht R	53.99	43-63	3.75	51.25	41-61	4.06
Obt For Wdt L	34.44	26-48	3.54	32.50	25-39	3.14
Obt For Wdt R	34.60	25-43	3.16	32.64	23-39	3.15
Ace Dia L	55.80	49-64	3.09	54.59	46-62	2.76
Ace Dia R	56.14	49-65	3.17	54.65	46-62	2.75

GSN Wdt = Width of Greater Sciatic Notch; GSN Dpth = Depth of Greater Sciatic Notch; GSN Post Wdt = Posterior Width of Greater Sciatic Notch; GSN Ant Wdt = Anterior Width of Greater Sciatic Notch; Iliac Br = Iliac Breadth; Total Ht = Total Height; Pubic Lng = Pubic Length; Pubic Ht = Pubic Height; Pubic Wdt = Pubic Width; Ischial Lng = Ischial Length; Ob For Ht = Obturator Foramen Height; Ob For Wdt = Obturator Foramen Width; Ace Dia = Acetabulum Diameter; Ob For Index = Obturator Foramen Index; I/P Index = Ischiopubic Index; Ant Diag = Anterior Diagonal; Post Diag = Posterior Diagonal.

Table 3

Descriptive statistics of pelvic dimensions for white and black females. N=100 all groups.

Variable (mm)	White Females			Black Females		
	Mean	Range	SD	Mean	Range	SD
GSN Wdt L	48.83	34-72	5.78	43.35	28-58	5.82
GSN Wdt R	48.46	37-67	5.12	44.01	31-58	5.28
GSN Dpth L	25.11	15-39	3.24	22.41	15-34	3.29
GSN Dpth R	24.29	17-37	3.02	22.01	12-31	3.01
GSN Post Wdt L	22.23	11-37	5.02	17.06	4-31	5.10
GSN Post Wdt R	20.03	10-39	4.43	16.14	5-28	4.45
GSN Ant Wdt L	26.40	19-35	3.36	26.24	18-35	3.72
GSN Ant Wdt R	28.43	19-38	3.33	27.87	22-37	3.42
Iliac Br L	160.99	142-183	9.04	145.43	123-179	9.14
Iliac Br R	160.12	140-182	8.85	145.66	124-173	8.44
Total Ht L	207.13	173-235	10.48	190.87	168-248	10.97
Total Ht R	206.78	177-237	10.24	190.34	167-245	11.04
Pubic Lng L	102.21	89-114	5.56	93.31	81-117	5.43
Pubic Lng R	102.68	89-114	5.14	93.58	80-118	5.28
Pubic Ht L	40.15	32-50	4.18	36.40	24-47	3.76
Pubic Ht R	39.58	32-47	3.87	36.22	17-45	4.01
Pubic Wdt L	27.82	18-35	3.32	24.32	17-32	3.16
Pubic Wdt R	27.69	20-35	3.33	24.12	16-31	3.23
Ischial Lng L	100.69	88-115	4.78	95.63	82-126	6.19
Ischial Lng R	101.36	88-119	5.04	95.87	85-127	5.99
Obt For Ht L	50.74	42-60	3.74	48.95	41-64	3.64
Obt For Ht R	51.09	42-59	3.60	48.95	41-61	3.42
Obt For Wdt L	35.29	28-45	3.69	33.35	27-48	3.55
Obt For Wdt R	35.49	28-44	3.40	33.47	27-44	3.31
Ace Dia L	50.78	45-61	2.90	49.23	37-63	3.42
Ace Dia R	51.18	44-62	3.04	49.42	37-63	3.27

GSN Wdt = Width of Greater Sciatic Notch; GSN Dpth = Depth of Greater Sciatic Notch; GSN Post Wdt = Posterior Width of Greater Sciatic Notch; GSN Ant Wdt = Anterior Width of Greater Sciatic Notch; Iliac Br = Iliac Breadth; Total Ht = Total Height; Pubic Lng = Pubic Length; Pubic Ht = Pubic Height;Pubic Wdt = Pubic Width; Ischial Lng = Ischial Length; Ob For Ht = Obturator Foramen Height; Ob For Wdt = Obturator Foramen Width; Ace Dia = Acetabulum Diameter; Ob For Index = Obturator Foramen Index; I/P Index = Ischiopubic Index; Ant Diag = Anterior Diagonal; Post Diag = Posterior Diagonal.

Table 4

Means, standard deviations, and univariate F-ratios of pelvic measurements by sex in whites.

Variable (mm)	Male		Female		F Ratio
	Mean	SD	Mean	SD	
GSN Wdt L	43.03	4.99	48.83	5.78	59.71[b]
GSN Wdt R	43.95	4.92	48.46	5.12	40.97[b]
GSN Dpth L	26.55	2.99	25.11	3.24	9.49[b]
GSN Dpth R	26.16	3.06	24.29	3.02	17.37[b]
GSN Post Wdt L	15.56	4.24	22.23	5.02	113.20[b]
GSN Post Wdt R	14.61	4.07	20.03	4.43	85.15[b]
GSN Ant Wdt L	27.39	3.71	26.40	3.36	4.71[a]
GSN Ant Wdt R	29.55	4.17	28.43	3.33	4.76[a]
Iliac Br L	163.15	8.67	160.99	9.04	2.82
Iliac Br R	163.55	8.39	160.12	8.85	7.79[b]
Total Ht L	220.43	10.83	207.13	10.48	76.22[b]
Total Ht R	220.15	11.11	206.78	10.24	76.55[b]
Pubic Lng L	101.65	5.52	102.21	5.56	0.51
Pubic Lng R	102.00	5.38	102.68	5.14	0.82
Pubic Ht L	42.18	4.21	40.15	4.18	12.09[b]
Pubic Ht R	41.67	4.15	39.58	3.87	13.65[b]
Pubic Wdt L	23.91	2.73	27.82	3.32	83.03[b]
Pubic Wdt R	23.03	2.79	27.69	3.33	115.53[b]
Ischial Lng L	111.05	5.66	100.69	4.78	192.86[b]
Ischial Lng R	110.99	5.71	101.36	5.04	156.66[b]
Obt For Ht L	54.26	4.04	50.74	3.74	41.39[b]
Obt For Ht R	53.99	3.75	51.09	3.60	31.99[b]
Obt For Wdt L	34.44	3.54	35.29	3.69	2.44
Obt For Wdt R	34.60	3.16	35.49	3.40	3.36
Ace Dia L	55.80	3.09	50.78	2.90	138.64[b]
Ace Dia R	56.14	3.17	51.18	3.04	125.93[b]

[a]$p \leq 0.05$
[b]$p \leq 0.01$

Table 5

Means, standard deviations, and univariate F-ratios of pelvic measurements by sex in blacks.

Variable (mm)	Male		Female		F Ratio
	Mean	SD	Mean	SD	
GSN Wdt L	36.96	4.62	43.35	5.82	72.27[b]
GSN Wdt R	37.70	4.87	44.01	5.28	75.49[b]
GSN Dpth L	22.68	3.66	22.41	3.29	0.36
GSN Dpth R	22.46	3.66	22.01	3.01	0.99
GSN Post Wdt L	9.31	3.90	17.06	5.10	143.44[b]
GSN Post Wdt R	8.80	3.95	16.14	4.45	150.59[b]
GSNAnt Wdt L	27.63	3.89	26.24	3.72	6.56[a]
GSN Ant Wdt R	28.91	3.94	27.87	3.42	3.86
Iliac Br L	150.10	7.29	145.43	9.14	16.02[b]
Iliac Br R	150.78	7.69	145.66	8.44	20.32[b]
Total Ht L	203.93	9.64	190.87	10.97	78.64[b]
Total Ht R	203.60	9.67	190.34	11.04	80.36[b]
Pubic Lng L	93.26	4.69	93.31	5.43	0.00
Pubic Lng R	93.63	4.87	93.58	5.28	0.01
Pubic Ht L	38.98	3.48	36.40	3.76	25.29[b]
Pubic Ht R	38.68	3.28	36.22	4.01	22.65[b]
Pubic Wdt L	20.92	3.04	24.32	3.16	58.96[b]
Pubic Wdt R	20.74	2.87	24.12	3.23	60.27[b]
Ischial Lng L	104.36	4.78	95.63	6.19	125.50[b]
Ischial Lng R	104.20	4.57	95.87	5.99	122.55[b]
Obt For Ht L	51.46	3.87	48.95	3.64	22.41[b]
Obt For Ht R	51.25	4.06	48.95	3.42	18.76[b]
Obt For Wdt L	32.50	3.14	33.35	3.55	3.22
Obt For Wdt R	32.64	3.15	33.47	3.31	3.29
Ace Dia L	54.59	2.76	49.23	3.42	148.19[b]
Ace Dia R	54.65	2.75	49.42	3.27	148.58[b]

[a]$p \leq 0.05$
[b]$p \leq 0.01$

Table 6

Test of significance differences between left and right side values for whites and blacks (Student's t-Test: paired sample).

Pair	Variable (mm)	White t value		Black t value	
		Males	Females	Males	Females
1	GSN Wdt	-3.27[b]	1.15	-2.89[b]	-2.14
2	GSN Dpth	1.43	2.58[a]	0.73	1.43
3	GSN Post Wdt	2.86[b]	5.85[b]	1.77	2.89[b]
4	GSN Ant Wdt	-6.56[b]	-7.59[b]	-4.24[b]	-6.33[b]
5	Iliac Br	-1.57	2.85[b]	-2.69[b]	-0.98
6	Total Ht	1.15	1.65	1.65	2.73[b]
7	Pubic Lng	-1.63	-1.84	-1.56	-1.17
8	Pubic Ht	3.56[b]	2.84[b]	2.32[a]	1.01
9	Pubic Wdt	5.08[b]	0.61	1.00	1.19
10	Ischial Lng	0.30	-4.00[b]	0.91	-1.64
11	Obt For Ht	1.86	-1.98[a]	1.15	0.00
12	Obt For Wdt	-0.75	0.97	-0.84	-0.63
13	Ace Dia	-2.96[b]	-3.05[b]	-0.66	-2.12[a]

[a] $p \leq 0.05$
[b] $p \leq 0.01$

acetabulum diameter were highly significantly different between the two sides at $p \leq 0.01$ in white males. In white females even more asymmetries were observed. Significant asymmetries were found for the depth of sciatic notch, anterior/posterior width of sciatic notch, iliac breadth, pubic height, ischial length, obturator foramen height and acetabulum diameter.

Fewer asymmetries were found in blacks than in whites where only 4 of 13 dimensions were different in both sexes. Black males had asymmetries for the width of the sciatic notch, anterior width of sciatic notch; iliac breadth and pubic height, while black females differed significantly in posterior/anterior width of sciatic notch, total height and acetabulum diameter (Table 6).

Results showed that the occurrence of asymmetry is higher in whites than in blacks. Although asymmetry was observed, no particular side was observed to be considerably larger than the other. No consistent pattern in the asymmetries was observed.

There were no differences between left and right sides as far as the indices were concerned in both whites and blacks (Table 7). However, calculated variables for whites all proved significantly different between the two sides (Table 8). In black males, the anterior diagonal of the notch differed significantly at $p \leq 0.01$ while both anterior and posterior diagonals in black females were significantly different (Table 8).

Table 7

Test of significance differences between left and right side values of indices for both sex race groups (Student's t-Test: paired sample).

Variable (mm)	t
White Males	
Obt For Index	-1.47
I/P Index	-1.72
White females	
ObtFor Index	0.29
I/P Index	0.56
Black Males	
ObtFor Index	-1.53
I/P Index	-1.84
Black Females	
Obt For Index	-0.48
I/P Index	-0.18

Table 8

Test of significance differences between left and right side values of calculated variables for both sex race groups
(Student's t-Test: paired sample).

Variable (mm)	t
White Males	
Ant Diag	-5.18[a]
Post Diag	2.43[b]
White Females	
Ant Diag	-3.12[b]
Post Diag	5.31[b]
Black Males	
Ant Diag	-3.29[b]
Post Diag	1.05
Black Females	
Ant Diag	-4.11[b]
Post Diag	5.55[a]

[a] $p \leq 0.05$
[b] $p \leq 0.01$

Sex Differences

Table 9 shows the results of Student's t-Tests for determining whether significant differences exist between the sexes in whites. In this case only the left side of each bone was used. The iliac breadth, pubic length, and obturator foramen width were not found to differ significantly between the sexes. Sex differences between blacks were observed in all measurements with the exception of the depth of the greater sciatic notch, pubic length and obturator foramen width (Table 9).

Race Differences

Differences significant at $p \leq 0.001$ were found in all pelvic measurements between white and black males except in the anterior width of the greater sciatic notch (Table 10). As can be seen in Table 10 differences were observed between white and black females and the results the same. Ranges of the anterior width of the greater sciatic notch were almost identical for both black and white females.

Morphology

When looking at morphological characteristics, the male and female expression of each trait was quantified. The characteristic pubic bone shape for females is a rectangular form with males having a triangular shape. The presence of concavity in the subpubic region is associated with females while its absence is a male characteristic. The ischiopubic ramus ridge form has considerable roughness with noticeable eversion in males while the female form is more gracile with less eversion. The roughness due to muscle attachment was pronounced in males.

Table 9

Test of significance differences for measurements between white and black males and females (Student's t-Test).

Variable (mm)	Whites				Blacks			
	Male	Female	Mean Diff.	t	Male	Female	Mean Diff.	t
GSN Wdt	43.03	48.83	-5.80	-7.60[b]	36.96	43.35	-6.39	-8.60[b]
GSN Dpth	26.55	25.11	1.44	3.26[b]	22.68	22.41	0.27	0.54
GSN Post Wdt	15.56	22.23	-6.67	-10.16[b]	9.31	17.06	-7.75	-12.07[b]
GSN Ant Wdt	27.39	26.40	0.99	1.98[a]	27.63	26.24	1.39	2.58[a]
Iliac Br	163.15	160.99	2.16	1.72	150.10	145.43	4.67	4.00[b]
Total Ht	220.43	207.13	13.30	8.83[b]	203.93	190.87	13.06	8.94[b]
Pubic Lng	101.65	102.21	-0.56	-0.72	93.26	93.31	-0.05	-0.07
Pubic Ht	42.18	40.18	2.03	3.42[b]	38.98	36.40	2.58	5.03[b]
Pubic Wdt	23.91	27.82	-3.91	-9.10[b]	20.92	24.32	-3.40	-7.76[b]
Ischial Lng	111.05	100.69	10.36	13.99[b]	104.36	95.63	8.73	11.16[b]
Obt For Ht	54.26	50.74	3.52	6.40[b]	51.46	48.95	2.51	4.73[b]
Obt For Wdt	34.44	35.29	-0.85	-1.66	32.50	33.35	-0.85	-1.79
Ace Dia	55.80	50.78	5.02	11.84[b]	54.59	49.23	5.36	12.19[b]

[a] $p \le 0.05$
[b] $p \le 0.01$

Table 10

Test of significance differences for measurements between white and black males and females (Student's t-Test).

Variable (mm)	Males				Females			
	White	Black	Mean Diff.	t	White	Black	Mean Diff.	t
GSN Wdt	43.03	36.96	6.07	8.93[b]	48.83	43.35	5.48	6.68[b]
GSN Dpth	26.55	22.68	3.87	8.19[b]	25.11	22.41	2.70	5.84[b]
GSN Post Wdt	15.56	9.31	6.25	10.86[b]	22.23	17.06	5.17	7.22[b]
GSN Ant Wdt	27.39	27.63	-0.24	-0.45	26.40	26.24	0.16	0.32
Iliac Br	163.15	150.10	13.05	11.52[b]	160.99	145.43	15.56	12.07[b]
Total Ht	220.43	203.93	16.50	11.38[b]	207.13	190.87	16.26	10.72[b]
Pubic Lng	101.65	93.26	8.39	11.59[b]	102.21	93.31	8.90	11.45[b]
Pubic Ht	42.18	38.98	3.20	5.86[b]	40.15	36.40	3.75	6.67[b]
Pubic Wdt	23.91	20.92	2.99	7.33[b]	27.82	24.32	3.50	7.63[b]
Ischial Lng	111.05	104.36	6.69	9.03[b]	100.69	95.63	5.06	6.47[b]
Obt For Ht	54.26	51.46	2.80	5.01[b]	50.74	48.95	1.79	3.43[b]
Obt For Wdt	34.44	32.50	1.94	4.11[b]	35.29	33.35	1.94	3.79[b]
Ace Dia	55.80	54.59	1.21	2.92[b]	50.78	49.23	1.55	3.46[b]

[b] $p \leq 0.01$

The more medial orientation of the ischial tuberosity makes it visible from the front in females while the more posterior position in males makes it hard to see from the front. The sciatic notch has been previously described as wide in females and narrow in males. Here the observation of symmetry was added to assess variability.

Both sides were evaluated and the number of individuals associated with the expected trait was determined. The results appear in Table 11 for males and females. Black males were correctly sexed in 90 percent of individuals using all morphological characteristics except that of the pubic shape, where only 81 percent were correctly assigned. Subpubic concavity correctly assigned the highest percentage at 94 percent.

In white males the greater sciatic notch proved to be a very poor indicator, correctly assigning sex in 33 percent (left side) to 34 percent (right side) of cases. The best results were recorded for ischial tuberosity orientation at 96 percent. Pubic shape resulted in only 80 percent accuracy and the remaining characteristics were greater than 90 percent effective.

White females were correctly assigned greater than 90 percent of the time based on sciatic notch and pubis shape. These same two characteristics faired best in black females with 84 percent for the notch and 88 percent to 91 percent for pubis shape. Subpubic concavity resulted in accuracy of 84 percent and 85 percent.

Ischiopubic ramus form did not work well for either white or black females: the percentage of correctly assigned whites was 8-12 percent while blacks were only 19-20 percent. This indicates that the majority of females exhibited a male ischiopubic ramus form. It should be noted that

Table 11

Percent of correctly assigned males and females based on morphological characteristics for the left and right sides.

Characteristic	Males				Females			
	White		Black		White		Black	
	Lt	Rt	Lt	Rt	Lt	Rt	Lt	Rt
Shape of Sciatic Notch	33%	34%	91%	90%	96%	95%	84 %	84%
Subpubic Concavity	92%	91%	94%	93%	84%	85%	74%	76%
Ischiopubic Ramus Form	93%	95%	93%	91%	8%	12%	19%	20%
Ischial Tuberosity	96%	96%	92%	92%	39%	36%	40%	40%
Pubic Shape	80%	86%	81%	81%	96%	98%	88%	91%

none of the morphological traits worked as well for the black females as they did the white females, with the exception of pubic bone shape and greater sciatic notch width.

The frequency distribution for the shape of the greater sciatic notch for both sexes of whites and blacks appears in Table 12. A wide, symmetrical sciatic notch appears more prevalent in white females with 83 percent and 79 percent for left and right sides respectively. The narrow asymmetrical notch appears most frequently in black males with 73 percent being correctly assigned. The narrow symmetrical notch is the rarest form in both sexes and races followed by the wide asymmetrical notch.

The notch shape in whites is most often wide. This was the case in both males and females. White males had wide asymmetrical notches while most of the females had wide symmetrical notches. However, the overlap between the sexes is so great that this trait is of little practical use. In contrast black males tended to be narrow and the females wide with both differing in shape and symmetry.

Chi^2 test showed differences between the sexes for whites and blacks highly significant ($p \leq 0.001$) for all 5 morphological characteristics except for the sub pubic concavity in blacks ($p \leq 0.01$) (Table 13). Differences between the races for males and females using the Chi^2 test can be found in Table 14. All characteristics were highly significant in males ($p \leq 0.001$) while females were highly significant ($p \leq 0.001$) for all characters with the exception of the orientation of the ischial tuberosity which was found significant at ($p \leq 0.01$).

Table 12

Distribution of shape of the greater sciatic notch for whites and blacks (N=100 each group).

Character	Side	White		Black	
		Male	Female	Male	Female
Wide asymmetrical	Lt	26	13	6	26
	Rt	27	16	5	29
Wide symmetrical	Lt	41	83	3	58
	Rt	39	79	5	55
Narrow asymmetrical	Lt	18	2	73	11
	Rt	21	3	73	11
Narrow symmetrical	Lt	15	2	18	5
	Rt	13	2	17	5

Table 13

Chi^2 test of significance of morphologic sex differences between white males and females and black males and females.

Characteristic	Chi^2	Degr. of freedom	Signif.
Whites			
Arc shape of sciatic notch	151.72	3	0.001
Sub pubic concavity	93.37	2	0.001
Ischiopubic ramus form	304.69	2	0.001
Orientation of ischial tuberosity	64.98	1	0.001
Pubic bone shape	106.21	2	0.001
Blacks			
Arc shape of sciatic notch	46.60	3	0.001
Sub pubic concavity	8.00	1	0.005
Ischiopubic ramus form	245.83	2	0.001
Orientation of ischial tuberosity	54.08	1	0.001
Pubic bone shape	86.47	2	0.001

Table 14

Chi^2 test of significance of morphologic race differences between white and black males and white and black females.

Characteristic	Chi^2	Degr. of freedom	Signif.
Males			
Arc shape of sciatic notch	46.60	3	0.001
Sub pubic concavity	321.16	2	0.001
Ischiopubic ramus form	320.68	2	0.001
Orientation of ischial tuberosity	154.88	1	0.001
Pubic bone shape	203.68	2	0.001
Females			
Arc shape of sciatic notch	232.40	3	0.001
Sub pubic concavity	199.69	2	0.001
Ischiopubic ramus form	234.67	2	0.001
Orientation of ischial tuberosity	8.82	1	0.003
Pubic bone shape	310.84	2	0.001

Indices and Calculated Variables

Mean values for the indices of white males are less than those of white females (Table 15). In the case of calculated variables, the left and right anterior diagonal values in white males are larger than the corresponding values in females (Table 16). This is to be expected since males have a greater depth than females.

In contrast, the posterior diagonal is greater in the females, which can be attributed to by the greater posterior width of the female notch as well as overall greater width. The same holds true for the relationship between indices and calculated variables in blacks (Table 17 and 18). Indices for whites and blacks were found to be significantly different between the sexes at $p \leq 0.01$ (Table 19). Calculated variables displayed similar results with the exception of the anterior diagonal being significantly different at $p \leq 0.05$ (Table 20). Mean values of indices and calculated variables were found to be significantly different ($p \leq 0.01$) between the sexes for both whites and blacks (Table 19 and 20).

The ischiopubic index was found to be significantly different between white and black males and females (Table 21). Calculated variables were all significant at $p \leq 0.001$ for males and females (Table 22).

The ranges of both indices were not found to be of practical value as sex indicators. The categories were determined from the ranges as explained in the Materials and Methods section. Using the ischiopubic index for whites as an example, values below 87 fall into the male range. The female range is 107 and greater. The range from 88 to 106 is overlapping between the sexes.

Table 15

Obturator foramen and ischiopubic indices of whites.

Variable (mm)	Male			Female			F Ratio
	Mean	Range	SD	Mean	Range	SD	
Obt For Index L	63.57	44.83- 82.76	5.60	69.69	46.67- 88.89	6.71	48.65[b]
Obt For Index R	64.21	43.86- 82.69	5.46	69.56	54.72- 81.48	5.75	46.61[b]
I/P Index L	91.62	83.49-105.94	4.39	101.57	88.35-112.63	4.43	255.28[b]
I/P Index R	92.01	83.05-104.90	4.68	101.40	88.24-109.71	4.51	207.78[b]

[b] $p \leq 0.01$

Table 16

Calculated variables for whites.

Variable (mm)	Male			Female			F Ratio
	Mean	Range	SD	Mean	Range	SD	
Ant Diag L	38.30	31.76-47.38	3.27	36.60	28.32-45.45	3.10	14.22[b]
Ant Diag R	39.64	30.48-53.34	3.60	37.53	30.48-45.97	3.10	19.14[b]
Post Diag L	30.96	18.97-39.66	3.91	33.70	18.60-47.73	4.94	22.24[b]
Post Diag R	30.15	19.92-39.36	3.76	31.68	24.19-49.82	4.05	8.30[b]

[b] $p \leq 0.01$

Table 17

Obturator foramen and ischiopubic indices of blacks.

Variable (mm)	Male			Female			F Ratio
	Mean	Range	SD	Mean	Range	SD	
Obt For Index L	63.29	47.37- 78.26	5.62	68.22	57.14- 92.31	6.28	34.27[b]
Obt For Index R	63.89	45.00- 78.72	6.25	68.45	55.10- 80.43	5.64	29.24[b]
I/P Index L	89.43	77.59-106.74	3.92	97.70	80.36-106.38	4.24	204.65[b]
I/P Index R	89.90	82.30-109.78	3.87	97.75	83.64-107.78	4.53	172.16[b]

[b]$p \leq 0.01$

Table 18

Calculated variables for blacks.

Variable (mm)	Male			Female			F Ratio
	Mean	Range	SD	Mean	Range	SD	
Ant Diag L	35.98	27.46- 46.32	3.45	34.69	26.91- 43.42	3.49	7.01[b]
Ant Diag R	36.82	28.28- 48.41	3.67	35.64	27.73- 46.75	3.41	5.53[a]
Post Diag L	24.70	13.42- 41.79	4.40	28.43	17.00- 42.45	4.65	32.92[b]
Post Diag R	24.34	16.12- 39.29	4.27	27.52	16.12- 38.90	4.02	28.52[b]

[a]$p \leq 0.01$
[b]$p \leq 0.01$

Table 19

Test of significance for indices of white and black males and females.

Variable (mm)	White				Black			
	Male	Female	Mean Difference	t	Male	Female	Mean Difference	t
Obt For Index L	63.57	69.69	-6.13	-7.01[b]	63.29	68.22	-4.93	-5.85[b]
I/P Index L	91.62	101.57	-9.95	-15.94[b]	89.43	97.70	8.73	11.16[b]

[a] $p \leq 0.05$
[b] $p \leq 0.01$

Table 20

Test of significance differences for calculated variables of white and black males and females.

Variable (mm)	White				Black			
	Male	Female	Mean Difference	t	Males	Female	Mean Difference	t
Ant Diag	38.30	36.60	1.70	3.78[b]	35.98	34.69	1.29	2.63[b]
Post Diag	30.96	33.70	-2.74	-4.36[b]	24.70	28.43	-3.73	-5.83[b]

[b] $p \leq 0.01$

Table 21

Test of significance differences for indices between white and black males and females (Student's t-Test).

Variable	Males				Females			
	White	Black	Mean Difference	t	White	Black	Mean Difference	t
Obt For Index L	63.57	63.29	0.28	0.34	69.69	68.22	1.47	1.60
I/P Index L	91.62	89.43	2.19	3.73[b]	101.57	97.70	3.87	6.31[b]

[b]$p \leq 0.01$

Table 22

Test of significance differences for calculated variables between white and black males and females (Student's t-Test).

Variable (mm)	Males				Females			
	White	Black	Mean Difference	t	White	Black	Mean Difference	t
Ant Diag	38.30	35.98	2.33	4.89[b]	36.60	34.69	1.91	4.10[b]
Post Diag	30.96	24.70	6.26	10.63[b]	33.70	28.43	5.27	7.77[b]

Thus, if the value of an unknown skeleton falls into this range, sex is indeterminate. The overlap in whites for the obturator foramen index and ischiopubic index were 99 percent and 86.5 percent respectively (Table 23). The obturator foramen index in blacks had an indeterminate range of 94 percent while the ischiopubic index was also of no practical use (Table 23).

Table 23

Accuracy for the ranges of indices for whites and blacks.

Variable	Male	Indeterminate	Female
Whites			
Obt For Index	x -46 (0.5%)	47 – 83 (99%)	84 – x (0.5%)
I/P Index	x-87 (7.5%)	88 – 106 (86.5%)	107 – x (6%)
Blacks			
Obt For Index	x – 56 (4%)	57 – 78 (94%)	79 – x (2%)

Chapter V

Discriminant Function Analysis

Introduction

To make the results of the metric analysis applicable, a discriminant function analysis was done. This procedure produces formulae which are easy to use by just substituting values into an appropriate equation. Numerous authors, while focusing on various bones throughout the skeleton, have previously studied discriminant function analysis. For instance, North American blacks and whites [47,48,71,72,93,123], South African whites [54,55], South African whites and blacks [56], Chinese [103,124] and on a New Zealand Polynesian population [125] has undergone discriminant function analysis.

Methods

All dimensions were entered into a stepwise discriminant function procedure using the Wilks' lambda, to determine which variable provided the best discrimination between the sexes (with F = 3.84 to enter and F = 2.71 to remove). Stepwise analysis is when all pelvic dimensions are used and are systematically added and removed from the list once the first variable is selected it is removed from the analysis and the remaining variables are reassessed and selected [54]. A stepwise analysis was also performed on a series of measurements which were grouped together as seen in Table 24 Functions 2, 3 and 4. In addition, a direct discriminant function analysis was performed to produce a demarking point between the sexes. A direct analysis involves entering the variables, which one wants to know the outcome. A single dimensioned was entered in the cases of the

Table 24

Stepwise Discriminant Function analysis of pelvic dimensions for white South Africans.

Step	Variables (mm) entered	Wilks' lambda	Degr. Freedom
Function 1 (all dimensions)			
1	Ischial Lng	0.503	197
2	Pubic Wdt	0.347	196
3	GSN Post Wdt	0.312	195
4	Pubic Lng	0.292	194
5	Pubic Ht	0.283	193
6	GSN Dpth	0.276	192
Function 2 (Greater Sciatic Notch)			
1	GSN Post Wdt	0.658	198
2	GSN Dpth	0.537	197
Function 3 (Total bone measurements)			
1	Total Ht	0.720	197
2	Iliac Br	0.623	196
Function 4 (Pubis)			
1	Pubic Wdt	0.705	198
2	Pubic Lng	0.664	197

ischial length and acetabulum diameter, to make the results usable on fragmentary remains.

To measure the effectiveness of the functions, a "leave one out" classification procedure was applied to measure the accuracy of the multivariate classification. This procedure classifies each individual bone by the functions derived from all cases other than that case itself. This process continues for all individual bones, one by one, until they are all tested. The accuracy of assignments to either male or female categories are thus cross-validated. Multivariate classification provides an understanding of within sample assignments of every case, but the actual affinity of a particular individual is best assessed by its posterior probability to be reassigned to its original group [126]. Higher posterior probabilities confirm the percentage accuracy of an individual's affinity with the reference population. Posterior probabilities were thus calculated for all the functions.

Standardized coefficients are values which indicate how a particular dimension contributes to the overall classification. Structure coefficients are the simple product moment correlations between the variables and the function. To calculate the discriminant score, each dimension is multiplied by its raw (unstandardized) coefficient, which weights the variable according to its contribution to race differences. These values are then added together along with the constant. The constant has no inherent value and only serves to calibrate the sectioning point to zero if the number of cases in both groups are the same. When group numbers are different the sectioning point must be calculated by averaging the two group centroids.

The discriminant score is then compared with the sectioning point (the average of two centroids) [52].

Posterior probability of correct group membership increases with distance from the sectioning point. Discriminant function classification is based on whether the discriminant score of a given individual is above or below the sectioning point. However, posterior probability provides information about the probability of an individual to be reassigned to its original group [52].

Differences between sexes

Table 24 shows results of the stepwise discriminant function analysis of the pelvic dimensions in whites. All 13 pelvic dimensions were entered for Function 1 (width of notch, depth of notch, posterior/anterior width of greater sciatic notch, iliac breadth, total height, pubic length/height/width, ischial length, obturator foramen width/height, acetabulum diameter). Six measurements were selected: ischial length was selected first, followed by pubic length, greater sciatic notch posterior width, pubic length, pubic height, greater sciatic notch depth. Ischial length was chosen as the most sexually discriminating variable. In the next step a stepwise analysis was done entering the four greater sciatic notch measurements (greater sciatic notch width, depth and anterior/ posterior width). Two of the four greater sciatic notch measurements were chosen namely the greater sciatic notch posterior width and depth. In Function 3, total bone measurements namely total height and iliac breadth were entered- both values were chosen with total height of the os coxae as the best discriminator between the sexes. Two of the pubic measurements were picked for Function 4. Pubic width was chosen best overall. In all of these Functions, the Wilks' Lambda values reflect the order in which variables are chosen.

The stepwise discriminant function analysis of pelvic measurements in blacks is found in Table 25. Nine values were chosen for Function 1, with acetabulum diameter being selected as the best discriminator. However, once ischial length (step 4) was selected, the acetabular diameter (step 5) was removed. This is probably due to the fact that most of the contribution of the acetabular diameter is accounted for by the ischial length. In calculating the coefficients, the acetabular diameter was no longer included (Table 26). The greater sciatic notch measurements (Function 2) yielded the same results as in whites with the same variables chosen. Both total bone measurements (total height, iliac breadth) were chosen for Function 3. Similarly to what was found in whites, total height was chosen over iliac breadth. In Function 4 pubis width and height were chosen as the best pubic bone measurements from the dimensions entered (pubic length, pubic width/height) for determining sex in blacks.

Coefficients, group centroids and sectioning points appear in Table 26 for whites and Table 27 for blacks. The sectioning point (zero if sample sizes are equal) is the average of the two centroids when the sample sizes for the dimensions are not equal. Since a small number of the white individuals used missed a single measurement, the sectioning point in Functions 1 and 3 is not zero. Discriminant scores can be calculated from here. The discriminant score is calculated by multiplying the value for each

Table 25

Stepwise Discriminant Function analysis of pelvic dimensions for black South Africans.

Step	Variables (mm) entered	Wilks' lambda	Degr. Freedom
Function 1 (all dimensions)			
1	Ace Dia	0.571	198
2	GSN Post Wdt	0.409	197
3	Pubic Wdt	0.372	196
4	Ischial Lng	0.346	195
5	Ace Dia (removed)	0.350	194
6	Pubic Lng	0.329	193
7	Total Ht	0.318	192
8	GSN Wdt	0.311	191
9	Obt For Wth	0.303	190
Function 2 (Greater Sciatic Notch)			
1	GSN Post Wdt	0.576	198
2	GSN Dpth	0.517	197
Function 3 (Total bone measurements)			
1	Total Ht	0.712	198
2	Iliac Br	0.671	197
Function 4 (Pubis)			
1	Pubic Wdt	0.767	198
2	Pubic Ht	0.687	197

Table 26

Canonical discriminant function coefficients for pelvic dimensions of white South Africans.

Functions and Variables (mm)	Standard coeff.	Structure coeff.	Unstandardized coefficient	Centroids
Function 1 (all dimensions)				
GSN Dpth	-0.204	-0.143	-0.065	M= -1.602
GSN Post Wdt	0.426	0.456	0.092	F= 1.618
Pubic Lng	0.327	0.030	0.059	
Pubic Ht	0.243	-0.153	0.058	
Pubic Wdt	0.497	0.402	0.163	
Ischial Lng	-0.984	-0.614	-0.188	
Constant			7.173	
Sectioning Point*			0.008	
Function 2 (Greater Sciatic Notch)				
GSN Dpth	-0.690	0.778	-0.221	M= -0.923
GSN Post Wdt	1.106	-0.250	0.229	F= 0.923
Constant			1.387	
Sectioning Point*			0	
Function 3 (Total bone measurements)				
Iliac Br	-0.853	0.158	-0.096	M= 0.770
Total Ht	1.413	0.803	0.132	F= -0.778
Constant			-12.680	
Sectioning Point			0.004	
Function 4 (Pubis)				
Pubic Lng	-0.478	-0.269	-0.086	M= -0.708
Pubic Wdt	1.139	0.908	0.375	F= 0.708
Constant			-0.901	
Sectioning Point*			0	

* Values larger than sectioning point indicate female
** Values Larger than sectioning point indicate male

Table 27

Canonical discriminant function coefficients for pelvic dimensions of black South Africans.

Functions and Variables (mm)	Standard coeff.	Structure coeff.	Unstandardized coefficient	Centroids
Function 1 (all dimensions)				
GSN Wdt	0.337	0.403	0.064	M= -1.511
GSN Post Wdt	0.252	0.565	0.055	F= 1.511
Total Ht	-0.520	-0.419	-0.050	
Pubic Lng	0.427	0.003	0.084	
Pubic Wdt	0.443	0.363	0.143	
Ischial Lng	-0.618	-0.523	-0.112	
Obt For Wdt	0.229	0.084	0.068	
Constant			4.479	
Sectioning Point*			0	
Function 2 (Greater Sciatic Notch)				
GSN Dpth	-0.509	-0.040	-0.146	M= -0.961
GSN Post Wdt	1.104	0.888	0.243	F= 0.961
Constant			0.093	
Sectioning Point*			0	
Function 3 (Total bone measurements)				
Iliac Br	-0.633	0.406	-0.077	M= 0.696
Total Ht	1.384	0.908	0.134	F= -0.696
Constant			-15.132	
Sectioning Point**			0	
Function 4 (Pubis)				
Pubic Wdt	0.850	0.816	0.274	M= -0.672
Pubic Ht	-0.580	-0.530	-0.160	F= 0.672
Constant			-0.172	
Sectioning Point*			0	

* Values larger than sectioning point indicate female

** Values Larger than sectioning point indicate male

dimension by its raw (unstandardized coefficient). The products are added together along with the constant read from the table for the particular function. The discriminant score is then compared with the sectioning point. For example, a white individual had a depth of greater sciatic notch as 19 mm and a posterior width of the notch as 13 mm the calculation would be: [-(19 x 0.221) + (13 x 0.229)] + 1.387 = 0.165 (Table 27, Function 2). The result is greater than that of the sectioning point (zero) thus indicating a female. With the exception of total bone measurements, all values higher than the sectioning point indicate female.

The direct discriminant function analysis using the ischial length (Function 1) and acetabulum diameter (Function 2) were preformed for whites and blacks (Table 28). These two dimensions were singled out to do a direct analysis because ischial length was chosen as best discriminator of sex in whites and acetabulum diameter was chosen as best in blacks. Discriminant function coefficients for the direct analysis for whites and blacks are found in Table 29. In this table demarking points are given. Using this no calculations are required to determine sex and all that is needed is comparison with a demarking point. This direct analysis allows sex determination to take place when dealing with incomplete remains.

Percent of correct group membership is found in Table 30. Pelvic dimensions recorded high accuracies in Function 1 reaching 97 percent in white females and 93 percent in white males, 96 percent in black males and 93 percent in black females. The sciatic notch and ischial length reported good accuracies. Notch accuracies ranged from 81 to 83 percent in whites and 80 to 89 percent for blacks. Ischial length achieved 85 to 87 percent in

Table 28

Direct analysis of pelvic dimensions for white and black South Africans.

	Variables (mm) entered	Wilks' lambda	Degrees of Freedom
Whites			
Function 1			
	Ischial Lng	0.503	199
Function 2			
	Ace Dia	0.585	199
Blacks			
Function 1			
	Ischial Lng	0.614	199
Function 2			
	Ace Dia	0.571	199

Table 29

Canonical discriminant function coefficients for direct analysis of pelvic dimensions for white and black South Africans.

Functions and Variables (mm)	Standard coeff.	Structure coeff.	Unstandardized coefficient	Centroids
Whites				
Function 1 (Ischium)				
Ischial Lng	1.000	1.000	0.191	M= 0.989
Constant			-20.216	F= -0.989
Sectioning Point**			0	
Demarking Point			Female < 105.87< Male	
Function 2 (Acetabulum)				
Ace Dia	1.000	1.000	0.334	M= 0.837
Constant			-17.778	F= -0.837
Sectioning Point**			0	
Demarking Point			Female < 53.29 < Male	
Blacks				
Function 1 (Ischium)				
Ischial Lng	1.000	1.000	0.181	M= 0.789
Constant			-18.083	F= -0.789
Sectioning Point**			0	
Demarking Point			Female < 100 < Male	
Function 2 (Acetabulum)				
Ace Dia	1.000	1.000	0.322	M= 0.862
Constant			-16.696	F= -0.862
Sectioning Point**			0	
Demarking Point			Female < 51.91 < Male	

* Values larger than sectioning point indicate female
** Values Larger than sectioning point indicate male

Table 30

Percentage of correct group membership and crossvalidation for white and black South Africans.

Functions	Predicted group membership			
	Whites		Blacks	
	Males N	Females N	Males N	Females N
Stepwise				
Original	93/100	97/100	96/100	93/100
Crossvalidated	93/100	97/100	96/100	92/100
Sciatic Notch				
Original	83/100	81/100	89/100	80/100
Crossvalidated	82/100	78/100	89/100	80/100
Total Bone				
Original	80/100	79/100	76/100	81/100
Crossvalidated	80/100	79/100	76/100	81/100
Pubis				
Original	79/100	74/100	69/100	75/100
Crossvalidated	79/100	74/100	69/100	75/100
Ischial Length				
Original	85/100	87/100	87/100	81/100
Crossvalidated	85/100	87/100	83/100	81/100
Acetabulum				
Original	77/100	86/100	89/100	78/100
Crossvalidated	77/100	86/100	89/100	78/100

whites and 81 to 87 percent in blacks. Acetabular diameter classified 86 percent of females and 77 percent of males for whites and 78 percent of females and 89 percent of males for blacks. Total bone measurements consisting of total height and iliac breadth classified 80 percent of white males and 79 percent of white females while blacks achieved 76 percent and 81 percent respectively. Pubic bone was awarded the lowest percentage at 69 percent for black males, however females achieved 75 percent accuracy. In whites pubic bone measurements correctly assigned 74 percent and 79 percent of females and males respectively.

Crossvalidation classifications for both races and sex groups are contained in Table 30. Black females lost 1 percent in cross validation when using all dimensions (Function 1). In sciatic notch cross validation white females decreased by 3 percent and males by 1 percent. With crossvalidation of the direct analysis of the ischial length in black males, 5 percent were wrongly assigned.

The posterior probability of correct group membership was determined and results recorded in Table 31. The posterior probability shows with what degree of probability individuals were awarded their group membership. Function 1 received the highest posterior probability with 97 percent of whites and 95 percent of blacks correctly with posterior probabilities greater than 0.80 or 80 percent. In the case of the greater sciatic notch, 71 to 75 percent had a posterior probability of more than 80 percent to be assigned to the correct group. The majority of the individuals had 80 percent or more posterior probability to be correctly assigned, while no one was classified with less than 40 percent posterior probability.

Table 31

Percentage of posterior probability intervals of correct classification of sex.

Posterior	Whites				Blacks			
Probability	Males		Females		Males		Females	
Intervals	N	%	N	%	N	%	N	%
Stepwise Function								
0.00-0.19	-	-	-	-	-	-	-	-
0.20-0.39	-	-	-	-	-	-	-	-
0.40-0.59	1	1.1	-	-	-	-	2	2.2
0.60-0.79	2	2.2	3	3.1	5	5.2	3	3.2
0.80-1.00	90	96.8	94	96.9	91	94.8	88	94.6
Sciatic Notch								
0.00-0.19	-	-	-	-	-	-	-	-
0.20-0.39	-	-	-	-	-	-	-	-
0.40-0.59	2	2.4	5	6.3	2	2.3	5	6.3
0.60-0.79	22	26.8	15	19	21	24.4	18	22.8
0.80-1.00	58	70.7	59	74.7	63	73.3	56	70.9
Total Bone								
0.00-0.19	-	-	-	-	-	-	-	-
0.20-0.39	-	-	-	-	-	-	-	-
0.40-0.59	2	2.4	4	5.2	9	12.2	8	10.3
0.60-0.79	24	28.9	21	27.3	27	36.5	29	37.2
0.80-1.00	57	68.7	53	68.8	38	51.4	41	52.6
Pubis								
0.00-0.19	-	-	-	-	-	-	-	-
0.20-0.39	-	-	-	-	-	-	-	-
0.40-0.59	8	10.5	7	9.6	10	14.9	8	10.8
0.60-0.79	27	35.5	20	27.4	24	35.8	23	31.1
0.80-1.00	41	53.9	46	63	33	49.3	43	58.1
Ischium								
0.00-0.19	-	-	-	-	-	-	-	-
0.20-0.39	-	-	-	-	-	-	-	-
0.40-0.59	4	4.7	4	4.6	12	13.6	5	6.1
0.60-0.79	20	23.5	12	13.8	31	35.2	26	31.7
0.80-1.00	61	71.8	71	81.6	45	51.1	51	62.2
Acetabulum								
0.00-0.19	-	-	-	-	-	-	-	-
0.20-0.39	-	-	-	-	-	-	-	-
0.40-0.59	-	-	11	12.6	10	11.2	-	-
0.60-0.79	8	12.7	24	27.6	27	30.3	28	35.9
0.80-1.00	55	87.3	52	59.8	52	58.4	50	64.1

Differences between races

The stepwise discriminant function analysis was preformed to differentiate between the races by entering all pelvis dimension (width of notch, depth of notch, posterior/anterior width of greater sciatic notch, iliac breadth, total height, pubic length/height/width, ischial length, obturator foramen width/height, acetabulum diameter) into Function 1. Pubic length was chosen first from all the pelvic dimensions as the best discriminator for males. Posterior width of the greater sciatic notch was second, followed by total height and acetabulum diameter (Table 32). Of pelvic dimensions for discriminating race in females, iliac breadth was selected first followed by posterior width of the greater sciatic notch, pubic length, and acetabulum diameter (Table 32). Coefficients and sectioning points appear in Table 33 for males and females. Discriminant scores can be calculated using these tables. A value greater than that of the sectioning point (zero) is considered white and values below black.

Eighty-two to 89 percent of individuals were correctly assigned to their original race group (Table 34). With crossvalidation, only one white male was lost. The posterior probability of correct group membership was determined and results recorded in Table 35. The majority of the individuals had 80 percent or more posterior probability to be correctly assigned, while no one was classified with less than 40 percent posterior probability. It therefore seems possible to determine racial affinity by using pelvis diameters, but this aspect will need further investigation.

Table 32

Stepwise Discriminant function analysis of pelvic dimensions for white and black South African males and females.

Step	Variables (mm) entered	Wilks' lambda	Degrees of Freedom
Males			
Function 1 (all dimensions)			
1	Pubic Lng	0.596	198
2	GSN Post Wdt	0.457	197
3	Total Ht	0.433	196
4	Ace Dia	0.421	195
Females			
Function 1 (all dimensions)			
1	Iliac Br	0.575	197
2	GSN Post Wdt	0.535	196
3	Pubic Lng	0.504	195
4	Ace Dia	0.476	194

Table 33

Canonical discriminant function coefficients for pelvic dimensions of white and black South African males and females.

Functions and Variables (mm)	Standard coeff.	Structure coeff.	Unstandardize d coefficient	Centroids
Males				
Function 1 (all dimensions)				
GSN Post Wdt	0.575	0.658	0.141	W= 1.166
Total Ht	0.573	0.690	0.056	B= -1.166
Pubic Lng	0.391	0.703	0.076	
Ace Dia	-0.276	0.177	-0.094	
Constant			-15.858	
Sectioning Point			0	
Females				
Function 1 (all dimensions)				
GSN Post Wdt	0.303	0.501	0.060	W= 1.050
Iliac Br	0.591	0.819	0.065	B= -1.039
Pubic Lng	0.596	0.771	0.108	
Ace Dia	-0.418	0.230	-0.132	
Constant			-15.145	
Sectioning Point			0.005	

Table 34

Percentage of correct group membership and crossvalidation for male and female South Africans.

Functions	Predicted group membership			
	Males		Females	
	White N	Black N	White N	Black N
Stepwise				
Original	87/100	89/100	82/100	88/100
Crossvalidated	86/100	89/100	82/100	88/100

Table 35

Percentage of posterior probability intervals of correct classification of race.

Posterior Probability Intervals	Males				Females			
	Whites		Blacks		Whites		Blacks	
	N	%	N	%	N	%	N	%
All Measurements								
0.00-0.19	-	-	-	-	-	-	-	-
0.20-0.39	-	-	-	-	-	-	-	-
0.40-0.59	3	3.4	-	-	3	3.6	6	6.8
0.60-0.79	18	20.7	14	15.7	13	15.6	14	15.9
0.80-1.00	66	75.9	75	84.3	67	80.7	68	77.2

CHAPTER VI

DISCUSSION

Population specific standards, especially metric, need to be developed for accurate sex determination. The results of this research show that there are significant differences in the expression of sexual dimorphism in races between the South African whites and blacks. It should, however, be kept in mind that the individuals used in this study mostly originated from the Gauteng area. Although there is no reason to expect that these individuals are not representative of the South African population as a whole, the results of this study need to be tested on other South African groups.

Metric Differences between the sexes

On average, metric differences between the sexes were more pronounced in whites than in blacks. Pubic bone height was larger in males than females for both whites and blacks. A sample of 100 pubic bones from autopsies observed mean height in males 39.1 mm mean and females 34.2 mm consistent with the findings of this research [91]. American Indians of the Southwest average 36.3 mm and 34.1 mm in males and females respectively [127]. Howells and Hotelling [127] tabulated comparisons with Europeans and Japanese where males were also larger. Day and Pitcher-Wilmott [97] investigated 60 os coxae of European origin and observed 36.4 mm and 33.0 mm for pubic bone height in males and females respectively. The South Africans studied here yielded consistent results with findings in other populations. There is, however, clear variation in the magnitude of the difference between sexes. In Indian there was only 2 mm in absolute sex difference for pubic height. In Suri and Tandon's [91] sample there was a 5 mm difference between mean values. South African whites and blacks were similar to Indian with just over 2 mm difference between the sexes.

The pubic bone was significantly wider in females than males for both races (Table 9). Luo [103] found of the 122 known sex adult skeletons from the Human Identification Laboratory, University of Arizona that the male mean was 22.3 mm and female mean was 27.7 mm. This research found accuracy of 84.4 percent for pubic width using a sectioning point (the mean of the male and female means). Day and Pitcher-Wilmott [97] used a variation of the measurement used in this study (measured half way down the pubic symphysis to the edge of the obturator foramen) and found significant differences ($p \leq 0.05$) between the sexes.

The vast majority of the previous studies have used the measurement of pubic length as defined by Schultz [117] [e.g., [50,57,84,88,96]. Their pubic length was defined as the distance from the point in the acetabulum where the ilium, ischium, and pubis meet to the superior point of the pubic symphysis. Although the measurement of pubic length used here was not the standard one, females were still larger. Segebarth-Orban [87] used the centre of the acetabulum and found females to have larger pubic bones than males, but not significantly. Day and Pitcher-Wilmott [97] used the border of the pubic symphysis to the nearest point on the acetabulum. They also observed only marginal differences between males and females. Day and Pitcher-Wilmott [97] also found females to have a length of 66.5 mm for females and 66.3 mm for males and significantly different at p>0.5. In this study white males had a length of 101.65 mm and females 102.21 mm: black males were 93.26 mm and females 93.31 mm. Since the new measurement used in the current study, achieved similar results to the majority of others, one can assume variations in the method for measuring pubic length can produce similar results although the exact numbers are not comparable. The advantage of the method used here is that it has clear landmarks and is easily repeatable.

Three measurements were shared in this research with those of a previous study by Washburn [57] on a Bantu and Bush race in South African: pubic and ischial length and greater sciatic notch width. All mean values for measurements were larger in the population sampled here for both males and females.

The obturator foramen height and width were measured in similar fashion to the present study by Day and Pitcher-Wilmott [97] and Orford [128] with analogous results. Females were smaller in height than males, but larger in width, yet the difference between height and width measurements was smaller in females. Metric results can be used to visualize the morphology of the foramen and confirms that females obturator foramina are smaller, more triangular or circular in shape while those of males are larger and most often ovoid in shape.

Acetabulum diameter is obviously correlated with femur head diameter. It was significantly larger for whites than blacks. Male values were found significantly larger than female values as previously found [49,97,125,129]. Femur head diameter dimorphism has been examined in South African whites and sexing accuracies of 86 to 91 percent were obtained [54]. Rogers [33] achieved accuracy levels of 91.7 percent using the acetabulum diameter. The results of the present work were lower with accuracies of, 77 to 86 percent in whites and 78 to 89 percent for blacks (Table 30). Rogers [33] also noted accuracies varied with age intervals, in the less than 25 age group 87.5 percent, 25 to 44 100 percent and 45 plus 88 percent. The majority of the present sample fell into the greater than 50 age interval (Table 1). MacLaughlin and Bruce [129] also found male means to be significantly greater than female means. They also reported population differences, the Dutch sample was found to be significantly larger than the English. They calculated and achieved 81.7 to 85.9 percent accuracies in the English sample compared to 74.3 to 84.8 percent in the Dutch sample.

Ischial length has also been the subject of many studies. Like the measurement of pubis length, this measurement was modified to improve consistency in this study. Previous work found ischial lengths to be significantly larger in males than females for populations of American Whites and Negroes, Eskimo's and Japanese [50,84,88,96,106]. Results of in this study correspond to earlier findings (males larger than females/ whites larger than blacks). Ranges in ischial length for white males were 96 mm to 124 mm, black males 89 mm to 116 mm, white females 88 mm to 115 mm, and black females 82 mm to 126 mm (Tables 2 and 3). For blacks the female range completely overlaps the males. Regardless of the ranges statistical analysis found ischial lengths highly significant ($p \leq 0.001$) between sexes and races and, therefore, it is a functional measurement for sex determination.

Iliac breadth and total height of the os coxae were described as the total bone measurements in this research. The present, as well as previous studies, have shown iliac breadth to be significantly wider in males than females [87,96]. Other aspects of the iliac crest have also been examined for their use in sexing human skeletal remains [30]. Total height means were also found significantly larger in males than females [47,85,87]. These results are understandable since males in a given population are usually more robust.

Width of the greater sciatic notch was significantly larger in females than males as previously found by other researchers [47,57,83,83,85-87,94,97,107,129]. This dimension, like the ischial and pubis lengths, has been measured in different ways. Kelley [92] used the same measurement as was used here in investigating the sexes of whites, blacks and Indians, and found that female means significantly exceeded males in all three populations. Washburn [57] investigated a South African population of Bantu and Bushmen and found female notches to be wider than those of the males, but thought the variability was so great in the female that it was not a reliable indicator of sex. Jovanović and Živanović [106] used a width measurement: the distance between the lowest point of the posterior superior iliac spine and the most medial point on the inside ridge of the sciatic tubercule. Their results indicated males had marginally, but not significantly greater, sciatic notch width with mean measurements of 119.7 mm for males and 119.4 mm for females. The width of the greater sciatic notch can be a worth while dimension to investigate, but it must be kept in mind that significant asymmetries were observed in the male sample of both races, therefore, both the left and right side should be examined where possible.

Hager [108] also looked at width of greater sciatic notch in great apes, but the occurrence of the female notch as being larger was not observed in the other primates examined (*Gorilla gorilla, Pongo pygmaeus, Pan troglodytes*). Although, changes have been made throughout the skeleton to accommodate bipedalism the orientation of the pelvis in other primates varies from the modern human. A full description of adaptations to bipedalism can be found in common evolutionary texts [130-133]. The ilium has become broader and shorter to fulfill its weight bearing function. The sacrum is situated closer to the point of articulation between femur and pelvis and now creates a bony ring through which the infant's skull must pass. Other animals' brains are more developed at birth than those of humans. For instance, the chimpanzee's skull at birth is already 50 percent the adult size in contrast to the humans which, is about 25 percent. Only *Homo sapiens* have a larger female greater sciatic notch likely relating to the larger head size at birth to accommodate the superior brain size in modern humans.

Overall, males had greater sciatic notch depth than females, with whites larger than blacks (Tables 2 and 3). Regardless of the method of measuring the width of the notch, researchers have consistently used the greatest depth as perpendicular to the line made by the width. Jovanovič and Živanovič [106] found males had a greater sciatic notch depth with more variation among the females. Ranges for male depth were 40 mm to 53 mm while females ranged from 35 mm to 53 mm. Other researchers

[83,86,94] also found male measurements to exceed corresponding female values, but Singh and Potturi [94] thought both width and depth useless criteria for sexing. Davivongs [85] found the male dimension to be less than that of the female in a population of Australian Aborigines which is not consistent with other findings. This may, therefore, be a population specific phenomenon. Hager [108] also observed the sciatic notch depth in *Homo sapiens* and other primates. Male depths exceeded female depths in all cases.

Anterior greater sciatic notch width examined by DiBennardo and Taylor [47] in a sample of North American whites and blacks, and found the males larger than females and whites larger than blacks. Present research produced similar results, but the difference between the male and female means for both races was marginal. Hager [108] also observed larger male values using the tip of the ischial spine as a landmark instead of its base in a population of primates (*Gorilla gorilla, Pongo pygmaeus, Pan troglodytes*) including modern humans of known sex from the Dart, Hamann-Todd, Terry and Weisback collections.

Posterior greater sciatic notch width was found to be significantly larger in females than males and greater in whites than in blacks in this study (Table 9 and 10). Examining the posterior width of the sciatic notch of American whites and blacks Letterman [83] also found the females larger for both races and the whites larger than the blacks. This posterior width of the notch proved to be an important sex determinant with a very small overlap of the sexes by Davivongs [85]. Similar results were found by other authors [86,94,108]. The larger posterior region of the greater sciatic notch ensures that the sacrum is positioned back out of the birth canal, therefore, increasing dimensions of the pelvic outlet in females [108].

Variation between the sexes has mostly been attributed to modifications of the female pelvis for childbirth. Characteristics like the pre- and post-auricular groove have been rated as present in females due to changes in the pelvis created for childbearing [76,104]. Modifications have also been made over time for bipedal locomotion, e.g., shortening of the ilium [65]. Overall dimensions are often larger in males pelves, so robusticity also plays a role in the sexual dimorphism of the os coxae.

Sex differences for South African whites were found in the iliac breadth, pubic length and obturator foramen width (Table 9). Sex differences for blacks were observed between the same dimensions with an added exception of the depth of the sciatic notch (Table 9).

It is interesting to see that the pubic length was not found to be significant between the sexes of either race. In contrast, Day and Pitcher-Wilmott [97] found what he considered to be a certain degree of significant difference for pubic length ($p > 0.5$). Kimura [96] found pubic length significantly different ($p \leq 0.01$) between the sexes for American whites, and blacks, and Japanese. Mean values for the pubic length for white males and females were 101.6 mm and 102.2 mm while blacks were 93.2 mm and 93.2 mm respectively.

Iliac breadth, like the findings within the white sample in this study, was not found to be significantly different between the sexes for a Japanese and American black sample examined (Table 9) [96]. However, others did find dimensions significantly different like those found in the South African blacks (Table 9) [85,87].

In general it's thus clear that male and female means differ substantially. For both sexes, male means were larger in all dimensions except for various measurements of the pubic bone, greater sciatic notch and obturator foramen (Tables 2 and 3). Also, results here generally followed results predicted by previous studies. The overlap between the sexes, however, was very large. The variability was too much to use a single measurement as a clear indicator of sex, and therefore the multivariate approach (multiple discriminant function analysis) including many measurements simultaneously, is more effective.

Asymmetries

It is not uncommon for variations in size between the sides of the human skeleton to exist [116]. Significant asymmetries were observed, however, there was no consistent pattern in difference between sides or in the occurrence of the same measurement being asymmetrical more so than any other (Tables 6). It can be said that significant differences between the means of the left and right side were more prevalent in the South African whites than blacks. Differences may be attributed to several factors such as irregular growth and development or hereditary proclivities, for example. With significant difference between the sides it is, therefore, important to observe both sides, especially if a multiply discriminant function analysis is not done, before a diagnosis is made.

Morphological

Several studies have addressed the male and female form of morphological characteristic, used in this and other research, found within the pelvis [33,34,98-100,102,107]. The male form of the greater sciatic notch was described as narrow, deep and asymmetrical. This, however, was not observed in the white South African population sampled here. Only 33 percent of the white males sampled fit into this category (Table 11). Of the black males, 91 percent did share the accepted male sciatic notch shape. From this it can be said that there is a population specific expression of greater sciatic notch shape in South African white male's, which is different than that of other populations. In white males, 67 percent of notches were wide and only 33 percent narrow. Most of the white male pelves also displayed symmetry- where 41 were symmetrical. Of those 33 notches that were narrow, 54.5 percent were asymmetrical and 45.5 percent symmetrical. South African white males thus do not fit in with the pattern seen elsewhere- neither in width nor asymmetry. Female's, on the other hand do show the common pattern of the wide sciatic notch shape.

Subpubic concavity is mostly present in females and absent in males. In males sex was correctly determined greater than 90 percent of the time, but female whites and blacks achieved accuracies of 84 percent and 74 percent respectively. The possible absence of the subpubic concavity in the black females could play a role in the increased prevalence in problems with childbirth in this population.

The form of the ischiopubic ramus ridge being rough in males and smoother in females seems to work poorly for this population. The increased roughness and eversion on the ischiopubic ramus ridge is due to muscle attachment of the crus penis in males. The corresponding attachment in females for the clitoris, however, is poorly developed [64]. The presence and degree of roughness has to be classified more precisely than what was used in this research for greater accuricies to be observed for both males and females. Only 27 percent of the total female sample were correctly classified so they, therefore, showed considerable roughness in the ischiopubic ramus.

The pubic bone was by far the easiest to examine and the most reliable morphological indicator of sex overall for white and black females. In examining fragmented remains researchers should regard pubic bone shape and greater sciatic notch shape as the two most important factors for sex identification.

Orientation of the ischial tuberosity also proved consistent in this sample. The ischial tuberosity in females was characteristically orientated more laterally in contrast to the posterior orientation in males.

There are advantages and disadvantages to both metric and morphological analysis. Although in metric analysis it is necessary to employ equipment like an osteometric board or calipers the method of measuring can easily be taught or learned and replicated when landmarks can be clearly and consistently identified. Morphological examination does not require equipment to examine, but experience on the part of the observer enhances results.

Indices and Calculated Variables

Two indices were calculated from measurements made from each os coxae, namely obturator foramen index and ischiopubic index. The use of the ischiopubic index has been extensive [e.g., 50,57,71,84,88,88,96,122]. Values of indices were larger for females than males in both races (Table 15 and 17). In this research, indices were found to be significantly different ($p \leq 0.01$ Student's t-Tests) between the sexes of whites and blacks (Table 19). Kimura [96], also found this index larger in females in Japanese, North American white and black samples. This author also found significant differences between the sexes ($p \leq 0.01$) for all groups. Of the two indices used in this study, only the ischiopubic index showed significant ($p \leq 0.01$) differences between the females and males of both races (Table 21). With an overlap of 86.5 to 99 percent in the ranges of these two indices, the accuracies achieved in previous studies were not achieved here (Table 23). Accuracies of greater than 90 percent have been achieved using the ischiopubic index in other groups [50,84]. Washburn [57], examining the Bantu and Bush race in South African did achieve 98 percent sex accuracy in using the ischiopubic index and greater sciatic notch width.

The anterior and posterior diagonal of the greater sciatic notch has not been used extensively in previous research. Descriptive statistics showed the anterior diagonal to be larger in white males than females, but the opposite is true for the posterior diagonal (Table 16). The same was true for the blacks (Table 18).

Sex differences using discriminant function analysis

This study used discriminant function analysis to determine which pelvic dimensions are the most sexually dimorphic between males and females of white and black South Africans. Stepwise discriminant analysis of black South Africans selected acetabulum diameter as the most sexually discriminating measurement from all pelvic measurements based on Wilks' lambda values (Table 25). Function 1, which included all pelvic measurements of whites, selected ischial length first (Table 24). This was somewhat surprising since it gives more weight to differences in robusticity rather than differences due to modifications of the female pelvis for childbirth. Depending on measurements/function used, accuracies ranging from 50 to 97 percent were obtained (Table 31).

Race differences

The concept of race has undergone great discussion with regard to whether or not there are different "races" [114,134]. Contrary to efforts to avoid differentiation between the races osteological investigations indicate otherwise [63,135]. There is information in the literature for determining race from cranial shape and measurements [18,20,25,51]. DiBennardo [47] used a series of postcranial measurements to differentiate between North American whites and blacks. İşcan [48,81,115,136] found significant metric race differences in the pelvis between North American whites and blacks.

It is interesting to note, in this study, that statistically significant differences exist between the races of both sexes ($p \leq 0.001$) for all pelvic dimensions except the anterior width of the greater sciatic notch (Table 10).

Ranges between males of both races for this measurement were very similar. Whites had a mean of 27.3 mm whereas blacks had a mean of 27.6 mm (Table 2 and 3). Females were also much the same at 26.4 mm and 26.2 mm for whites and blacks respectively.

Size differences between the races were also observed. For every black female measurement the corresponding white female measurement was larger (Table 3). In males, all dimensions were larger in whites except for that of the anterior width of the greater sciatic notch on the left side (Table 2).

Of the three dimensions chosen as best discriminators of race (pubic length, greater sciatic notch posterior width, iliac breadth), two (pubic length, greater sciatic notch posterior width) were also chosen in the top three as preferred indicators of discriminating sex for South African whites and blacks (Tables 24,25 and 32).

In this study accuracies of correctly assigning race for females was 82 percent and 88 percent for whites and blacks respectively (Table 34). Males yielded accuracies of 87 percent for whites and 89 percent for blacks. In examining a sample of North American whites and blacks İşcan [48] reached accuracies of 83 percent in males and 88 percent in females for correct race assessment. Determining population affinity therefore seems a definite possibility, but this aspect will need more research in the future.

CHAPTER VII

CONCLUSION

Variation in the pelvis of South African whites and blacks has been demonstrated in this research both metrically and morphologically. Statistically significant differences were found between the races in both sexes, in 12 of the 13 pelvic dimensions tested. These results exemplify the importance of race and population specific standards to ensure the highest possible accuracy when identifying human skeletal remains.

Morphological race differences were noted in the expression of sexual dimorphism in the greater sciatic notch. Sciatic notch shape yielded unexpected results, with white males often exhibiting a wide and/or symmetrical pattern. White males showed a population specific variation in the greater sciatic notch shape and symmetry. The characteristic shape of the sciatic notch is not only different from that of South African blacks, but from that of other populations previously examined for notch morphology.

In overall size, whites were larger than blacks for all measurements. The most pronounced metric differences in the means, between the sexes, found in this study were total height, ischial length and posterior width of the greater sciatic notch for whites and blacks. Total height, iliac breadth and pubic length had greatest mean differences between the races.

Pelvic dimensions which faired best in discriminant function analysis for differentiating by sex included ischial length and pubis width in whites and acetabulum diameter and greater sciatic notch posterior width in blacks. Both of the primary discriminators for race were dimensions where variation was attributed to robusticity. The most effective discriminators of race for males were pubic length and posterior width of the greater sciatic notch. In females iliac breadth and posterior width of the greater sciatic notch were best.

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