Assessment of the variability in the clinically relevant dimensions of the pelvis in South Africans

by

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Declaration

I declare that the dissertation that I'm hereby submitting to the University of Pretoria for the MSc degree in Anatomy is my own work and that I have never before submitted it to any other tertiary institution for any degree.

____

Suvasha Jagesur

_____ day of _________________ 2013

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Summary

The dimensions of the pelvis are important when performing pelvic procedures and during obstetrics. As the dimensions of the pelvis may vary between sexes, populations and with height, it needs to be considered in the planning and performance of these procedures. Certain pelvic diameters of the pelvis are implicated in cephalopelvic disproportion (CPD) which is a major cause of mortality and morbidity in Africans during parturition.

The aim of this study was to assess the possible variations of the dimensions of the pelvis, relevant to the clinical applications considered, in South Africans. One hundred black male, 84 white male, 55 black female and 63 white female os coxae from the Pretoria Bone Collection and a total of 80 intact cadaver pelves, evenly distributed between the four groups, from the anatomy departments of both the University of Pretoria and Medunsa were sampled.

A total of five points on the os coxae and 12 on the intact pelves were marked and distances between these points measured. The subpubic angle was mathematically derived. Points describing the peri-obturator area and the pelvic canal were then further digitized with the 3DXL MicroScribe® Digitizer for shape analysis. Basic descriptive statistics was performed and comparisons were made between the various sex-population groups and according to stature.

The obturator canal was more medially placed in blacks and shorter individuals and therefore its contents could be endangered during inside-out transobturator procedures. In taller males and whites, the dimension of the route was greater, which could endanger the pudendal nerve branches related to the ischiopubic ramus during the outside-in transobturator procedure. The deeper and narrower pelvic canal, along with the broader ischiopubic rami in males may affect the safety or ease of performance of procedures.

The pelvic brim index was similar between groups and the pelvic inlet shape only differed between whites. The smaller pelvic inlet, midpelvis and shortened pubic symphysis, whilst

similar outlet diameters in black females contributed to the pelvic canal differences noted. Black women shorter than 163 cm, poses a risk for CPD according to established recommendations.

The findings on the obturator canal for peri-obturator procedures were anticipated, but not verified before in our populations. The difference between pelvic brim index (PBI) and pelvic shape was not expected and would have an impact on assessing individuals for the feasibility for natural childbirth or not.

The obstetric implications of the dimensions of the pelvic inlet and pelvic outlet as well as the pelvic shape are especially important to consider when caring for short black females in labour. Clinicians should also take note of the smaller peri-obturator dimensions in black males especially, when performing transobturator procedures.

Abstract

The dimensions of the pelvis are important when performing pelvic procedures and during obstetrics. The aim was to assess the clinically relevant dimensions of the pelvis, in South Africans. Eighty intact cadaver pelves and 303 os coxae, from the Northern Gauteng area were sampled. Five points on the os coxae and 12 on the intact pelves were marked, digitized for shape analysis and distances measured. Statistical comparisons were made between sex-population groups and according to stature. Smaller peri-obturator dimensions in blacks and shorter individuals exposed the obturator nerve during procedures, whilst in taller males and whites, the greater dimensions endangered the pudendal nerve branches. The deeper, narrower pelvic canal and broader ischiopubic rami in males may complicate pelvic procedures. The smaller pelvic inlet and midpelvis, whilst similar outlet diameters in black females contributed to pelvic canal shape differences. Shorter black women, poses a risk for CPD according to established recommendations.

peri-obturator dimensions; obturator nerve; pudendal nerve; pelvic inlet; midpelvis; pelvic outlet; shape analysis; pelvic canal; cephalopelvic disproportion; transobturator tape procedures

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1. Introduction

It is well known that there are measurable differences in the size and proportions of skeletal components of the pelvis between populations including white and black South Africans, as well as significant differences between the sexes and with stature.[1-4] These differences are not specifically taken into account when perineal procedures are planned, and specific dimensions relating to these procedures have not been investigated. During pelvic procedures or during childbirth, some of these differences are expected, but the extent of these differences is not always anticipated. Direct measurements on intact pelves are limited to accessible intra-operative dimensions.[4]

Several perineal procedures, especially those for stress urinary incontinence, intimately involve the pubic bone, ischiopubic ramus and obturator foramina. The space between the ischiopubic rami, as reflected by the subpubic angle and the length of the rami, determines the size of the dissection plane and the ease of performance of these procedures. Population, sex and individual variations in the dimensions of the pelvis may therefore influence the outcome.

As fixed distances for the insertion of the bone screws are often used, misplacement may result if individual body variations are not taken into account and may lead to trauma, ischemia, nerve entrapment, infection and osteomyelitis.

The tension-free vaginal tape, developed in the late 1990's, involves the blind passage of the trocar into the retropubic space to exit through the suprapubic incisions.[5] Similarly, the bulbourethral sling described in 1998, also involves a sling passing retro-pubically and suspended to the anterior rectus fascia by sutures.[6] The bulbourethral composite suspension sling (introduced in 2004), emerge from two suprapubic incisions when inserted from the perineum. During retropubic needle passage, care should be taken to maintain contact with the pubic bone at all times, and to exit as medially under the pubic arch as possible. Lateral placement of the needle is more likely to damage branches of the perineal nerve or the obturator or iliac vessels, or even the bowel in a posterior route.[6, 7]

The sub-urethral transobturator tape procedure, described in the early 2000's for females, involves the blind passage around the ischiopubic ramus at its intersection with the body of the pubis, either from inside-out or from outside-in.[8] The inside-out method was significantly closer to the obturator canal and further from the ischiopubic ramus than with the outside-in approach. The pudendal nerve is also endangered in the inside-out method while trying to find the inferior border of the obturator foramen. [9]

There are relevant anatomical dissimilarities that need to be considered to adapt this route of sling insertion along with surgical instruments in males. In males, the inferior pubic rami are thicker, roughened and everted, while the angle formed by the rami is less open and the obturator foramen more oval in shape.[10]

Some fixed landmarks are described for the performance of transobturator procedures, without consideration of stature. These variations may prove to be significant during surgical procedures performed on both sexes.[11] Shorter women have smaller obturator foramina and might be at a higher risk during such procedures.[10] This may also be the case in short males, and needs to be researched.

Over- or under-estimation of the broadness of the inferior pubic ramus and the size of the pubic bone as it varies between sexes, populations and stature[10] may result in incomplete circumventing of the inferior pubic rami, or cause diversion of the introducers into the pelvic space, or closer to the "dangerous area" for injury of the obturator vessels or to the perineal vessels.[12]

It will therefore be important to consider variations in the applicable pelvic dimensions amongst populations, sexes and stature, to determine what modifications should be made to the introducers, mesh tapes, including the technique.

During planning and performance of pelvic procedures or during childbirth, certain diameters in the pelvic inlet, pelvic canal and pelvic outlet are important to consider. A small pelvic canal may impede vision, access and space for surgical excision. Consideration of the pelvic anatomy may be pivotal in the planning of radical retropubic prostatectomy, rectal surgery and also for laparoscopic procedures.

Cephalopelvic disproportion (CPD) is common among Africans and is a major cause of maternal and perinatal mortality and morbidity.[13] As previous studies regarding pelvic dimensions was performed on African-American and European-American women, this data may not correlate with the unique South African population.[14, 15] It will therefore be of value to determine whether population group or stature is associated with the pelvic diameters favouring vaginal delivery or not. The relationships of these dimensions or conjugates determine the shape of the pelvis. The ideal shape for parturition is described as gynaecoid.[16]

There is therefore a need to determine the implicated distances and angles in both sexes and population groups while taking stature into account. Direct measurements on dried disarticulated as well as intact cadaver pelves will be done. Shape analyses of the pelvic inlet and pelvic canal as well as the obturator region will be done to highlight the impressions of the linear measurement results.

Findings on the shape and size differences of the pelvis are implemented to predict the impact that population group, stature and/or sex will have on planned procedures or childbirth, so that appropriate adaptations to these techniques or decisions regarding methods of delivery may be made.

2. Literature Review

2.1. Perineal procedures implicated in sex-population differences of the pelvis

Although pelvic dimensions in South African populations have been shown to differ, specific dimensions relating to the following procedures on dried disarticulated as well as intact pelves have not been investigated.

The following procedures are considered to illustrate the relevant pelvic dimensions:

2.1.1. Procedures for stress urinary incontinence (SUI)

Several procedures have been developed to alleviate stress urinary incontinence. Stress urinary incontinence (SUI) is defined as the involuntary loss of urine associated with activities that increase the intra-abdominal pressure in combination with intrinsic sphincter deficiency.(17) This dysfunction is caused by structural or functional damage to the urethra, which renders it unable to resist the increased abdominal pressure as an expulsive force, e.g. coughing, sneezing and laughing.(10, 17-20)

Stress urinary incontinence (SUI) is estimated to affect between 4 and 35% of adult women worldwide, and can lead to the deterioration in the quality of life of affected women.(21) Most pelvic floor disorders in women, including urinary incontinence, are associated with parity because the levator ani and pelvic floor muscles may be injured at the time of vaginal delivery.(22) Metric pelvic inlet and outlet dimensions were found to be significantly larger in incontinent women.(23)

While detrusor instability may play a role, malfunction of the internal urethral sphincter appears to be the primary reason for male stress incontinence after radical retropubic prostatectomy (RRP).(7, 12, 24-26)

The transobturator sling between the obturator foramina on either side forms a sub-fascial hammock of support under the urethra, mimicking the normal position of the pubo-urethral ligament. This means that the needle or the sling never enters the retropubic space. The transobturator sling replaces the damaged ligament with a permanent mesh tape that provides the support needed to prevent leakage.[27-29]

When conservative methods fail to alleviate SUI, as a result of more severe forms of incontinence in both sexes, sling placement may be considered. The following procedures are considered:

2.1.1.1. Males and females: Bone anchors

Another procedure used for the treatment of SUI in both sexes involves the use of bone anchors that provide a stable, fixed point of suture attachment.[18, 19, 30] In the trans-vaginal sling, the anchors are placed on each side of the urethra by estimating 2cm lateral to the pubic symphysis.[31] The suprapubic bone anchor procedure, explained by Goldberg et al., also advocate the use of fixed measurements for the insertion of the bone screws.[30]

Other authors describe the attachment of two sutures anchored to the pubic tubercle, using a bone locator during placement of an *in situ* vaginal wall sling.[18] They further describe the placement of an anchor behind the pubic bone, using an anchor insertion tool during transvaginal fascial sling placement. In this procedure they emphasize the need to confirm the correct placement of the anchor by gently “scraping” the tool behind the bone to test for position.

Madjar et al., illustrate the use of bone anchors placed just below the pubic symphysis on each side, and then a second pair inserted 3 to 4cm lower on the ischiopubic ramus, during the treatment of post-prostatectomy incontinence.[32]

Misplacement of the bone anchors may result from using fixed measurements, as individual and body variations are not taken into account[31] and may lead to trauma, ischemia, nerve entrapment, infection and osteomyelitis.[18, 30-34]

2.1.1.2. Males: Bulbo-urethral sling

The bulbo-urethral sling is used in the treatment of post-prostatectomy urinary incontinence in males.(6) In this procedure, the bolsters consisting of Cooley soft vascular material or polyethylene terephthalate is placed beneath the bulbar urethra (proximal part of the spongy urethra in the bulb of the penis).(35)

The route of the needle during this procedure is of high importance.(7) Care should be taken to ensure that the needle maintains contact with the body of the pubic bone at all times, and to exit the pelvis through the perineal membrane as anteriorly and medially under the pubic arch as possible. A more lateral and posterior placement, is likely to damage branches of the perineal nerve.(7, 36)

2.1.1.3. Females: Tension-free vaginal tape (TVT)

The tension-free vaginal tape (TVT) in females has resulted in significant long- and short term cure rates.(10, 37-39) The TVT procedure involves the introduction of a polypropylene sling under the mid-urethra using two trocar needles.(40, 41) The term 'mid-urethral' refers to a point just distal to the membranous urethra.

However, this technique is not without complications, the most frequent of which relates to the blind passage of the trocars in the retropubic space. There is a possibility that it may deviate in a vertical course toward the obturator or iliac vessels laterally, or toward the bowel in a posterior route.(10, 21, 40, 42)

It has been reported in 2002 that the incidence of bladder perforations was 6.3% and that of mild vascular injuries and bowel complications was 1.7% as a result of this procedure.(5, 40) Some authors maintained that these injuries could have been avoided by being familiar with the anatomy of the retro-pubic space.(37)

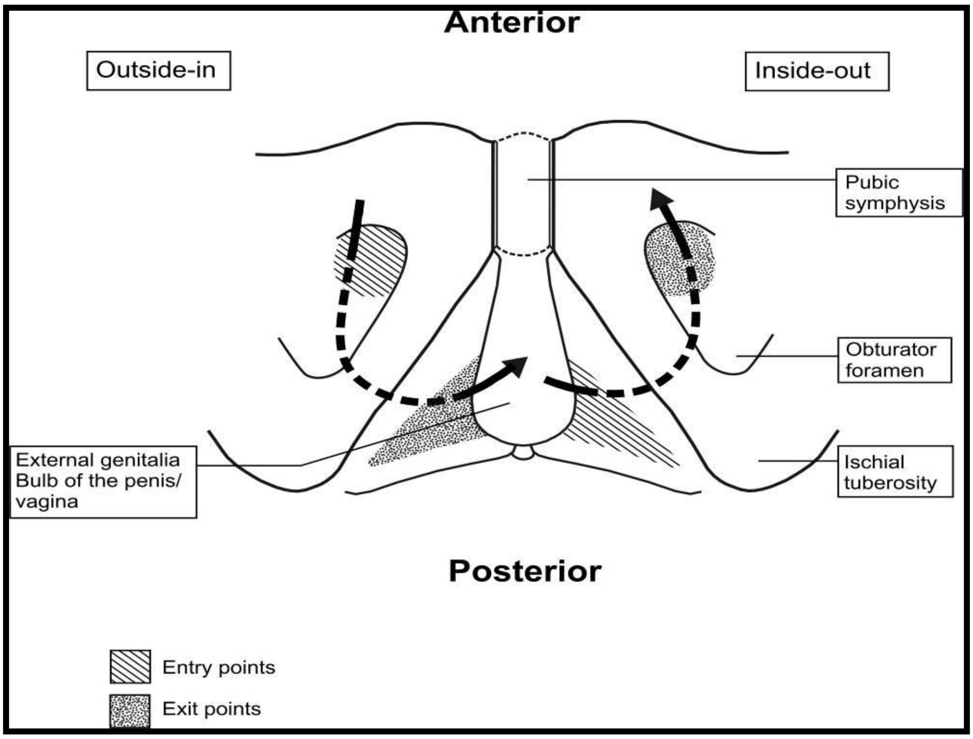
2.1.1.4. Males and females: Trans-obturator tape (TOT)

The TOT approach to apply urethral slings is used in both males and females. This technique was originally developed to minimize the complications of TVT by staying clear of the retropubic space and has proven to result in high short- and long-term cure rates, as suggested by multiple authors.[5, 17, 21, 37-41, 43]

The trans-obturator approach involves the placement of a synthetic mesh tape underneath the distal membranous urethra, and passing it bilaterally through the obturator foramina in females. In males, this technique involves the use of specific instruments and a polypropylene mesh with two arms that are passed from inside to outside through the obturator foramina, compressing the bulbar urethra upward, and tied to each other across the midline.[7, 10, 24]

Ridgeway et al., describe two methods of applying the obturator sling in women. The outside-in approach involves the mesh being passed from the genito-femoral fold to the mid-urethra. In the second instance, the inside-out trans-obturator approach (TVT-O), the mesh is passed from the mid-urethra to the genito-femoral fold (Figure 1).[10]

Figure 1. Suggested safe areas for the passage of the trans-obturator needle in trans-obturator sling placement



The inside-out and outside-in TOT approaches

Many variations of these two approaches exist; including dissimilarity in the incisions made, points of entry and exit of the introducers as well as different landmarks used to direct the incisions and course of the introducers.[10, 38, 39, 41, 44]

The outside-in TOT approach in females involves the blind passage of a curved trocar from just lateral to the labia majora, around the ischiopubic ramus and through the obturator foramen, to pass into the anterior vaginal wall at the level of the mid-urethra.[37] A different approach is explained for the inside-out technique in females, where a new helical tunnel and introducer were developed to pass the tape from the vaginal incision, through the obturator foramen and toward the genito-femoral fold, without entering the pelvic region.[17]

The inside-out technique TOT technique performed in males is described as the perforation of the urogenital diaphragm, followed by the advancement of the introducers to perforate the obturator foramen and the obturator internus muscle. The passer exits at the outer edge of the ischiopubic ramus where it intersects with the body of the pubis.[24] The outside-in approach in males, is described as a skin incision that is made just lateral to where the inferior pubic ramus can be identified. The passer is then advanced under manual guidance through the obturator foramen and exits lateral to the bulbospongiosus muscle.[45]

Although both methods of transobturator placement involve penetration of the obturator membrane and passage around the ischiopubic ramus, the actual route of the passage differs slightly between the two approaches.[9]

A study performed in 2007 compared the two transobturator procedures in females.[9] Results showed that transobturator tapes placed using the inside-out method were significantly closer to the obturator canal (mean distance 13.0 mm± 4.4 mm), as compared to the outside-in method (23.0 mm± 4.1 mm). Tapes placed with the inside-out method were also further from the ishiopubic ramus than those placed with the outside-in approach (3.9 mm± 4.4 mm compared with 0.4 mm ± 1.3 mm respectively).[37]

The position of the mesh tapes after the application of various male TOT slings; such as the bone-anchored slings, retro-urethral transobturator and retropubic slings, were found to be just below the most inferior point of the pubic symphysis on the ischiopubic ramus.[19]

Although these studies included various population groups; population differences were not investigated as the numbers representing each group were limited. This data may not correlate with the South African population.[46] These authors emphasize the need for every population to have its own standards that are tailored to the unique metric and morphological characteristics of that population.

Dissection plane created in TOT

A dissection plane is created by a scissor-initiated dissection path which involves the layers of the urogenital triangle, until it comes into contact with the upper part of the ischiopubic ramus, where the bulbospongiosus muscle is accessible. The muscle is then freed anteriorly, to expose the pubic symphysis, and dorsally to the central body of the perineum. The dissection is then expanded laterally to expose the ischiocarvenosus muscles along the ischiopubic ramus. After identifying these muscles, a triangular space is observed.[7, 24, 25, 45] The size of this space will differ amongst populations and sexes, which might be a limitation when performing these procedures.

Points of entry and exit of the introducers

The surgeon's finger can then be placed inside the perineal dissection to identify the inferior pubic ramus, along the contemplated pathway of the passer. During the outside-in approach in males, a skin incision is made just lateral to where the inferior pubic ramus can be identified.[45] Palpation of the inferior pubic ramus is also used; the proper position of entry of the needle should be just below the medial aspect of the palpable part of the adductor longus tendon.

Height is not specifically taken into account when these landmarks were considered and this is evident in the variety of approaches used by various authors. Measurements such as: a puncture of the root of the thigh, 4 cm from the median line and 4 cm below the adductor longus muscle; as well as a stab incision in each inguinal crease 1cm below the insertion of the adductor longus tendon are mentioned.[25]

Rehder and Gozzi report that a tiny skin incision is made in the leg fold on the lateral side of the scrotum at a height corresponding to the base of the penis held up onto the lower abdomen.[28] In other studies, these procedures were performed independent of the patient's size and mass.[24]

The highly variable architecture of the obturator foramina in females; as well as the correlation of the obturator foramina area with the height of the individual, may have implications for urogenitial surgical procedures involving the transobturator approach.[10] The dimensions of the obturator foramen and its correlations to stature may also vary in males and needs to be researched.

The importance of a thorough understanding of the surgical anatomy necessary for the safe and effective completion of surgical procedures is emphasised.[37] This is especially true when new surgical techniques or devices, such as these minimally invasive slings, are introduced in a blind fashion without direct or endoscopic visualization of anatomical structures.[18, 31, 40]

It will therefore be important to consider the variation in pelvic shapes and sizes amongst populations, to determine what modifications should be made in the incisions and dissections.

<u>Introducers, mesh tape and technique used in TOT</u>

The success of the trans-obturator sling has resulted in the production of several procedural kits in which as many as four trochars that are passed through the obturator foramen during a single procedure. These trocars have fixed sizes and angles and therefore findings of variability are clinically important.[10, 24, 38, 41]

Researchers are not likeminded regarding the reproducibility of the transobturator tape placement procedure.[5, 47] Patient characteristic and operator skills are important factors in dertermining the variablilty in the needle's path.[5] This is reflected in the package insert of the Gynecare TVT Obturator System, stating that variations may occur in specific procedures due to individual technique and patient anatomy.[48]

According to the researched techniques for inserting the transobturator tape, only the entrance of the passer is performed under direct vision and the rest of the procedure is done blindly.[45] Schaeffer et al., caution that with needle passage in females, care should be taken to maintain contact with the pubic bone at all times and to exit through the perineal membrane as anteromedially under the pubic arch as possible. A lateral placement of the needle is more likely to damage branches of the perineal nerve.[7]

Over or under-estimation of the broadness of the inferior pubic ramus, as it varies between sexes, populations and stature, may result in incomplete circumventing of the inferior pubic rami or cause diversion of the introducers into the pelvic space or closer to the obturator neurovascular bundle[12] or to the perineal vessels.[7] This area has been described as the "dangerous area" for injury of the obturator vessels.[12]

There are relevant anatomical dissimilarities that need to be considered to adapt the route of sling insertion in men. Firstly, the inferior pubic rami are thicker and secondly, the angle formed by these rami (pubic arch) is less open in males than in women.[10, 24] Taking these differences into account, these authors affirm that the surgical instruments currently used for inserting TOT's in women would require some modification to accommodate the male anatomy.

De Leval[24] also found that where sub-urethral tapes are placed without tension to treat female SUI, considerable lifting forces must be applied to male slings to prevent urinary leakage. Shah[49] suggests that complications such as bleeding, haematoma, injury to adjacent organs related to the use of synthetic mesh in the management of stress urinary incontinence and pelvic organ prolapse repair, occur during placement of mesh. They further conclude that these complications are primarily related to technique.

As the size of the subpubic angle will give a reflection of the available space for the mesh(10) a mesh tape with a fixed distance as described by the package insert of the Gynecare TVT Obturator System(48) of 1.1 x 45 cm may result in discrepancy in the tension of the tape around the urethra, due to the differences in the distance of the course of the mesh. As folding might be an important contributing factor in mesh exposure, it is important to assess the available space between the ischiopubic rami in the various groups.

Ridgeway(10) commented that the fixed sizes and angles of the instrumentation used in prolapse repair kits may not take into account the variability in the relevant dimensions of the pelvis observed within the female population. It will therefore be important to consider variation in pelvic shapes and sizes amongst populations to determine what modifications should be made to the introducers, mesh tapes and also to adapt the technique.

2.1.1.5. Males: "Four-Armed" or Quadratic male sling system

The quadratic male sling system is an implantable, permanent, synthetic sub-urethral sling indicated for the treatment of SUI.The sling consists of a broad-based mesh material placed under the bulbar urethra similar to the bulbo-urethral sling. It is then self-secured with four mesh arms which are placed in both a transobturator (two arms) and prepubic (two arms) manner. The limbs may then be further secured to create additional points of fixation as needed.(19)

According to the Coloplast Virtue Male Sling System package insert(50), an incision is made 2cm above the pubic symphysis and 2 cm lateral to the midline on either side. The introducer is passed pre-pubically through the pubic incision and out through the perineal incision lateral to the urethra. A hemet or helical needle is used according to surgeon preference.(36) This sling has only recently been introduced and extensive research as to the exact placement of the sling has not yet been investigated.(19)

2.1.1.6. Females: Mini-arc anterior repair procedure

The Mini-Arc Single-Incision Sling system is a procedure for female SUI that uses a single-incision approach with no retropubic or groin passage. This results in less tissue trauma and is easier to use than other single-incision slings as reported by various authors.(21, 51) The mini-arc sling comprises of a propylene mesh with integrated self-fixing tips that is inserted using a curved needle.[51]

The dissection path follows the same path of the Monac sling, but is made only slightly larger than the mesh to avoid a full dissection. One technique used, involves a mark that is made on the patient's skin just inferior to where the adductor longus tendon meets the pubic ramus, to aid in the placement of the sling. The sling is then placed in a dissected tunnel and directed toward the obturator space into the obturator internus muscle at an approximately 45 degree angle. The needle tip is cautioned to be kept in close proximity to the posterior surface of the ischiopubic ramus to avoid bladder, urethral or bowel injury.[21]

Reported cases of possible nerve damage or haematoma have been reported due to violation of the obturator membrane.[52]

Similar consideration for inter-population and sex differences of the pelvis in the obturator region is applicable to mini-sling procedures.

2.1.2. Relevant pelvic anatomy for SUI procedures

In order to consider the dimensions applied to the abovementioned procedures, the following anatomy is of importance: There are numerous known differences between the male and female pelvis. The female pelvis appears broader, yet more gracile with lighter, more slender bones; while that of the male is more robust, with more prominent muscle attachments.[11, 53] Along with the subpubic angle being wider in females, these abovementioned differences have important implications for the application of the obturator sling.[10]

A significant variation in the degree of openness of the pubic arch has also been established within the female population.[54] The subpubic angle may be mathematically calculated in the clinic; by measuring radiological landmarks, or by palpation of the pubic symphysis and ischial tuberosities; and in anthropology by determining similar landmarks on dried bones.[10, 55-57] The subpubic angle is unfortunately not a true reflection of the subpubic space as the subpubic concavity forming the pubic arch is not taken into account.[58] The subpubic angle is sharper and narrower in males and more rounded and obtuse in females.[59, 60] This angle may be easier to measure in females, because of its rounded nature.[60]

The ischiopubic rami also display some differences.[56, 60, 61] in females, the rami are much more lightly built and narrower near the symphysis. In males, the rami bear a distinctly roughened and everted shape for the attachment of the crus of the penis. The corresponding attachment for the clitoris is poorly developed.[60]

There are also variations that exist in the shape structure of the obturator foramen, with females having a more rounded foramen compared to the more oval shape found in males. Findings by Ridgeway et al., on the female bony pelvis, indicated that there is considerable variability in the bony architecture of the obturator foramen, especially its internal border.[10]

The obturator nerve runs along the lateral wall of the pelvis to the obturator canal. This is an opening in the obturator membrane that fills the obturator foramen. The nerve divides into anterior and posterior branches and leaves the pelvis though this canal to supply the medial thigh muscles.[53, 56, 60-62] All the nervous and vascular structures that cross the obturator foramen travel laterally - this allows for the safe passage of trocars along the medial margin of the obturator foramen.[12] Previous studies investigated the variability of the trajectory of the obturator needle, with special emphasis to its proximity to the obturator canal.[5, 9, 37, 38, 40, 53, 63]

The pudendal nerve is the main nerve of the perineum and chief sensory nerve of the external genitalia. It is accompanied by the pudendal artery, as it leaves the pelvis through the greater sciatic foramen between the piriformis and the coccygeus muscles. It then hooks around the ischial spine and sacrospinous ligament and enters the perineum through the lesser sciatic foramen.[53]

The pudendal nerve is reported to lie on the medial surface of the ischiopubic ramus, 1 cm below the border of the obturator foramen at the inferior border of the obturator internus muscle and at the superior border of the deep transverse perineal muscle and surrounding fascia. It is found in a fibrous sheath lying flush against the bone.[62]

Further, there is no risk of injury to the pudendal nerve as the needle track goes from the thigh to the perineum, since the nerve is protected by bone. However, when the needle is introduced from the perineum towards the thigh, the needle could traverse and damage the pudendal nerve while trying to find the inferior border of the obturator foramen. This approach is therefore associated with a risk of injury of pudendal nerves and vessels.[62]

Both the gracilis and the adductor brevis muscles are transversed by the tape in their muscular parts. The adductor muscles of the thigh originate in the form of a semi-circle, from different points of the bony edge of the obturator foramen and are arranged in three layers.[38, 62, 64]

It is unknown as to exactly how the size of the foramen affects the location of the vessels and nerves, but they do believe that women with smaller foramina are at higher risk during these procedures.[10]

Guidelines, taking into account the relative distances and angles between landmarks and the most desirable course of the surgical instruments related to various bony structures, could prove to be invaluable in doing these procedures with more confidence, ease and safety.

Studies have also shown that a wider transverse inlet and a shorter obstetrical conjugate common to a platypelloid shape were significantly associated with pelvic floor disorders in females. They also found that the pelvic type at lowest risk may be the heart-shaped anthropoid pelvis. These pelves have a narrow transverse inlet and wide obstetrical conjugate. The anthropoid pelvis is more prevalent in black women.[22]

As the study of Ridgeway et al., was performed on African-American and European-American women; this data may not correlate to the South African population.[11, 46] These authors emphasize the need for every population to have its own standards that are tailored to the unique metric and morphological characteristics of that population.

2.1.3. Sacrospinous colpopexy

Transvaginal sacrospinous colpopexy is currently used by reconstructive pelvic surgeons to repair varying degrees of vaginal vault prolapse.[65, 66] This involves placing a stitch from the vaginal cuff to the sacrospinous ligament, approximately 2 cm medial to the ischial spine, to correct the defect. This may be associated with pudendal artery and nerve (pudendal complex) and sciatic nerve injury if the procedure is not carefully performed.[66]

The use of certain bony landmarks is highlighted for the safe and effective performance of this surgery.[65] This includes the importance of the measurement of the pelvic outlet diameter (distance between the ischial spines). Also, the use of the obstetric conjugate and the distance from the ischial spine to the midpoint of the lateral border of the sacrum (this distance is consistent with the length of the sacrospinous ligament) during this procedure.[66] These authors noted that, after dissection of 24 female cadavers, there was a correlation between the sacrospinous ligament length and the obstetric conjugate.

They established that the longer the obstetric conjugate, the longer the sacrospinous ligament and vice versa. Also, the distance from the ischial spine to the sciatic nerve correlated with the size of the obstetric conjugate.

The pudendal complex and sciatic nerve travel underneath the lateral third of the sacrospinous ligament. It is therefore recommended that the placement of the stitch be made medial to that portion of the ligament.[66]

2.1.4. Rectal incontinence (Prolapse) procedures

Rectal prolapse is associated with deformation of the pelvic floor. This is largely muscular, and composed of the levator ani enclosed in fascia. The sling portion of the muscle is known as the puborectalis muscle. It functions by elevating the lower portion of the rectum in a forward direction toward the pubic arch, compressing the structures in front of it to decrease the aperture in an anteroposterior diameter. This action is supportive. Relaxation of the sling causes a descent of the pelvic floor with an increase in the size of the pelvic aperture.(67)

The management of full-thickness rectal prolapse involves surgical intervention in the majority of cases, with many procedures been described.(68) Rectal prolapse can be repaired by an abdominal and laparoscopic approach or via a perineal approach. Perineal procedures are generally reserved for patients with multiple conditions or those considered too elderly or frail to withstand an abdominal surgical approach. The perineal repair of rectal prolapse involves a surgical approach around the anus and perineum.

The two most common perineal repair procedures are those of Altemeier and Delorme. During the Altemeier procedure (also called a proctosigmoidectomy), the prolapsed portion of the rectum is removed and the cut ends reattached. The weakened structures supporting the rectum may be stitched into their anatomical position. The Delorme procedure involves the resection of only the mucosa (inner lining) of the prolapsed rectum. The exposed muscular layer is then folded and stitched up and the cut edges of mucosa stitched together.(68, 69)

2.2. Pelvic procedures implicated in sex-population differences of the pelvis

2.2.1. Males: Radical retropubic prostatectomy (RRP)

Radical prostatectomy is regarded as the treatment of choice for curative therapy of localized prostate cancer. This procedure may be performed with greater ease in a more wide and shallow pelvis. Pelvic size as well as certain anatomical variations in the pelvic dimensions, such as the ISD (narrowest distance between the tips of the ischial spines) and intertuberous distance (widest distance between the ischial tuberosities), are important factors in performing RRP.[70]

A wide pelvis is regarded as one that presents with a large transverse diameter, a large interspinous distance and a large external diameter. A narrow pelvis possesses a shorter anatomical conjugate (distance from the superior border of the pubic symphysis to the sacral promontory).

In the current era of laparoscopic and robot-assisted retropubic prostatectomy, the pelvic dimensions, such as the pelvic depth and height could be important, since the instruments are manipulated in a confined space and there is limited freedom of movement during laparoscopic pelvic surgery.[70]

Population variations in the pelvimetric measurements, which have an impact on the surgical margins during RRP were found.[71] These authors found that African-American males have significantly smaller pelvic inlets and subpubic angles than Caucasian males.

2.2.2. Males and females: Surgical procedures for rectal cancer

Surgery for rectal cancer and laparoscopic surgery is complicated by a deep, narrow pelvis. In these pelves, access and vision are both restricted by the pelvic anatomy.[72, 73]

A prominent sacral promontory, or a pelvis particularly narrow in the transverse plane, could represent anatomical bottle-necks, impeding vision, access and space in which instruments can be manipulated.[72]

This could hinder operations involving the resection of rectal cancers, which require adequate vision, maximum retraction and access to the depth of the pelvis via the pelvic inlet. Pelvic dimensions are a major factor influencing the difficulty of safe surgical excision. Pelvic width and depth, as well as the size of the tumour relative to the pelvic dimensions may influence the difficulty of surgical excision.[73]

2.2.3. Relevant pelvic anatomy for other procedures considered

The pelvis is divided into a greater (false) and lesser (true) pelvis by the oblique plane of the pelvic inlet or pelvic brim. The greater pelvis lies superior to the pelvic inlet. It is bound by the iliac alae posterolaterally and the anterosuperior aspect of the S1 vertebra posteriorly. It contains abdominal viscera such as the ileum and sigmoid colon.(53)

As discussed, the primary sexual differences between pelves are centred on the needs of childbirth. This reproductive adaption particularly affects the lesser pelvis; however these changes affect the proportions and dimensions of the greater pelvis to a variable degree in females.

Since males are more muscular and therefore more heavily built, the overall dimensions of the pelvis are greater in males. Markings for muscles are more pronounced and the general architecture is relatively stouter. The iliac crests are more rugged and curves medially at its anterior end. In females, these crests are less curved. The iliac blades are more vertical in the female, but do not extend as far upwards. The iliac fossae are therefore shallower and the pectin pubis is more vertical. (60, 61)

The interspinous diameter is greatest width between the ischial spines. The ischial spines are closer together in males, being classically inverted. The greater sciatic notch is also much wider in females.(60, 61) The sacrospinous ligament passes from the lateral sacrum and coccyx to the ischial spine, transforming the large sciatic foramen into a greater and lesser sciatic foramen.(51, 53) Significant variation in the degree of openness of the pubic arch has also been established within the female population.(54)

As discussed previously, an increased distance between the ischial tuberosities found in females, which in turn lead to a wider subpubic angle as well as differences in the ishiopubic rami, is thought to be significant. Delmas cautions that bone variants as such be assessed according to gender(62) and the general shape of the pelvis during consideration of these pelvic procedures.(10, 60, 61)

2.3. Parturition

Sexual dimorphism in the human pelvis is related to parturition.[74] Morphological features of the pelvis, in particular the size of the lesser pelvis, are significant in obstetrics, because it is the bony canal through which the infant passes during vaginal birth. To determine the capacity of the female pelvis for childbearing, the dimensions of the pelvis are noted radiographically.[75, 76]

According to Turner's method, pelvic brim (inlet) shape can be predicted by calculating the pelvic brim index. The pelvic brim can then be classified into three categories as described by Turner.[77] The three categories are dolichopellic, mesatipellic and platypellic.

Although the classification groups created by Turner is commonly believed to correspond to three of the four classification groups of Greulich and Thomas (1939)[78] for pelvic shape. The definitions are not completely similar and may not correspond exactly.[60, 61, 78]

The gynaecoid pelvis has an ideal shape with a round to slightly oval inlet and provides the best conditions for normal vaginal delivery. The android pelvis has a more triangular inlet, prominent ischial spines and more angulated pubic arch. In the anthropoid pelvis, the transverse inlet is greater than the inlet obstetrical diameter. The platypelloid pelvis has a flat inlet with a shortened obstetrical diameter. The four pelvic types are outlined in the table below (Table 1) and are adapted from Gray's Anatomy.[60]

The diameters of the pelvic inlet include the transverse diameter of the inlet (joining the two most widely separated points of the pelvic inlet) and the anteroposterior (AP) diameter of the pelvic inlet (measured from the upper margin of the pubic symphysis to the sacro-vertebral angle).

Table 1. Morphological classification of the pelvis according to typical values quoted by Gray's Anatomy 35th Edition

Pelvic type	Conjugate (AP) diameter (mm)	Transverse diameter (mm)	Pelvic inlet shape
Gynaecoid (= mesatipellic)	108.5	137.6	Oval shaped
Android (= brachypellic)	105.9	135.6	Heart-shaped
Anthropoid (= dolichopellic)	117.5	129.4	"Kite shaped" elongated in the AP plane
Platypelloid (= platypellic)	85.5	144.5	"Kite shaped" elongated in the transverse plane

The diameters of the pelvic outlet include: the transverse diameter of the outlet; joining the medial surfaces of the ischial tuberosities. Studies emphasise that pelvic points of reference must be fixed and locatable either by x-ray or manually. It is suggested that the pelvic outlet should be measured at the level of the ischial tuberosities which are fixed and easily located by x-ray or manually, while the inlet is taken slightly below the true conjugate.(76)

The true (obstetrical) conjugate is the minimum AP diameter of the lesser pelvis. It extends from the midpoint of the sacral promontory to the midline of the upper posterior border of the pubic symphysis.(53, 65, 72)

Variations between populations have been found by Katanozaka et al.,(75) and Sonal et al.,(79), who performed the measurement of the obstetric conjugate ultrasonically on the Indian and Ghanaian population respectively. They found varying results in each study with a distance of 11.4 ± 1.07 cm and 12.90 ± 0.88 cm respectively. It would therefore be of value to determine to what extent this variability extends to the South African population.

The diagonal conjugate measures the distance from the under surface of the pubic arch to the sacral promontory. The length of the diagonal conjugate depends on the height and slope of the pubic bone and is measured as a value larger than the obstetric conjugate length.(75)

The subpubic angle was found to range between 75 and 155 degrees (mean of 116.11 degrees) in females in the Ugandan population as determined by anteroposterior radiographs. However, these values are still significantly narrower than those of the Malawian population that had a mean angle of 129.07 degrees. These differences have been suggested to be an indication of regional variation of the subpubic angle among black subjects.[64] Furthermore, the presence of sexual, regional and population variability of the subpubic angle could possibly be explained by genetic, dietary and environmental factors.

It is believed that this angle should be 90 degrees or more if problems during delivery are to be avoided.[57] Moore and Dalley maintain that, if the ischial tuberosities are far enough to permit three fingers to enter the vagina side by side, the subpubic angle is considered sufficiently wide to permit the passage of an average head at full term.[53]

Despite the importance of the subpubic angle, only a few such studies exist.[64, 80-82] The subpubic angle has been quantified South African males and females of both African (black) and European (white) descent and to determine whether any statistically significant differences exist between the sexes and the population groups.[82] In this study, all pelves were articulated with elastic bands, placed into a custom-built stand and the subpubic angles were photographed.

The photographs were imported into Microsoft Paint (Version 6.1) and a line was drawn tangentially from the point where the two pubic bones meet, superiorly, to the ischial tuberosities, inferiorly; on both sides of the articulated bone. The thickness of the symphyseal fibrocartilage was not taken into consideration. They found that black males and females have mean subpubic angles of 63.98 and 84.18 degrees respectively, whilst white males and females proved to have larger mean subpubic angles of 70.78 and 93.98 degrees, respectively.

The interspinous distance is normally the narrowest part of the pelvic canal through which the baby's head must pass through during birth and should be greater than 10 cm.[53] This however is not a fixed distance. Increased levels of sex hormones and *relaxin*, causes the pelvic ligaments to relax during the latter half of pregnancy, allowing increased, movement of the pelvic joints. Relaxation of the sacroiliac joints and the pubic symphysis permits increases of as much as 10-15 % in the transverse and interspinous diameters. This facilitates the passage of the fetus through the pelvic canal. The one diameter that remains unaffected is the true conjugate diameter.[53]

Pelvic differences also reflect climatic variation in body build and proportions. These variations between South African populations are expected to be different to those observed elsewhere, e.g. African-Americans and European-Americans. Due to temporal change, founder's effect, and admixture, South African whites have become osteologically distinguishable from both their European and North-American counterparts.[83]

Taking the abovementioned known differences of the pelvis in South African populations into account, specific clinically applied dimensions measured on dried disarticulated as well as intact wet specimens, have not been investigated, and is therefore proposed. These findings, indicating the possible variability in the clinically relevant dimensions of the pelvis in South Africans should have an impact on the initial assessment of patients as well as planning surgical procedures as outlined before.

As previous studies regarding pelvic dimensions was performed on African-American and European-American women[10, 46, 72, 73, 76], this data may not correlate with the unique South African population.[11, 46] There are known significant metric variations concerning the pelvis among Caucasoid populations in North America and Europe and South Africa.[1]

CPD is common among Africans and is a major cause of maternal and perinatal mortality and morbidity.[46] It will therefore be of value to determine whether certain population groups or individual body variations are more likely to be associated with pelvic diameters favouring vaginal delivery or not. In addition these diameters can be useful when planning procedures involving other pelvic organs and structures and will be discussed below.

As nutrition influences pelvic size and stature, it has been suggested that that women with poor nutrition are shorter in stature and have smaller pelvic brims than women with better nutrition.[84] To distinguish a malnourished woman from a genetically short woman, Baird established threshold height and suggested that malnourished women, whose growth was shunted at development, are below 5'1" (155 cm) in height and have flat pelvic brims.

Women between 5’2” and 5’4” (157 cm and 163 cm) have smaller pelves in proportion to their height, but their pelves are not pathologically flattened and the pelvic brim shape remains favourable for childbirth.(85)

These impressions were confirmed by a study conducted by Adadevoh et al., who also related the size of the true conjugate with the height of the individual and found that the true conjugate measured a mean distance of 10.61 ± 0.81 cm in 114 Ghanaian subjects without CPD), while the mean heights of the individuals were 157.2 ± 5.69 cm. Those with CPD were found to have a significantly shorter conjugate of 9.54 ± 0.63 cm and a height of 152.68 ± 5.46 cm.(46)

Adadevoh et al.,(46) commented on a study done by Steward et al.,(86) who radiologically determined the true obstetric conjugate in Shona and Zulu women. Among the Shona women, who had major CPD in labour requiring Caesarean-section had a mean maternal height of 151.32 cm and mean true conjugate diameter of 9.9 cm. The Zulu women with major CPD had a mean true conjugate diameter of 9.6 cm. Their heights were not stated. Thus all patients who had CPD in the three populations reviewed, had a mean true conjugate diameter of less than 10.00 cm and a mean maternal height less than 155.00 cm.

In contrast, Adadevoh et al.,(46) also compared a study by Bernard(84) on a group of Scottish women. In this study, the true conjugate was determined radiologically and they found that women with a height of 152 cm a true conjugate of 10.8 cm. Those with a height of 167 cm had a true conjugate of 12.70 cm and showed that the degree of mechanical difficulty in labour was inversely proportional to the patient’s height.

Population and sex both have effects on birth mass. Female neonates were found to be on average 95 g lighter, 0.6 cm shorter and had a head circumference that was 0.6 cm smaller than male neonates. Black neonates were smaller than Hispanic and white neonates. These sex and population group differences were also found to increase with gestational age.(87)

Further, a woman with a height of 146 cm in relation to one of 160 cm, has a 2.5 times higher risk of intra-partum caesarean delivery.(15) Smaller women however, tend to have smaller babies, some of whom will show signs of intrauterine growth restriction; raising the possibility that this biological relationship may protect shorter women from suffering an excess of delivery complications.

Determinants of CPD, as described by these various authors are compared in Tables 2 and 3 respectively.

Table 2. Predisposing characteristics for CPD in the various population groups

Author	Population	Maternal height (cm)	Conjugate (AP) diameter (cm)	Infant birth weight (g)	Infant bi-parietal diameter (cm)
Adadevoh[46]	Ghanaian	152.68	9.54	3101.18	8.45
Steward [86]	Shona	151.32	9.9	-	-
Steward[86]	Zulu	-	9.6	-	-
Bernard[84]	Scottish	152	10.8	-	-
Merchant[15]	Guatemala City	152.3	-	3128	33.8 (head circumference)

Table 3. Characteristics not associated with CPD in the various population groups

Author	Population	Maternal height (cm)	Conjugate (AP) diameter (cm)	Infant birth weight (g)	Infant biparietal diameter (cm)
Adadevoh[46]	Ghanaian	157.2	10.61	2980.40	8.46
Steward[86]	Shona	156.80	11.5	-	-
Steward[86]	Zulu	-	10.4	-	-
Bernard[84]	Scottish	167.64	12.7	-	-

A similar study conducted on the South African population,[16] found that the mean birth mass of females were 3.028 kg as compared to males, which was 3.119 kg. The study was made up of black subjects who constituted the greatest number of the sample size, followed by whites, coloureds, and lastly indians. The exact number of each group was however not stated. The birth mass of children have been consistently used to reflect the wellbeing of communities; as maternal malnutrition, ill-health, and other deprivations are the most commonly cited causes of retarded fetal growth and/or prematurity.

Many pelvic diameters considered, are important in parturition and may vary amongst populations and with stature. Malnutrition may be a factor influencing these diameters directly or indirectly by influencing stature. Nutritional status may also account for the differences between populations due to socio-economic factors.

2.3.1. Relevant pelvic anatomy for parturition and involvement of pelvic viscera

In order to consider the dimensions applied to the abovementioned clinical settings, the following anatomy should be noted:

In humans, the true pelvis is on average larger in females than in males, whereas for other measurements of the skeleton, males have greater values than females.(74)

The cavity of the lesser pelvis is described as being short and curved.(60, 61) It is notably longer in its posterior wall than in its anterior wall. It is bound by the body of the pubis, the rami of the pubis and the pubic symphysis anteriorly and inferiorly. Posteriorly, it is limited by the concave anterior surface of the sacrum and the coccyx. Laterally it is made up of the smooth quadrangular area formed by the pelvic aspect of the fused ilium and ischium.

The pelvic cavity is formed between the pelvic inlet and outlet. The pelvic inlet has been considered before. The inferior pelvic aperture (pelvic outlet) is limited posteriorly by the coccyx and the sacrum, and on each side by the ischial tuberosities. The perimeter of the opening thus consists of three wide notches – the anterior being the pubic arch between the ischiopubic rami, with the two large sciatic notches laterally. These notches are divided by the sacrotuberous and sacrospinous ligaments into the greater and lesser sciatic foramina. Taking into account these ligaments, the inferior aperture is rhomboidal or diamond shaped.

The true (obstetrical) conjugate is described as a diameter measured from the middle of the sacral promontory to the posterosuperior margin of the pubic symphysis. This diameter is anticipated to measure 11.2 cm in traditional western females presenting with a gynaecoid pelvis with a heart shaped brim.[60] This diameter cannot be measured directly during a pelvic exam, because of the presence of the bladder.[53]

The diagonal conjugate may be measured by palpating the sacral promontory with the tip of the middle finger, using the other hand to mark the level of the inferior margin of the pubic symphysis.[53] After the examining hand is withdrawn, the distance between the tip of the index finger (1.5 cm shorter than the middle finger) and the marked level of the pubic symphysis is measured to estimate the true conjugate, which should be 11.0 cm or greater. The length of the diagonal conjugate depends on the height and slope of the pubic bone and is measured as a value larger than the obstetric conjugate length.[75]

The interspinous diameter is described as the greatest width between the ischial spines and forms the dimension of the mid-pelvis. When the fetal head enters the pelvic midplane (between the ischial spines), it is compressed by the narrowing lateral walls of the passage and consequently rotates so that its long axis lies anteroposteriorly.[74]

A narrow pelvic outlet predisposes to a difficult vaginal delivery. A rapid assessment of the outlet adequacy may be made by estimating the angle of the subpubic arch.[57] This angle is subtended by the inferior border of the pubic symphysis and the ischial tuberosities on each side. The smaller the angle, the closer together the ischial tuberosities are and therefore, the narrower the pelvic outlet.

2.4. Metric assessment of differences in South African pelves

2.4.1. Metric assessment of the population differences in South African pelves

A study conducted by Patriquin et al., found that most of the pelvic measurements taken, including the pubic height, showed a statistically significant difference ($p < 0.001$) between black and white male and female pelves. It was also found, that all dimensions were larger in whites than in blacks, with the exception of the greater sciatic notch's anterior width in males.(1) These findings were consistent with earlier studies demonstrating size differences in other parts of the skeleton in South African black and whites.(4, 88, 89)

Populations differ with regards to robusticity, degree of sexual dimorphism and body size, thus making the use of measurements from one population to another unreliable.(90)

2.4.2. Metric assessment of the sex differences in South African pelves

A study conducted by Patriquin(2) found significant differences ($p \leq 0.001$) between the sexes within population groups. She also found that the mean metric values for males exceeded most corresponding females' measurements (once again including the pubic height). Robusticity, as well as child bearing modifications, play a role in producing metric manifestations of sexual dimorphism.(2, 74)

2.5. Assessment of shape differences in pelvic morphology in South African pelves

Pelvic shape differences include that of the pubic bone and the ischial tuberosity orientation, amongst others, which could influence SUI procedures. The pubic bone shape differs between sexes. Females were associated with a more rectangular shape and males a more triangular shape. The orientation of the ischial tuberosity is posterolaterally in males, while anterolaterally in females.(4)

Morphological characteristics of the skeleton are often difficult to assess due to a number of factors, such as inter- and intra- observer errors(56, 91) and the experience of the observer(56, 91-93). This may be a great disadvantage to the researcher, as potentially important morphological information may be overlooked.

Geometric morphometric analysis has proved to be a valuable and reliable alternative to verify morphological characteristics observed with more traditional methods.[56, 91] This analysis allows the researcher to visually identify the exact areas of the morphological structure that causes the variations between the specimens or the groups.[91] It provides the researcher with useful visual information when applied to the study of differences between skeletal features. The exact areas of morphological structure that cause the variation between specimens or groups can be visually identified.[56] It is a relatively new method to quantify the shape of rigid structures that have curves and bulges that are not easily analysed by traditional metric methods. It therefore seems to be the most reliable method when doing metric and morphological shape studies directly on the physical structures involved.

2.6. Stature

There are various ways to estimate stature from bones, but the easiest and most reliable method is by regression analysis.[94-96] In the past, scientists have used each and every bone of the human skeleton; right from the femur to metacarpals in estimation of stature. They all have reached a common conclusion that stature can be estimated with great accuracy even from the smallest bone although; they have encountered a small error of estimate in their studies.

Some authors have used fragments of the long bones i.e. upper or lower end, but most frequently, long bones have been used in the determination of stature because they give relatively better accuracy in the prediction of stature.[96] Lundy and Feldesman[97] relates formulae for estimating stature in male and female black South Africans. The research was based on the development of regression formulae from the metric assessment of long bones with data obtained from 175 male and 122 black female South Africans belonging to the Raymond Dart Collection, University of Witwatersrand, Johannesburg.

Dayal et al., similarly developed regression formulae for the estimation of antemortem stature using white male and female South Africans.[98] The regression formulae for total skeletal height were derived from metric assessment of the lengths of the femur, tibia and four other long bone measurements. These included the maximum length of the humerus, radius, ulna and fibula. The sample comprised of 98 white male and 71 white female skeletons from the Raymond Dart Collection and Pretoria Bone Collection.

It has been suggested that certain morphological features observed in certain sex groups may be associated with the stature of that individual.[4] South African white males have longer bones and are thus taller than their American counterparts.[91] Therefore, in South Africa, what may be "medium" stature for a white individual, may be tall for a black South African.[99]

Previous impressions precluded that the size and shape of the birth canal is dependent on the height of the individual. If this is true, other pelvic dimensions might also be dependent on height. This needs to be confirmed on the study group at hand.

2.7. Aim

The aim of this study is to assess the possible variations of the dimensions of the pelvis, relevant to the clinical applications considered, for South African groups.

Research objectives

1. To measure distances between applicable landmarks on wet intact pelves and dry disarticulated os coxae.
2. To determine whether there is a significant difference between the sexes, population groups and body variations (including height differences) when considering clinically relevant measurements involving bony landmarks.
3. To determine the degree of shape variation that exists between the sexes and population groups on the wet intact pelves using 3DXL MicroScribe® Digitizer and Morphologika.

4. To apply this knowledge to predict the adaptations necessary in each surgical procedure according to sex, population group and body variations.

3. Materials and Methods

3.1. Measurements on dry disarticulated os-coxae

3.1.1. Materials

A total of 303 disarticulated dry os coxae from the Pretoria Bone Collection were sampled. The sample represented both sexes and two South African population groups i.e. black and white. The sample distribution between the groups is presented in Table 4. The sample consisted of 84 white males, 100 black males, 64 white females and 55 black females. The population group and sex of the individuals were derived from the records reserved at the Pretoria Bone Collection.[100] The height was derived from femur lengths by established formulae.[97, 98]

Table 4. Distribution of the total number of dry disarticulated os coxae

	White	Black	Total
Male	85	100	185
Female	63	55	118
Total	148	155	**303**

The population groups considered in this study includes white and black South Africans. White South Africans are mostly of European descent, primarily from the Netherlands, France, Germany, Great Britain and Portugal. However, due to temporal change, founder's effect, and admixture, South African whites have become osteologically distinguishable from both their European and North American counterparts.[1, 89, 101] Although the South African black group is composed of several different ethnic groups, osteological differences amongst them are not great enough to justify separation.[102] South African blacks are significantly different from other African and American blacks.[3]

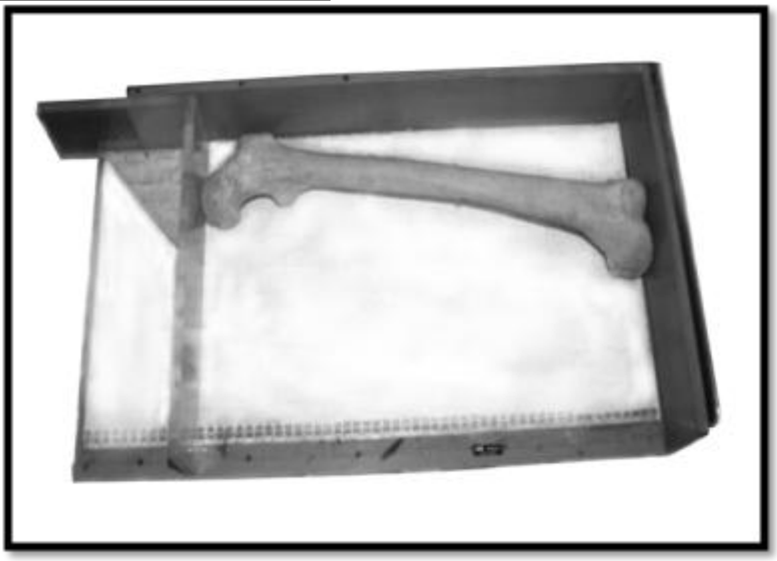
Skeletal remains demonstrating pathology, surgical alteration, skeletal abnormality or deformity were excluded as it could have an effect on the measurements done.[98]

3.1.2. Methodologies

Apart from the known sex and population group, it was necessary to determine the height of the individuals studied. Height estimations were made from measured femur lengths. Femur lengths were taken using an osteometric board, standardized to the nearest millimetre shown in Figure 2. Measurements were taken using the left femur only. The points were marked with a standard HB pencil and ruler.

Femur length was measured on an osteometric board using the technique described by Moore-Jenson et al., as it is easy to use, reliable and produces repeatable measurements. The maximum length of the femur is defined as the distance from the most superior point on the head of the femur to the most inferior point on the distal condyles. The posterior surface of the femur was placed parallel to the long axis of the osteometric board. The medial and lateral condyles were pressed against the vertical endboard while applying the movable upright to the femoral head until the maximum length was obtained.[103]

Figure 2. Osteometric board



Metric assessments were made on the dried left os coxae from the research collection. All measurements were taken using a sliding digital calliper calibrated in millimetres. The five points marked on the dry left os coxae (L) relating to dimensions of the obturator foramen is represented in Figure 3.

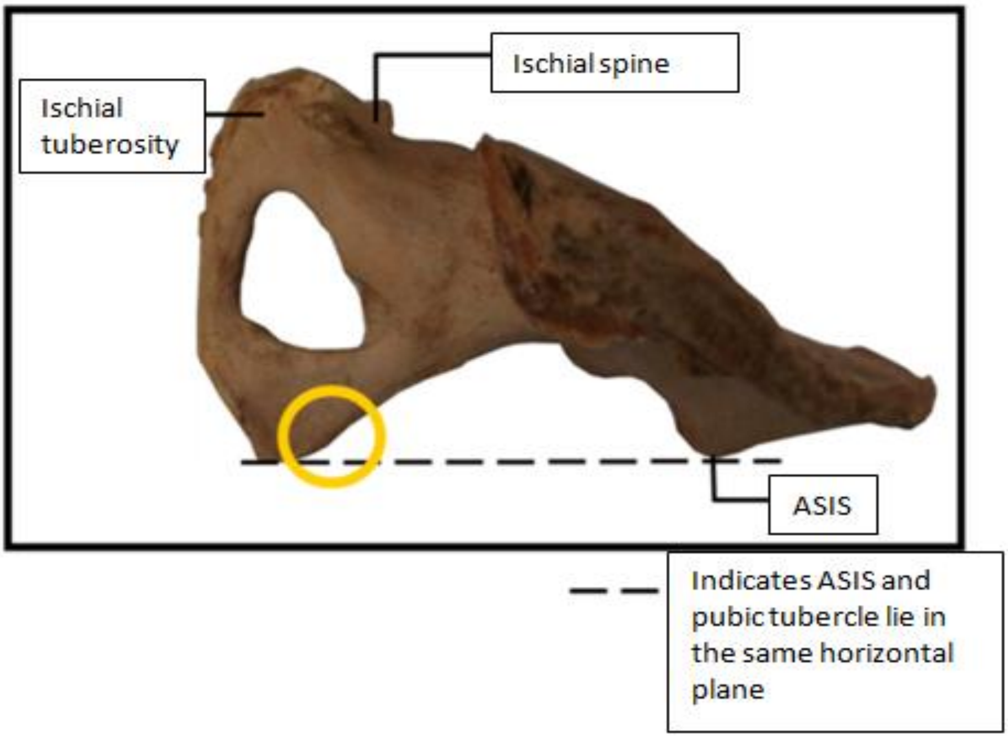
Figure 3. Landmarks marked on dry disarticulated os coxae

A_L. Pubic tubercle
B_L. Most superior point of the obturator canal
C_L. Most medial point of the obturator foramen
D_L. Most inferior point of the obturator foramen
E_L. Most inferior point on the ischial tuberosity

Following, is a description of how the five points were established.

A_L. Pubic tubercle: This point is marked by inverting the hemi-pelvis so that the anterior superior iliac spine (ASIS) and pubic tubercle lie in the same horizontal plane (against a flat surface on a table). The most prominent forward projecting point that is in direct contact with the horizontal surface is marked. (Figure 4)

Figure 4. Pubic tubercle encircled as seen from the pelvic surface of the os coxae

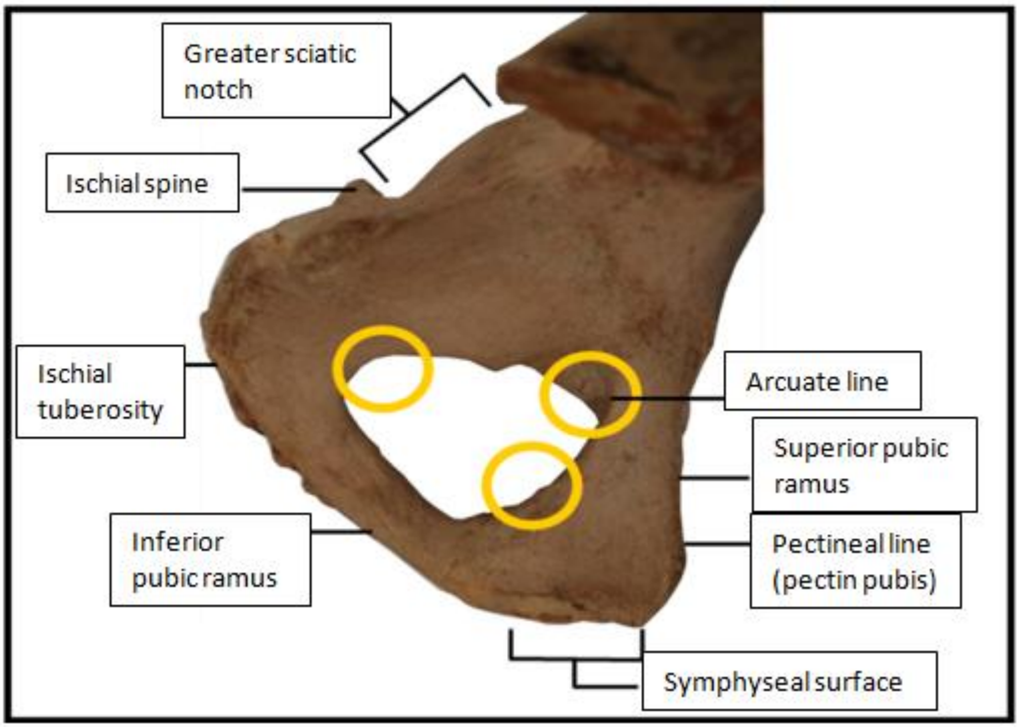


B_L. The most superior point of the obturator canal: The hemi-pelvis is placed on a flat surface with the acetabulum facing inferiorly. This allows the obturator foramen to be clearly viewed by the observer. (Figure 5)

$C_{L.}$ The most medial point of the obturator foramen: This is viewed by positioning the bone as before. (Figure 5)

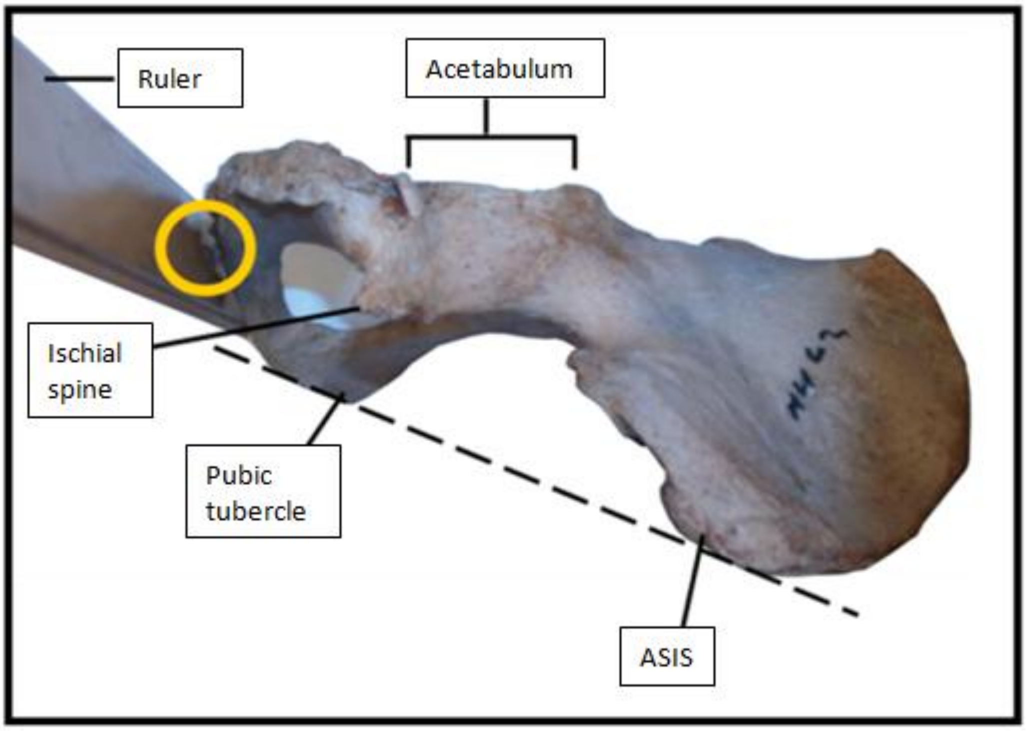
$D_{L.}$ The most inferior point of the obturator foramen: This is viewed by positioning the bone as before. (Figure 5)

Figure 5. Points related to obturator canal and foramen encircled as viewed from gluteal surface of the os coxae



E_L. Most inferior point on the ischial tuberosity: This point is marked by inverting the hemi-pelvis so that the anterior superior iliac spine (ASIS) and pubic tubercle lie in the same horizontal plane (as for measurement (A). A perpendicular plane to the surface is created by sliding a ruler against the ischial tuberosity. The contact between the ruler forming the tangent to the bone is regarded as the most inferior point on the ischial tuberosity. (Figure 6)

Figure 6. Most inferior point on the ischial tuberosity viewed from the gluteal aspect of the os coxae



After defining the abovementioned landmarks, the following measurements were taken using a sliding digital calliper. All the measurements are illustrated in Figure 7 and 8.

Table 5. List of measurements taken on dry disarticulated os coxae

Measurement	**Definition**
A-B_L	Distance between the pubic tubercle and the most superior point of the obturator canal
A-C_L	Distance between the pubic tubercle and the most medial point of the obturator foramen
A-D_L	Distance between the pubic tubercle and the most inferior point of the obturator foramen
A-E_L	Distance between the pubic tubercle and the most inferior point on the ischial tuberosity
B_L-E_L	Distance between the most superior point of the obturator canal and the most inferior point on the ischial tuberosity
B_L-C_L	Distance between the most superior point of the obturator canal and the most medial point on the obturator foramen
Inferior pubic ramus width	This measurement is achieved by sliding the digital calliper on either side of the inferior pubic ramus until the shortest distance across the bone is measured

Figure 7. Measurements taken on dry disarticulated os coxae (I)

Figure 8. Measurements taken on dry disarticulated os coxae (II)

Verification of the documented height of each specimen was conducted using the methods described by Lundy and Feldesman[97] and Dayal et al.[98]

Estimation of antemortem stature was performed using two methods. The first methodology, revised by Lundy and Feldesman[97], relates to formulae for estimating stature in male and female black South Africans (Tables 6 and 7 respectively). The research was based on the development of regression formulae, from the metric assessment of long bones with data obtained from 175 male and 122 black female South Africans belonging to the Raymond Dart Collection, University of Witwatersrand, Johannesburg. While the final computed living stature may deviate from the actual living stature, Fully[104] found that the deviations were less than ±2 cm.[97, 98, 104]

The second methodology was based on that described by Dayal et al.,[98]. These researchers developed regression formulae for the estimation of antemortem stature using white male and female South Africans (Tables 8 and 9 respectively). The sample consisted of 98 white male and 71 white female skeletons also from the Raymond Dart Collection and Pretoria Bone Collection. The researchers came to a similar conclusion to that made by Lundy and Feldesman[97]; that femur measurements demonstrate the highest correlation with total skeletal height. The first step was similar to that described by Lundy and Feldesman[97]. The author highlight that the derived formulae are population specific and are designed for the use of forensic analysis of South African whites.

These regression formulae are specific for each South African population group only, and are not suitable for stature estimation in other population groups as recommended by multiple authors.[97, 98, 104] The values used in each table are derived from the below-mentioned formula:

Total skeletal height (TSH) = intercept + [bone length (cm) X slope] ± standard error of estimate (SEE).

This formula is symbolic of the equation representing a straight line:

$y = mX + c$

The intercept represents the minimum possible height obtained, while the slope quantifies the steepness of the line. The slope therefore is equal to the change in Y for each unit change in X. The main purpose of the standard error values is to compute the 95% confidence intervals. Considering the assumptions of linear regression, there is a 95% probability that the 95% confidence interval of the slope contains the true value of the slope, and that the 95% confidence interval for the intercept contains the true value of the intercept.

The living stature is then determined by adding Raxter's value for soft tissue.

Table 6. Formulae for estimating stature in male South African blacks (revised from Lundy and Feldesman)

Bone measurements	Intercept	Slope	r	SEE
Femur(physiol)	45.721	2.403	.896	2.777

Add Raxter's value for soft tissue:

Stature = 1.009 x TSH (in cm) – 0.0426 x age + 12.1

Stature = 0.996 x TSH (in cm) +11.7

Table 7. Formulae for estimating stature in female South African blacks (revised from Lundy and Feldesman)

Bone measurements	Intercept	Slope	r	SEE
Femur (physiol)	27.424	2.769	.896	2.789

Add Raxter's value for soft tissue:

Stature = 1.009 x TSH (in cm) – 0.0426 x age + 12.1

Stature = 0.996 x TSH (in cm) +11.7

Table 8. Equations for estimating living stature in South African white males (revised from Dayal)

Bone measurements	Intercept	Slope	r	SEE
Femur (physiol)	51.17	2.30	0.92	2.64

Add Raxter's value for soft tissue:

Stature = 1.009 x TSH (in cm) – 0.0426 x age + 12.1

Stature = 0.996 x TSH (in cm) +11.7

Table 9. Equations for estimating living stature in South African white females (revised from Dayal)

Bone measurement	Intercept	Slope	r	SEE
Femur (physiol)	34.69	2.64	0.93	2.40

Add Raxter's value for soft tissue:

Stature = 1.009 x TSH (in cm) – 0.0426 x age + 12.1

Stature = 0.996 x TSH (in cm) +11.7

3.2. Measurements on wet intact pelves

3.2.1. Materials

A total of 80 intact cadaver pelves from the anatomy departments of both, the University of Pretoria and the School of Medicine, Medunsa Campus at the University of Limpopo were sampled. Both sexes of two South African population groups, i.e. black and white were represented in the sample. The distribution between the groups is shown in Table 10. The sample consisted of 20 white males, 20 black males, 20 white females and 20 black females. Eight black females were sampled from the University of Pretoria and the rest of the black females were supplemented from the collection housed at Medunsa. The population group and sex of the skeletal remains were derived from the records at both centres.

Table 10. Distribution of the total number of wet intact pelves

	White	**Black**	**Total**
Male	20	20	40
Female	20	20	40
Total	40	40	**80**

Any skeleton that exhibited features that would affect the measurements such as pathology, surgical procedures or any skeletal abnormality or deformity were excluded from this study as this may influence the measurements.

The pelves were previously dissected and partially defleshed in preparation to be macerated and skeletonised without disarticulating the pelves. This facilitated the identification of bony landmarks and the measurements.

Cadavers used in this study that have been obtained from Medunsa, have all been received between 2007 and 2009 as unclaimed bodies from the Leratong Hospital in the Krugersdorp area and therefore, have similar origins as those from the Pretoria Bone Collection discussed earlier.

3.2.2. Methodologies

As with the measurement of the dry left os coxae, stature was derived using femur length measurements.

Points were marked and measurements were taken using a sliding digital calliper and spreading calliper calibrated in millimetres. Measurements were taken using the left femur and fully articulated pelves only.

The first set of measurements relates to perineal procedures: the application of transobturator tape procedures and application of bone anchors for treatment of stress urinary incontinence (SUI), and rectal incontinence procedures. The perineal and obturator regions of each cadaver were marked and dissected. The points that were marked with ordinary pins and the corresponding measurements that were taken were divided into two sets. Points marked on the left were indicated by '$_L$' and points marked on the right are indicated with by an '$_R$'. The descriptions of the points taken, as well as the methods used, are listed in table 11.

The following seven points were marked: (Figure 9)

Figure 9. Landmarks on wet intact pelves for perineal procedures

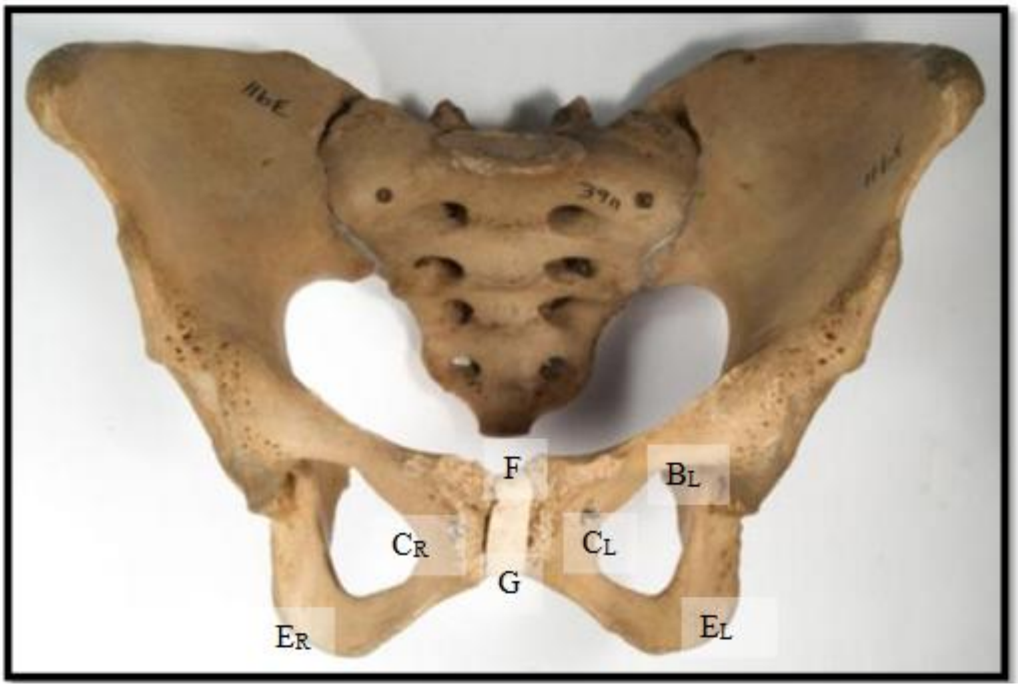


Table 11. Descriptions of the landmarks on the wet intact pelves for perineal procedures

Point	Description	Methods
B_L	Most superior point on the obturator canal (left)	With pelvis in the same position as before and just tilting the pelvis slightly toward the observer, the most superolateral point on the obturator foramen can be distinguished and marked
C_L	The most medial point of the obturator foramen (left)	Both these points were visualized by positioning the bone in a vertical position (ischial tuberosity in contact with a flat surface against a wooden block)
C_R	The most medial point of the obturator foramen (right)	
E_L	Most inferior point on the ischial tuberosity (left)	Identification of both these points required that the pelvis be situated in anatomical position with pubic symphysis and anterior superior iliac spine in the same vertical plane and both ischial tuberosities firmly placed against the flat surface of a table. The point that makes direct contact with the table on each respective side was marked
E_R	Most inferior point on the ischial tuberosity (right)	
F	The most superior point in the midline of the pubic symphysis	This point was identified by stabilizing the pelvis on the sacrum allowing easy accessibility to the pubic region. This was achieved by resting the pelvis against a wooden block. The most superior point in the midline of the pubic symphysis uniting the superior pubic rami of the right and left pubic bones was marked
G	The most inferior point in the midline of the pubic symphysis	The pelvis was placed in the same position as before. The most inferior point on the midline of the pubic symphysis uniting the inferior pubic rami of the right and left pubic bones was marked

Table 12. Definition of measurements taken on wet intact pelves for perineal procedures (Illustrated in Figures 10 and 11)

Measurement	**Definition**
C_R-C_L	Interobturator foramina distance
F-G	Pubic symphysis length
F-B_L	Distance between the most superior point on the pubic symphysis to the obturator canal
G-B_L	Distance between the most inferior point on the pubic symphysis to the obturator canal
F-E_L	Distance between the most superior point on the pubic symphysis to the most inferior point on the left ischial tuberosity
G-E_L	Distance between the most inferior point on the pubic symphysis to the most inferior point on the left ischial tuberosity (length of the ischiopubic ramus)

Figure 10. Measurements taken on wet intact pelves for perineal procedures (I)

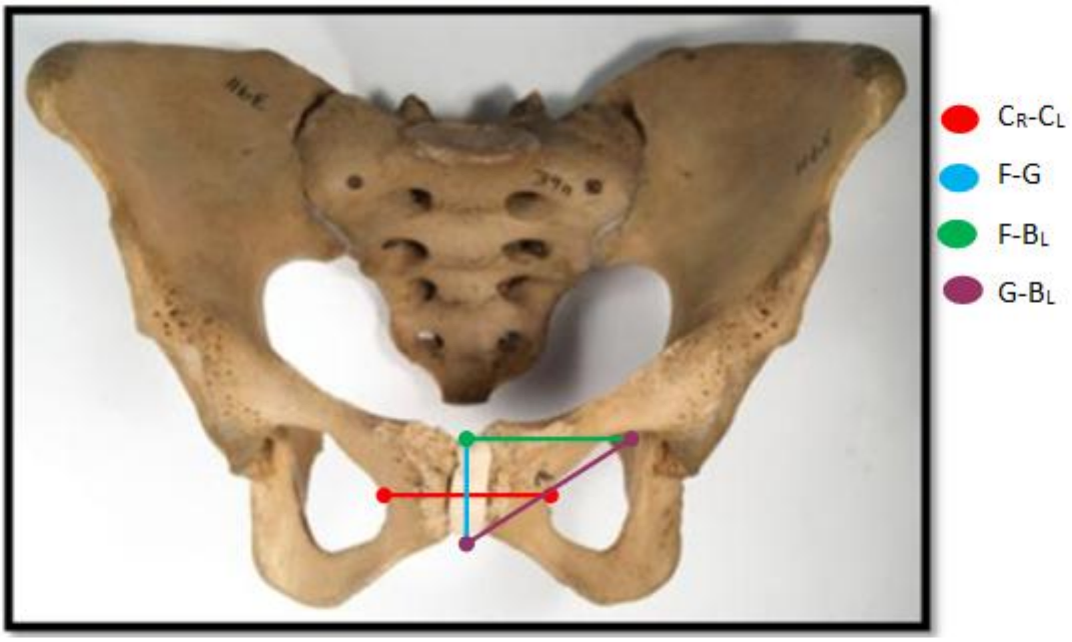
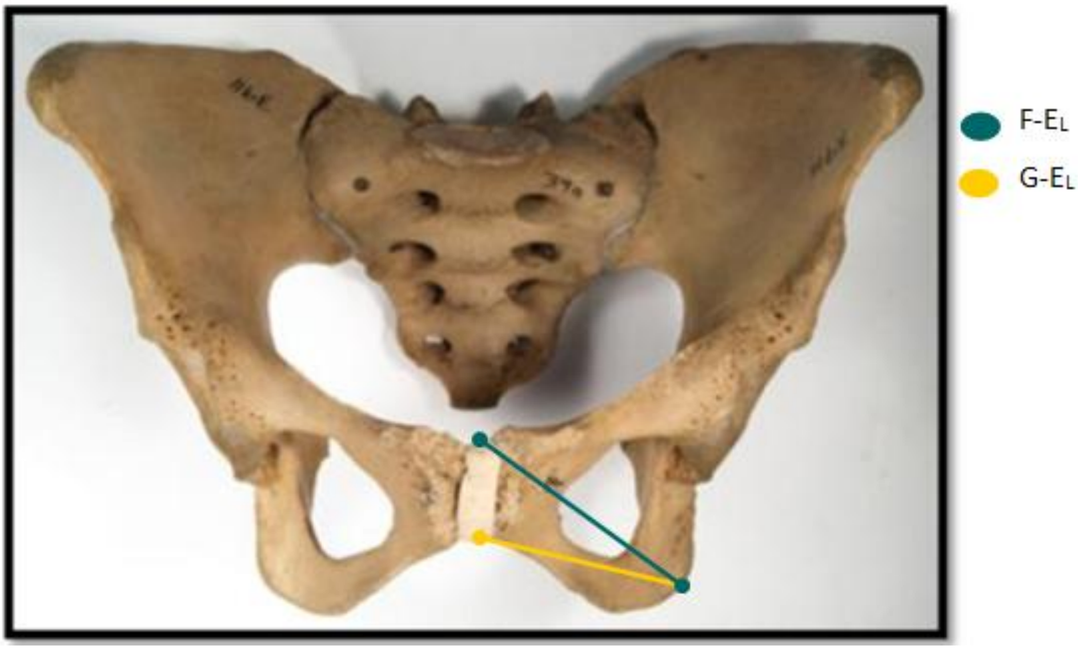
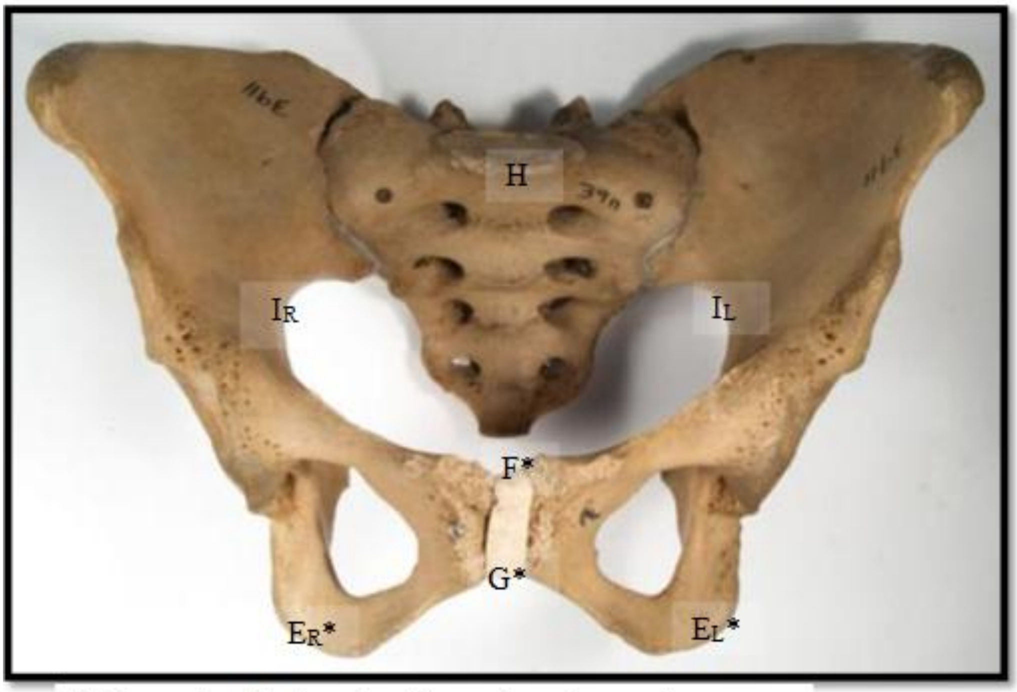


Figure 11. Measurements taken on wet intact pelves for perineal procedures continued (II)



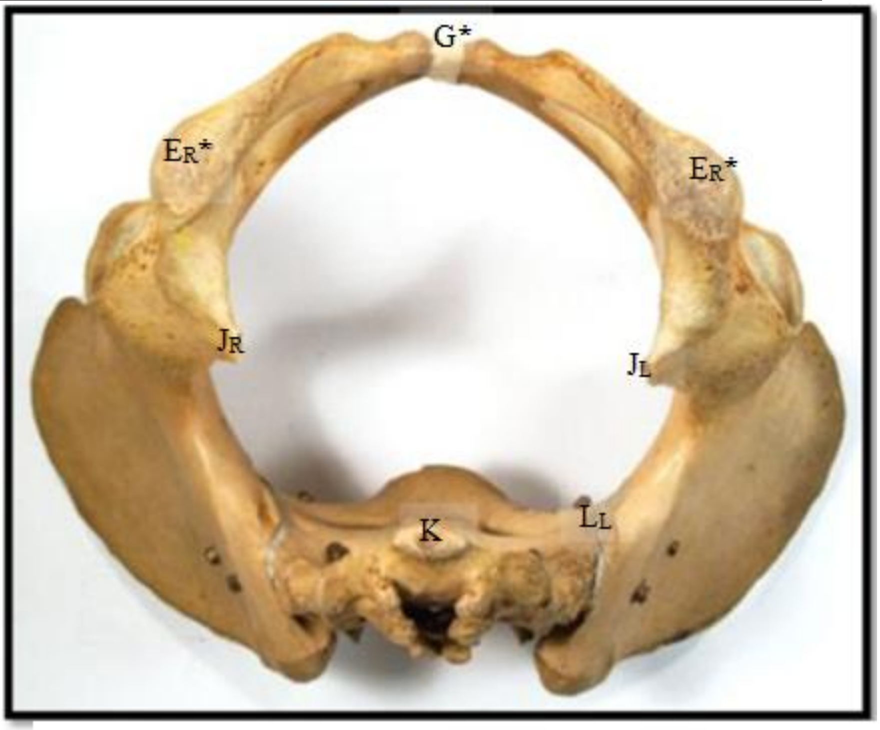
The second set of measurements relates to obstetrics and intrapelvic clinical applications, such as retropubic prostatectomy and rectal cancer procedures. The following eleven points were marked (Figure 12 and 13):

Figure 12. Landmarks on wet intact pelves for intrapelvic applications



*Points already described for perineal procedures

Figure 13. Landmarks on wet intact pelves for intrapelvic applications



*Points already described for perineal procedures

Table 13. Descriptions of the landmarks on the wet intact pelves for intrapelvic applications

Point	Description	Method
H	Midpoint of the sacral promontory	The pelvis is stabilized in an upright position against a wooden block. The pelvis is observed from a superior point of view.
I_L	Most widely separated points in the diameter of the pelvic inlet (left)	Both these points are identified with the pelvis positioned in the same manner as above. This allowed maximum efficiency for the use of the sliding digital calliper.
I_R	Most widely separated points in the diameter of the pelvic inlet (right)	
J_L	Ischial spine (left)	The pelvis was turned over so that it rested on the pubis. The pelvis could now be viewed from inferiorly.
J_R	Ischial spine (right)	
K	Lowest limit of coccyx	
L_L	Midpoint of the lateral border of the sacrum (left)	The pelvis was placed vertically, resting on the coccyx and ischial tuberosities.

After defining the abovementioned landmarks, the following measurements were taken and are described in Table 14. All the measurements are illustrated in Figures 14 and 15.

Table 14. Definition and techniques of measurements taken on wet intact os-coxae for intrapelvic applications

Measurement	Definition
F-H	Pelvic inlet antero-posterior (AP) diameter
I_R-I_L	Pelvic inlet transverse diameter
J_R-J_L	Pelvic outlet interspinous diameter
E_R-E_L	Pelvic outlet ischial tuberosity diameter
K-G	Pelvic outlet AP diameter
J_L-L_L	Distance between the left ischial spine and the left lateral border of the sacrum

Figure 14. Measurements on wet intact pelves for intrapelvic applications as seen from anteroinferiorly

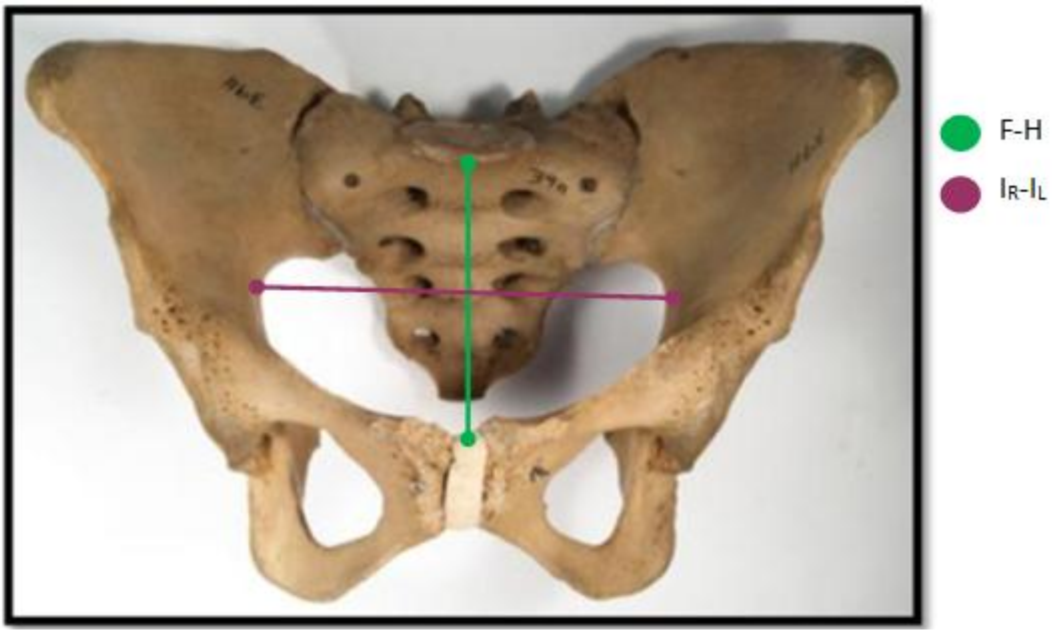
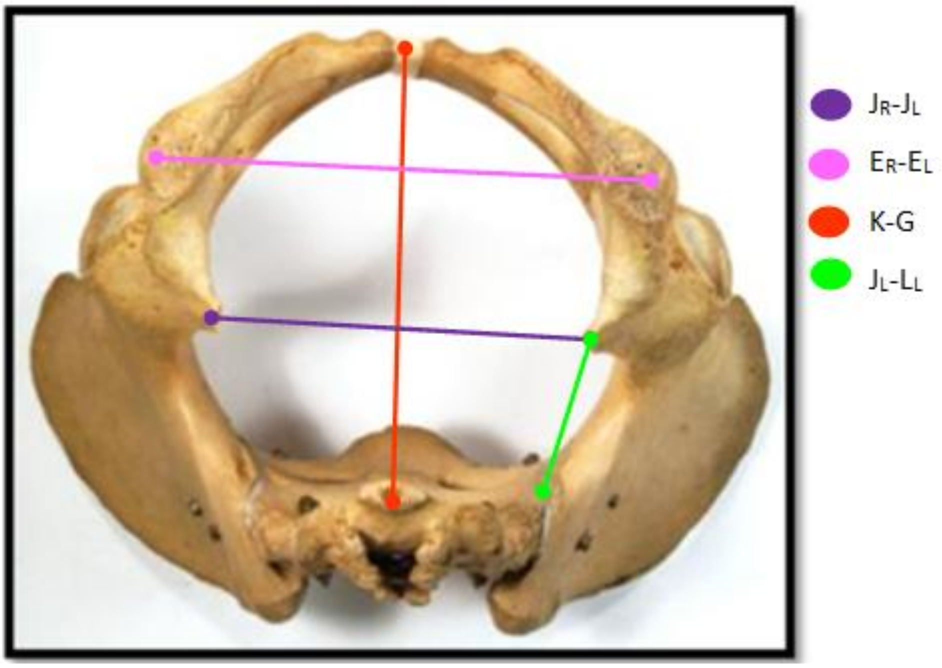


Figure 15. Measurements on wet intact pelves for intrapelvic applications as viewed from posteroinferiorly

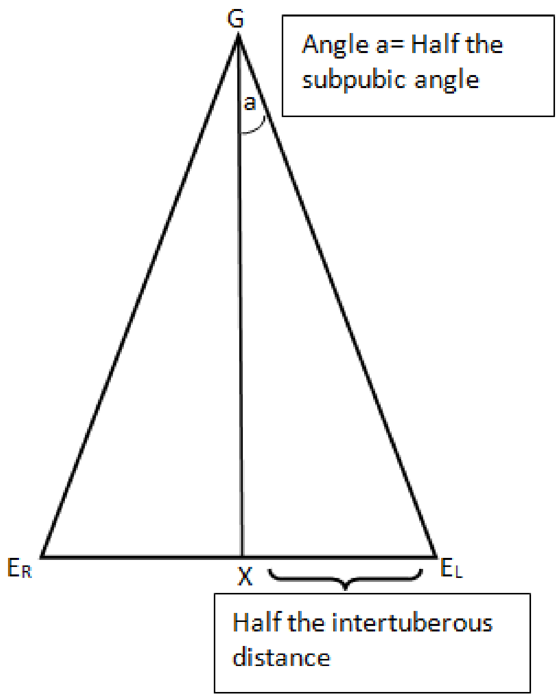


The subpubic angle was calculated mathematically using half of the pelvic outlet ischial tuberosity diameter (E_R-E_L) and the distance from the inferior pubic symphysis to the ischial tuberosity (G-E_L) (illustrated in figure 16). This method assumed bilateral symmetry. The ratio gives the sine of half the subpubic angle.

The mathematical method was chosen to omit the error of using a protractor to measure the angle manually, as it was not possible to create a flat surface to measure this angle accurately on wet specimens. Measurements E_R-E_L and G-E_L could be accurately determined, using a sliding digital calliper up to two decimal places. Other researchers used similar methods to calculate the subpubic angle.(57)

Figure 16. Illustration of measurements used to calculate the subpubic angle

G	The most inferior point in the midline of the pubic symphysis
E_R	Most inferior point on the ischial tuberosity (right)
E_L	Most inferior point on the ischial tuberosity (right)
ER-X/ EL-X	Half the pelvic ischial tuberosity diameter



Method:

Calculation of angle a: $\tan \hat{a} = \frac{(E_R - E_L) \div 2}{(G-X)}$

Therefore the subpubic angle= â X 2

The pelvic inlet AP diameter (measurement F-H or true conjugate) and the pelvic inlet transverse diameter (measurement I_R-I_L) were used in the determination of the pelvic brim index (PBI). The index was computed as the AP inlet diameter divided by the transverse inlet diameter multiplied by 100[(77)]. According to Turner's classification a dolicopellic pelvis shape has a pelvic brim index greater than or equal to 95, a mesatipellic pelvis shape has a pelvic brim index between 91-94 and a platypellic pelvic shape has a pelvic brim index less than or equal to 90.

Correlation of the pelvic brim size to stature was determined, by the method described by Baird[85].

3.3. Statistical analysis of measurements taken

Basic descriptive statistics i.e. the mean, standard deviation and the 95% confidence interval of all the data was performed. Statistical comparisons of parameters were made between the various sex-population groups, as well as comparisons according to stature. Inter-observer errors were tested by re-measuring a total of 30 randomly selected dry disarticulated os coxae using reliability coefficient. The reliability coefficient for the wet intact pelves was also assessed at a later occasion by another observer familiar with the method.

3.4. Geometric morphometric analysis

Some of the marked points were further considered as landmarks for shape analysis. Shape analysis was performed on the wet intact specimens using the 3DXL MicroScribe® Digitizer. The 3DXL MicroScribe® Digitizer is a registered trademark of the Immersion Corporation. The 3DXL MicroScribe® Digitizers provides spatial information about a three-dimensional object to a computer system for a 3D (three dimensional) representation of that object to be manipulated as digital data. The 3DXL MicroScribe® Digitizer consists of mechanic linkages ending in a stylus that allows the user six degrees of motion in a three dimensional space. This is the ability to move forward/backward, up/down, and left/right (i.e. *x, y* and *z* positions). This is combined with three perpendicular axes', which is roll, pitch and yaw orientations. As the movement along each of the three axes is independent of each other, and independent of the rotation about any of these axes, the motion indeed has six degrees of freedom.[105, 106]

The stylus is used as a probe devise to trace over the surface of the 3D object and thereby provide the spatial coordinate data of the object to the host computer system via a standard

RS-232 serial port. The computer is then able to receive the precise data points at different spatial coordinates. The position and orientation of the stylus is uniquely determined by the configuration of the five-linkage arm. The arm can be assembled by placing the joints of the arm in joint fixtures at the desired distance and angle apart. The stylus is fixed to one end of a series of mechanical linkages, and the other end of the linkage chain is connected to a base fixed to a stationary surface.[105, 106]

Sensors are included in the joints of the linkage chain to sense the relative orientation of linkages, and therefore where the stylus is located with respect to the base. The angle data read by the sensors can be converted into coordinate data by the microprocessor. The sensors of the probe apparatus are zeroed by placing the probe apparatus in the only possible home position.[105, 106]

In this way, 3D repetitive landmarks of an object are determined by the 3DXL MicroScribe® Digitizer with click of the hand switch. The X, Y and Z coordinates of each 3D landmark appears on a Microsoft excel chart of a linked laptop, which can later be used with the free soft ware programme: Morphologika2 v2.5 for shape analysis.[105]

Shape analysis was performed on all the intact pelves by introducing the data into Morphologika2 v2.5. The landmarks were grouped into those of the obturator foramen area as well as the pelvic inlet landmarks, pelvic outlet landmarks and pelvic canal landmarks (which included those of the pelvic inlet and outlet). A generalized full procrustes analysis was performed. This function eliminates the influence of size, rotation and translation of the pelvis. In doing so, the landmarks from each specimen could be superimposed and the shape variation between the pelves could be compared to each other and assessed.[105, 106]

The distribution of variance were plotted for principle component 1 and 2 to visually evaluate the scattering patterns amongst the groups as well as demonstrate the deformation of the mean shape by wireframe images for instance the pelvic inlet shape

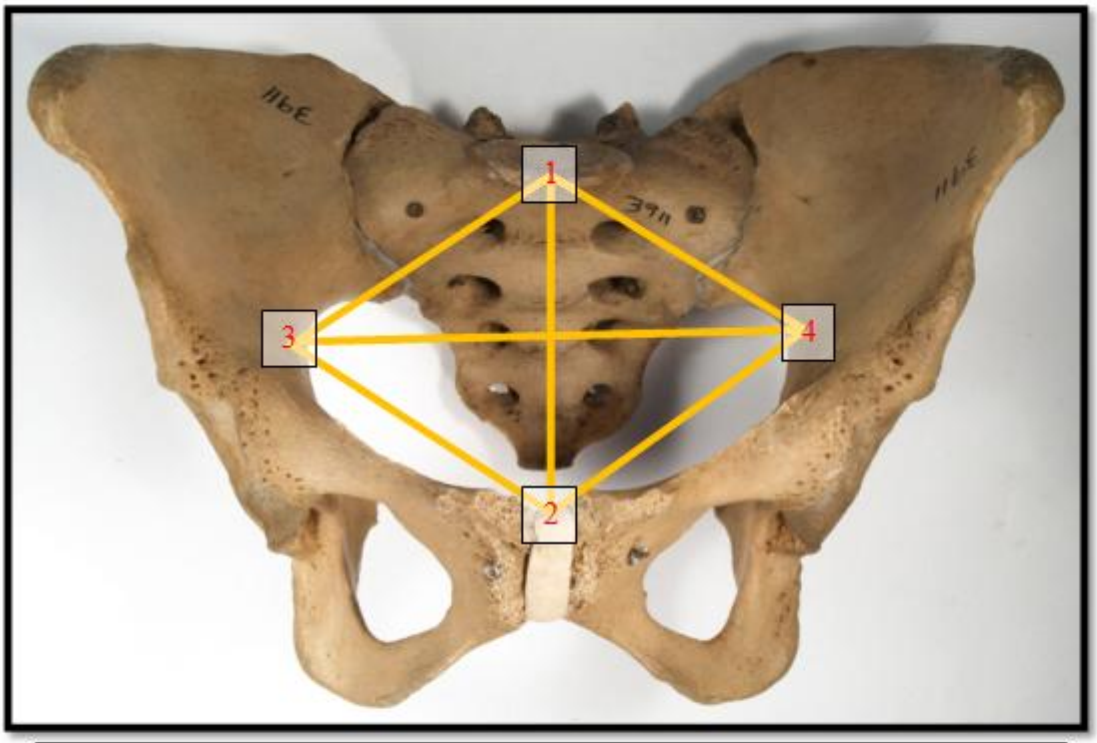
Morphologika2 v2.5 was used to compare the shapes of the pelves between the populations. Wireframe rendering was utilized and principal procrustes analysis using principal component 1 and 2 was performed.

The points marked in both males and females pelves, relating to the dimensions of the obturator foramen are shown in Figure 17. The points marked for both males and females pelves, relating to the pelvic inlet are shown in Figure 18, the points marked for both males and females pelves relating to the pelvic outlet are shown in figure 19. Lastly, points marked for both the inlet and outlet describing the pelvic canal is shown in figure 20. An antero-inferior view is depicted in figure 20 while a lateral view in figure 21.

Figure 17. Landmarks used in shape analysis of points implicated in transobturator procedures

1. F- Most superior point in the midline of the pubic symphysis
2. G- Most inferior point in the midline of the pubic symphysis
3. C_L. Most medial point of the obturator foramen (left)
4. B_L - Most superior point of the obturator canal
5. E_L- Most inferior point on the ischial tuberosity (left)

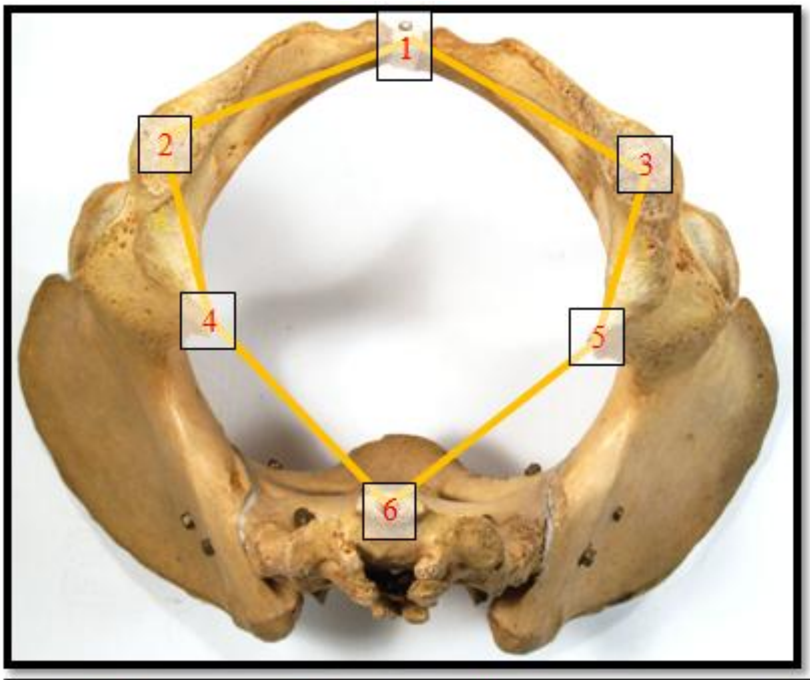
Figure 18. Landmarks used in shape analysis for the pelvic inlet



1. H- Midpoint on sacral promontory
2. F- Most superior point in the midline of the pubic symphysis
3. I_R- Most widely separated points in the diameter of the pelvic inlet (right)
4. I_L- Most widely separated points in the diameter of the pelvic inlet (left)

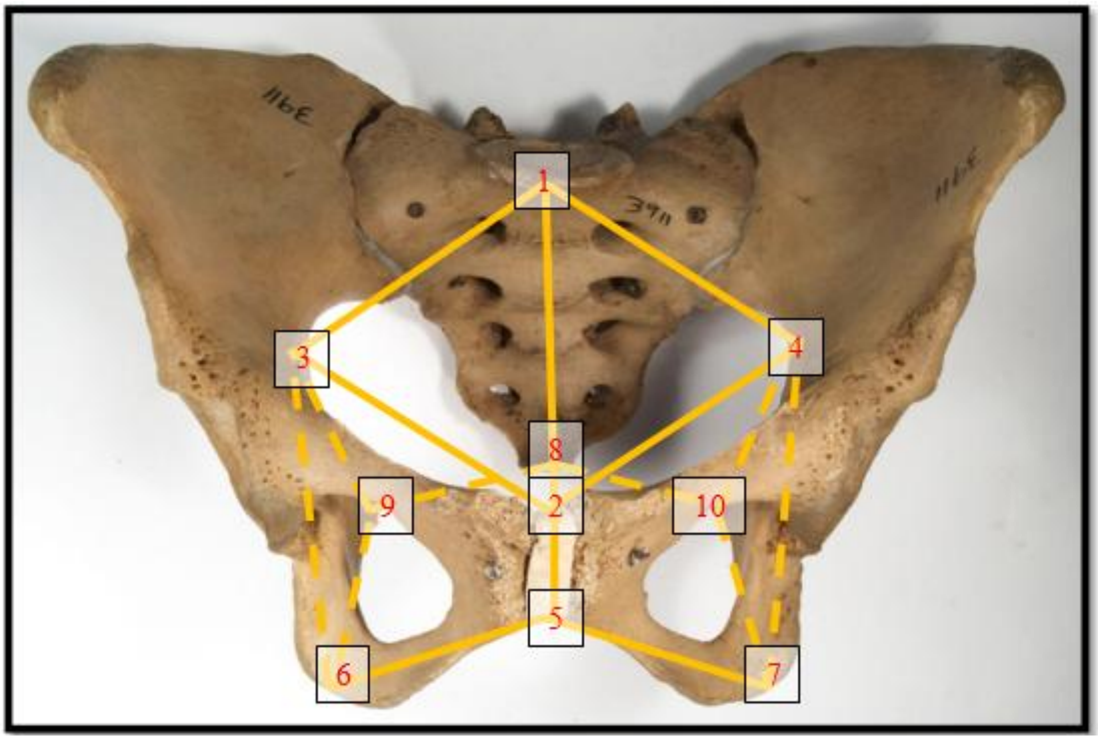
The 4 landmarks on the pelvic inlet are incorporated, to classify the pelvic inlet according to the system proposed by Greulich and Thomas[78] and Gray's Anatomy[60, 61]. If the AP and transverse diameter axis intersects in approximately the midline: a gynaecoid inlet is defined; when the transverse axis crosses the AP axis more posteriorly, a more android shaped pelvic inlet is defined; when the transverse inlet axis crosses the AP axis anteriorly it represents a more anthropoid shaped pelvis and lastly the platypelloid shaped inlet where the AP axis is narrower than the transverse axis.

Figure 19. Landmarks used in shape analysis for the pelvic outlet



1. G- Most inferior point in the midline of the pubic symphysis
2. E_R- Most inferior point on the ischial tuberosity (right)
3. E_L- Most inferior point on the ischial tuberosity (left)
4. J_R- Ischial spine (right)
5. J_L- Ischial spine (left)
6. K- Lowest limit of coccyx

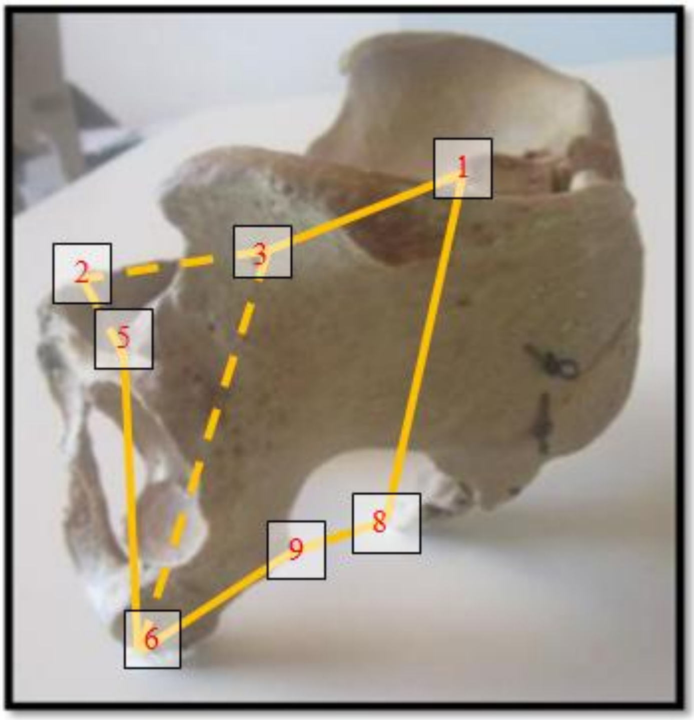
Figure 20. Landmarks used in shape analysis for the pelvic canal (seen from an anterior)



1. H- Midpoint on sacral promontory
2. F- Most superior point in the midline of the pubic symphysis
3. I_R- Most widely separated points in the diameter of the pelvic inlet (right)
4. I_L- Most widely separated points in the diameter of the pelvic inlet (left)
5. G- Most inferior point in the midline of the pubic symphysis
6. E_R- Most inferior point on the ischial tuberosity (right)
7. E_L- Most inferior point on the ischial tuberosity (left)
8. K- Lowest limit of coccyx
9. J_R- Ischial spine (right)

10 J_L- Ischial spine (left)

Figure 21. Landmarks used in shape analysis for the pelvic canal (seen from lateral)



1. H- Midpoint on sacral promontory
2. F- Most superior point in the midline of the pubic symphysis
3. I_R- Most widely separated points in the diameter of the pelvic inlet (right)
5. G- Most inferior point in the midline of the pubic symphysis
6. E_R- Most inferior point on the ischial tuberosity (right)
8. K- Lowest limit of coccyx
9. J_R- Ischial spine (right)

After visual evaluation of the scattering pattern for principle component 1 and 2, PAST, PAleontological STatistics v1.92 was used to test for statistical significant differences between groups.

3.5. Clinical applications of all measurements taken

All clinical situations considered in the determination of the distances to be measured were reconsidered to evaluate the effect of intergroup variations. Table 15 represents the procedures considered as well as their clinically relevant dimensions.

Table 15. Dimensions applied in the clinical procedures considered

Procedures→ Measurements taken on dry disarticulated os coxae↓ Measurements taken on wet intact pelves↓		TVT	Mini-arc and TOT	Rectal incontinence procedures	Sacrospinous colpopexy	Bone anchors	4 Arm sling	Bulbourethral sling	RRP	Rectal cancer	Obstetrics
Description of dimensions	Dimensions										
Around obturator foramen	$A\text{-}B_L$, $A\text{-}C_L$, $A\text{-}D_L$, $A\text{-}E_L$ $B\text{-}E_L$, B-C		X	X		X	X	X	X		
	Inf. ramus width		X			X	X	X	X		
Interobturator	$C_R\text{-}C_L$	X	X		X	X	X	X	X		
Pubic symphysis length	F-G	X			X	X	X	X	X		
To obturator canal	$F\text{-}B_L$, $G\text{-}B_L$		X								
To ischial tuberosity	$F\text{-}E_L$,$G\text{-}E_L$			X	X	X					
Obstetric conjugate	F-H				X	X				X	X
Inlet transverse	$I_R\text{-}I_L$									X	X
Outlet interspinous	$J^R\text{-}J_L$										X
Outlet tuberosity	$E_R\text{-}E_L$		X	X			X	X	X		X
Outlet AP	K-G										X
Ischial spine to sacrum	$J_L\text{-}L$				X	X					
	Subpubic angle		X	X			X	X	X		X

3.6. Ethical considerations: National Health Act

The skeletal material originates from two sources: donations and unclaimed bodies. In South Africa, under the National Health Act No. 61 of 2003[(107)], anyone may donate his/her body for tissue transplants, medical training and research. This act also provides for any destitute individual, who dies in a public hospital to have the body donated. If an individual dies in a public institution and is not removed for burial by a spouse, a relative or a friend within 24 h after death, then the body is handed over to an institution such as the University, for the purposes of medical research. The body is defined as unclaimed, even though the identity of the individual may be known. Prior to death, an individual can register as a 'whole body' donor at the Tissue Bank of the Faculty of Health Sciences at the University of Pretoria. After death, a spouse or a family member is also permitted to donate the body, provided that the deceased did not specifically state that his/her body is not to be donated. Donated bodies of individuals over 65 years of age or individuals who had a disease (such as cancer) cannot be used for tissue transplants. These bodies are automatically handed over to the Department of Anatomy for medical training and research.

4. Results

The dimensions of the pelves in the four sex population groups were recorded, and basic descriptive statistics i.e. the mean, standard deviation (SD), range and 95 % confidence intervals of all the data was performed. Statistical comparisons (using two-sample t test with unequal variances) of parameters were made between the various sex- population-groups and correlated to stature. The broad application of this data was to possibly link the stature of the individuals within these groups, to various pelvic dimensions that can be applied to the clinical procedures discussed. Shape analysis was also considered for each of the groups.

4.1. Descriptive and comparative analysis for the dry os coxa

Unilateral measurements taken on the dry os coxa are illustrated in figure 22 and the statistical analysis of this data is represented in Table 16.

Figure 22. Unilateral measurements taken on dry disarticulated os-coxae

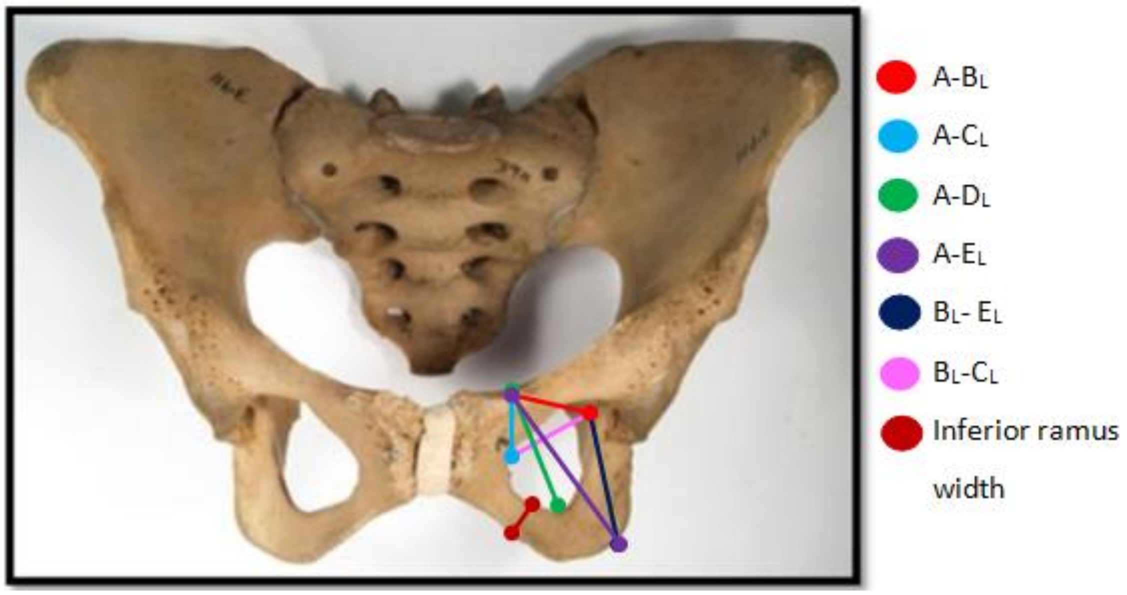


Table 16. The mean (mm), SD, range, 95% confidence intervals and significance between the four sex-population groups for unilateral measurements on dry os coxae

Parameter	**1** (N=55)	**2** (N=63)	**3** (N=100)	**4** (N=85)
A-B_L	**37.92** *5.57* (26.75- 55.11) [36.42- 39.43]	**39.51** *4.79* (29.31-54.42) [38.30- 40.71]	**38.88** [a c] *4.39* (29.65-51.25) [38.01- 39.74]	**40.47** [a] *5.09* (16.65-51.51) [39.37- 41.57]
A-C_L	**29.56** [a b] *3.63* (20.02- 38.58) [28.57- 30.54]	**31.70** [a b] *4.200* (22.87- 42.26) [30.64- 32.76]	**31.81** [a b c] *3.20* (24.04-41.62) [31.18- 32.45]	**34.60** [a b] *4.64* (25.39- 56.81) [33.59- 35.60]
A-D_L	**72.29** [a b] *5.53* (59.33- 83.03) [70.80- 73.79]	**76.27** [a b c] *5.30* (63.45- 95.39) [74.93- 77.60]	**77.13** [a b c] *5.35* (62.81-88.34) [76.07- 78.19]	**79.45** [a b c] *6.53* (44.99-91.25) [78.04- 80.86]
A-E_L	**86.13** [a b] *7.07* (70.01- 102.73) [84.22- 88.04]	**92.99** [a b] *6.31* (79.81- 105.63) [91.40- 94.58]	**90.66** [a b c] *7.48* (66.89-117.28) [89.18- 92.13]	**99.06** [a b c] *6.81* (83.05-119.22) [97.59- 100.53]
B_L-E_L	**67.57** [a b c] *5.44* (56.52- 82.43) [66.10- 69.04]	**73.10** [a b c] *5.02* (62.02- 84.16) [71.83- 74.36]	**74.20** [a b c] *5.05* (58.42-95.11) [73.20- 75.19]	**80.12** [a b c] *5.65* (66.12-92.45) [78.90- 81.34]
B_L-C_L	**23.53** *4.45* (14.03- 35.12) [22.33- 24.73]	**24.79** *3.23* (18.23- 34.37) [23.98- 25.60]	**24.05** *6.73* (14.84-28.49) [22.72- 25.38]	**24.06** *3.73* (13.88-34.57) [23.26-24.86]
Inf. pubic ramus width	**10.25** [a b] *3.10* (3.49- 15.41) [9.42- 11.09]	**11.90** [a b] *3.46* (3.98- 20.64) [11.03- 12.77]	**13.73** [a b c] *2.31* (8.12-20.92) [13.27- 14.19]	**15.09** [a b c] *3.45* (7.64-22.43) [14.34- 15.83]
Stature (cm)	**156.09** [a b] *5.98* (141.88- 167.53) [154.47- 157.70]	**161.83** [a b] *6.15* (145.38- 173.25) [160.28- 163.38]	**166.57** [a b] *5.52* (154.17- 180.98) [165.48- 167.66]	**169.95** [a b] *6.28* (155.90- 190.26) [168.58- 171.31]

The four sex-population groups are abbreviated in Table 1 as follows: 1= black females; 2= white females; 3= black males; and 4= white males. The number per group is indicated by N values. The mean (mm) values are indicated in **bold.** The standard deviation is indicated in *italics,* the range is shown within the round (brackets) and the 95% confidence intervals values are indicated within the square [brackets].

[a] Indicates a significant difference in the mean values between population groups within sex groups
[b] Indicates a significant difference in the mean values between sex groups within population groups
[c] Indicates an interaction between stature

The estimated reliability of the mean was high, except for the distance between the pubic tubercle and the most inferior point on the ischial tuberosity (measurement $A\text{-}E_L$).

4.1.1. Comparisons between populations within sexes

Mean values for white females were overall greater than those of black females. Six of the eight measurements were significantly larger in white females ($p \leq 0.05$). These are:

- The distance between the pubic tubercle and the most medial point on the obturator foramen ($A\text{-}C_L$)
- The distance between the pubic tubercle and the most inferior point on the obturator foramen ($A\text{-}D_L$)
- The distance between the pubic tubercle and the ischial tuberosity ($A\text{-}E_L$)
- The distance between most superior point on the obturator canal and the most inferior point on the ischial tuberosity ($B_L\text{-}E_L$)
- The inferior pubic ramus width
- The stature

The two dimensions crossing the obturator foramen from medial to lateral showed no significant difference when comparing these two groups: measurements $A\text{-}B_L$ (pubic tubercle to obturator canal) and $B_L\text{-}C_L$ (the most medial point of the obturator foramen to obturator canal).

The distance between the pubic tubercle and the most inferior point on the obturator foramen (measurement $A\text{-}D_L$) showed a correlation to stature in white females only; while the distance between the most superior point on the obturator canal to the most inferior point on the ischial tuberosity (measurement $B_L\text{-}E_L$) showed a correlation to stature in all females.

This is also the case for white males, who have larger mean values than black males for all the measurements. Seven of the eight measurements were significantly larger in white males ($p \leq 0.05$). These are:

- The distance between the pubic tubercle and the obturator canal (A-B_L)
- The distance between the pubic tubercle and the most medial point on the obturator foramen (A-C_L)
- The distance between the pubic tubercle and the most inferior point on the obturator foramen (A-D_L)
- The distance between the pubic tubercle and the most inferior point on the ischial tuberosity (A-E_L)
- The distance between the most superior point on the obturator canal and the most inferior point on the ischial tuberosity and (B_L-E_L)
- The inferior pubic ramus width
- The stature

One dimension crossing the obturator foramen from medial to lateral, measurement B_L-C_L (most medial point on the obturator foramen to obturator canal) was the only measurement that showed no significant difference when comparing these two groups.

The distances between the pubic tubercle to both the inferior point on the obturator foramen (measurement A-D_L) and to the most inferior points on the ischial tuberosity (measurement A-E_L); the distance between the most superior point on the obturator canal to the most inferior point on the ischial tuberosity (measurement B_L-E_L) and the distance across the inferior ramus width showed a correlation with stature in both black and white males. The distance between the pubic tubercle to both the obturator canal and to the most medial point on the obturator foramen (measurements A-B_L and A-C_L respectively) showed a correlation to stature in black males only.

4.1.2. Comparisons between sexes within populations

The mean values for six out of the eight measurements were significantly larger in black males compared to black females ($p \leq 0.05$). These are:

- The distance between the pubic tubercle and the most medial point on the obturator foramen (A-C_L)
- The distance between the pubic tubercle and the most inferior point on the obturator foramen (A-D_L)
- The distance between the pubic tubercle and the most inferior point on the ischial tuberosity (A-E_L)
- The distance between the most superior point on the obturator canal and the most inferior point on the ischial tuberosity (B_L-E_L)
- The inferior pubic ramus width
- The stature

Two dimensions crossing the obturator foramen from medial to lateral: A-B_L (pubic tubercle to the obturator canal) and B_L-C_L (the most medial point on the obturator foramen to the obturator canal) showed no significant differences.

The distance between the obturator canal and the most inferior point on the ischial tuberosity (measurement B_L-E_L) showed a correlation to stature in both black males and females. While, the distances between the pubic tubercle to the most medial and inferior points on the obturator foramen (measurements A-C_L and A-D_L respectively), to the obturator canal (measurement A-B_L) as well as to the most inferior point on the ischial tuberosity (measurement A-E_L) and the distance across the inferior pubic ramus width showed a correlation to stature in black males only.

The mean values for six out of the eight measurements were significantly larger in white males compared to white females ($p \leq 0.05$). These are:

- The distance between the pubic tubercle and the most medial point on the obturator foramen (A-C_L)
- The distance between the pubic tubercle and the most inferior point on the obturator foramen (A-D_L)

- The distance between the pubic tubercle and the most inferior point on the ischial tuberosity (A-E_L)
- The distance between the most superior point on the obturator canal and the most inferior point on the ischial tuberosity (B_L-E_L)
- The inferior pubic ramus width
- The stature

The two dimensions crossing the obturator foramen from medial to lateral that showed no significant differences when comparing these two groups were: measurements A-B_L (pubic tubercle to the obturator canal) and B_L-C_L (the most medial point on the obturator foramen to the obturator canal). Although not significant, measurement B_L-C_L was larger in white females.

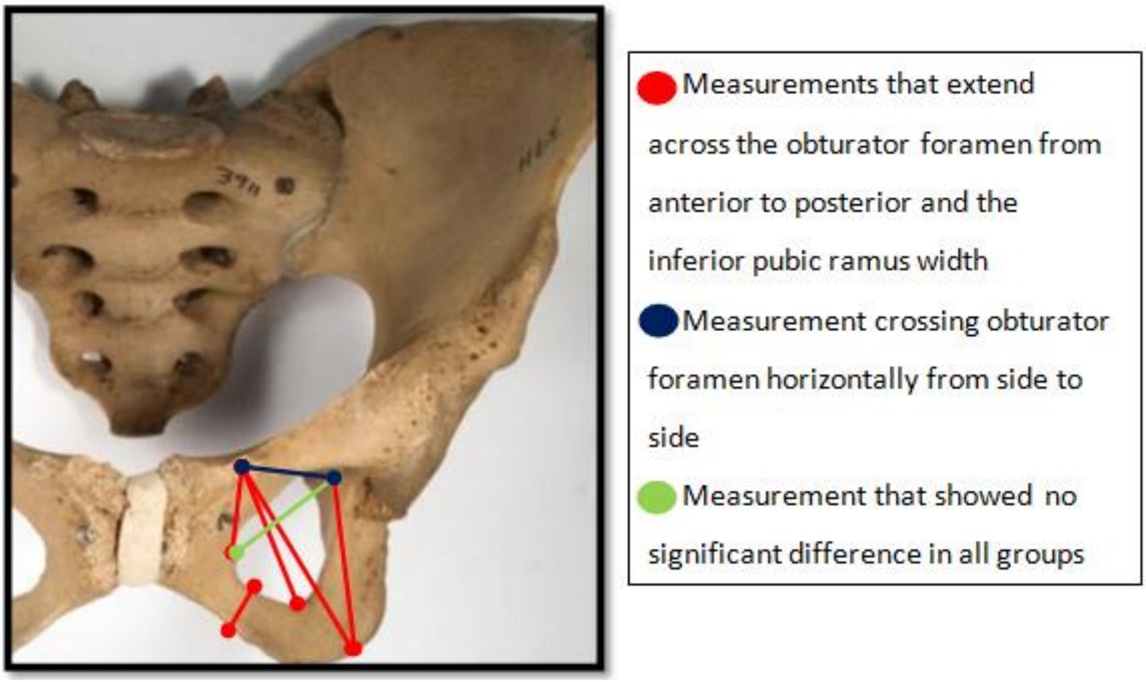
The distance between the pubic tubercle to the most inferior point on the obturator foramen (measurement A-D_L) and the distance between the obturator canal to the most inferior point on the ischial tuberosity (measurement B_L-E_L) showed a correlation to stature in both white males and females. While the distances between the pubic tubercle and the most inferior point on the ischial tuberosity (measurement A-E_L) and the distance across the inferior pubic ramus width showed a correlation to stature in white males only.

<u>Summary of findings</u>

When comparing the populations and sexes, similar dimensions were significantly different between groups. In addition, when comparing males; measurement A-B_L (distance between the pubic tubercle and the obturator canal) were statistically different as well. White males presented with the largest distances across all the points measured as well as tallest stature, followed by white females, black males and lastly black females.

All measurements that extended along the obturator foramen from anterior to posterior showed a significant difference in all groups and were largest in white males. The one measurement crossing the obturator foramen horizontally from side to side: measurement A-B_L (distance between the pubic tubercle and the obturator canal), showed a significant difference only when comparing males. The distance between the most superior point on the obturator canal to the most medial point on the obturator foramen (measurement B_L-C_L) showed no significant differences in any of the groups, and was not influenced by stature. All measurements are illustrated in figure 23.

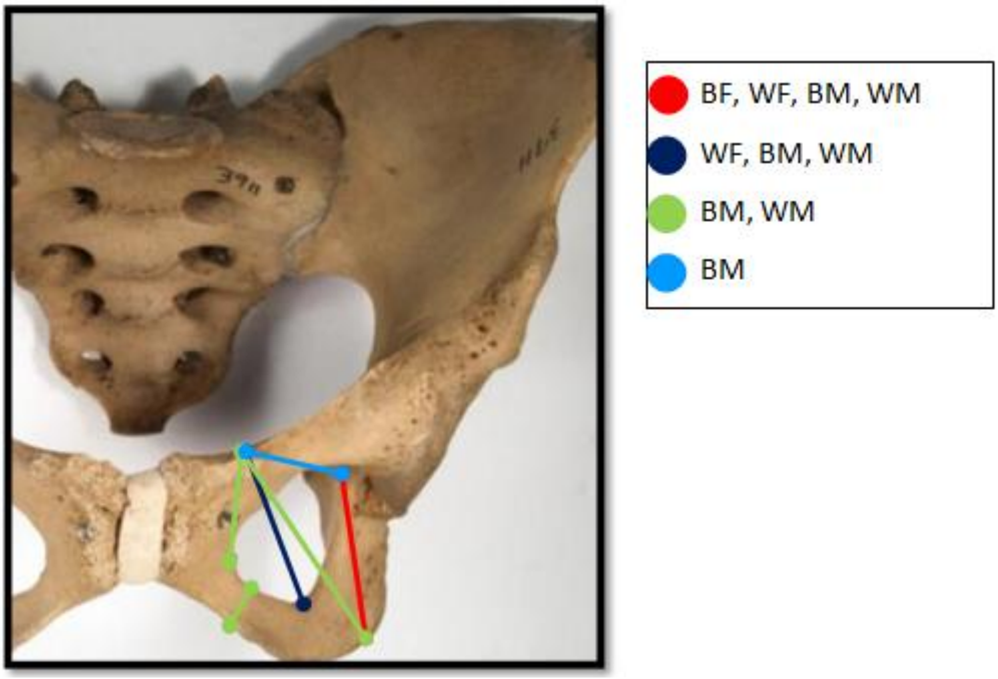
Figure 23. Summary of statistically significant differences for dry os coxae measurements



White males showed a correlation to stature in three of the measurements extending across the obturator foramen from anterior to posterior (i.e. measurements: A-D_L, A-E_L and B_L-E_L) and the distance across the inferior pubic ramus. Black males showed a unique correlation to stature in all but one measurement that extended horizontally across the obturator foramen (i.e. measurement A-B_L).

Females shared a correlation to stature in the one measurement extending along the obturator foramen form anterior to posterior (i.e. measurement B_L-E_L). White females showed a correlation to stature in one additional measurement: measurement A-D_L (distance between the pubic tubercle to the most inferior point on the obturator foramen), as well. All correlations are illustrated in figure 24.

Figure 24. Summary of results, relating the influence of stature to the four groups in dry os coxae



4.2. Descriptive and comparative analysis for the intact pelvis

Reviews of all the first and second sets of measurements taken on the intact pelvis are illustrated in figures 25 and 26. The statistical analysis of this data is represented in table 17.

Figure 25. Measurements taken on the intact pelvis as seen from anterio-inferior

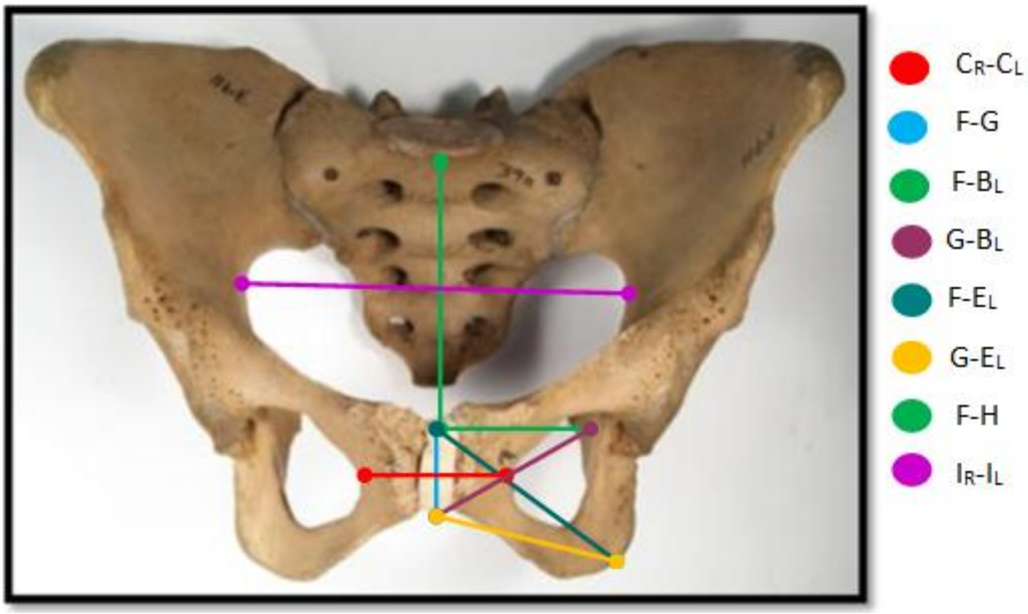


Figure 26. Measurements taken on the intact pelvis as seen from postero-inferior

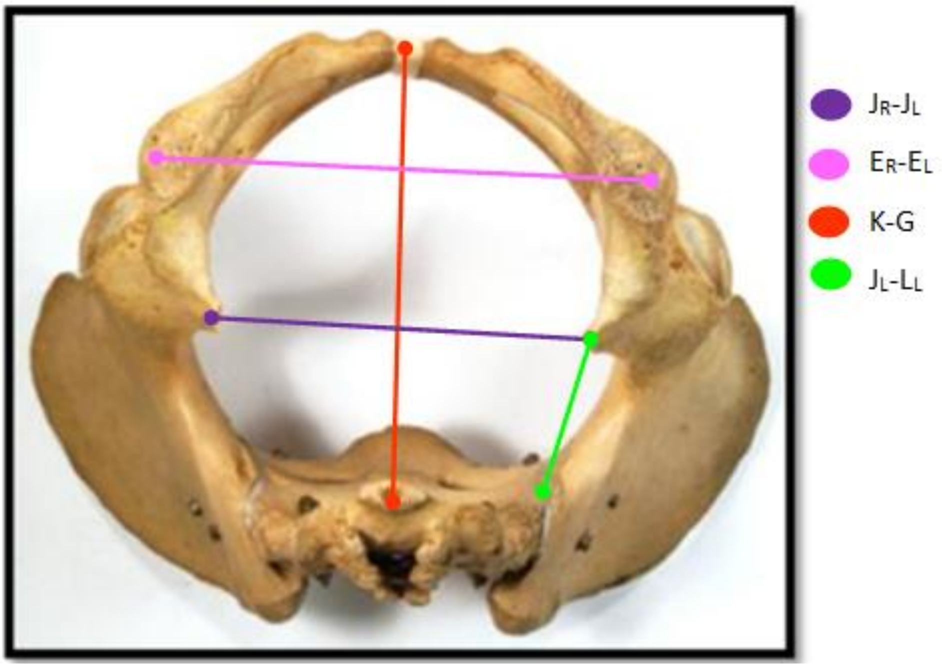


Table 17. The mean (mm), SD, range, 95% confidence intervals and significance between the four sex-population groups

Parameter	**1** (N=20)	**2** (N=20)	**3** (N=20)	**4** (N=20)
C_R-C_L	**56.67** [b] *11.53* (38.52- 77.95) [51.12- 62.23]	**59.34** [b] *4.82* (49.50-67.20) [57.08- 61.59]	**47.46** [a b] *5.77* (35.92- 55.61) [44.76- 50.16]	**54.31** [a b] *4.57* (43.55- 62.26) [52.17- 56.44]
F-G	**42.36** [a] *4.95* (33.59- 50.89) [39.98- 44.75]	**46.28** [a b c] *3.84* (41.03- 56.83) [44.48- 48.08]	**44.96** [a] *5.12* (31.68- 52.38) [42.56- 47.36]	**50.16** [a b] *5.61* (42.77- 60.35) [47.53- 52.78]
F-B_L	**67.25** [a b] *7.16* (52.62- 78.09) [63.80- 70.70]	**71.79** [a c] *5.92* (59.93- 87.90) [69.01- 74.56]	**62.35** [a b c] *6.50* (55.12-76.70) [59.30- 65.39]	**70.65** [a] *4.87* (62.49- 77.70) [68.37- 72.93]
G-B_L	**61.62** [a c] *6.45* (50.33- 61.23) [58.51- 64.73]	**65.21** [a c] *4.40* (56.54- 71.77) [63.15- 67.27]	**57.90** [a c] *5.34* (44.79- 69.78) [55.40- 60.40]	**65.20** [a] *4.87* (55.38- 75.41) [62.93- 67.48]
F-E_L	**97.74** [b] *10. 60* (78.83-116.43) [92.47-103.02]	**103.34** [b] *10.28* (85.59-117.08) [98.53-108.15]	**105.92** [a b] *8.45* (89.53-119.04) [101.96-109.87]	**111.03** [a b] *6.20* (97.62-122.35) [108.13-113.93]
G-E_L	**62.23** *11.06* (39.80-80.33) [57.06- 67.41]	**63.96** *8.29* (46.59-77.49) [60.08- 67.84]	**65.46** *5.49* (57.65-75.88) [62.89- 68.03]	**66.71** *5.15* (57.70-76.99) [64.23- 69.19]
F-H	**119.28** [a c] *7.87* (108.23- 131.19) [115.48- 123.07]	**131.05** [a] *11.77* (109.58- 150.47) [125.54- 136.56]	**115.96** [a c] *9.51* (102.22-135.61) [111.50- 120.41]	**127.84** [a] *7.46* (116.7- 142.66) [124.35- 131.33]
I_R-I_L	**118.84** [a b c] *6.59* (106.12- 135.27) [115.66- 122.02]	**134.18** [a] *7.86* (120.01- 147.26) [130.50- 137.86]	**113.10** [a b c] *7.73* (99.52- 126.73) [109.49- 116.72]	**130.40** [a] *7.18* (116.03- 142.01) [127.04- 133.76]
J_R-J_L	**103.36** [a b c] *10.49* (87.48- 129.70) [98.30- 108.41]	**110.96** [a b] *8.16* (96.63- 124.05) [107.14- 114.78]	**86.08** [a b] *6.78* (76.40- 98.83) [82.91- 89.26]	**98.27** [a b] *6.06* (86.86- 108.72) [95.43- 101.11]
E_R-E_L	**104.46** [b] *24.36* (114.30- 128.64) [92.72- 116.20]	**106.24** [b] *10.87* (90.74- 130.35) [101.15- 111.33]	**83.64** [a b] *8.12* (66.92- 100.47) [79.84- 87.44]	**99.22** [a b] *9.10* (84.18- 119.57) [94.97- 103.48]
K-G	**98.37** [b] *9.50* (75.58- 119.05)	**101.00** *13.46* (78.47- 125.59)	**91.94** [a b] *8.16* (72.80- 109.17)	**98.03** [a] *8.96* (76.73- 116.35)

	[93.80- 102.95]	[94.70- 107.30]	[88.12- 95.76]	[93.84- 102.23]
J_L-L_L	**40.67** [b] *11.27* (30.29- 72.11) [35.24- 46.10]	**43.14** [b] *5.85* (33.49- 53.44) [40.40- 45.88]	**26.39** [a b] *6.58* (16.53- 43.8) [23.31- 29.46]	**33.95** [a b] *6.42* (22.97- 44.69) [30.94- 36.95]
Subpubic angle	**83.97** [b] *10.57* (67.46- 106.63) [78.71- 89.22]	**80.20** [b] *11.14* (60.98- 100.73) [74.98- 85.41]	**65.44** [a b] *7.31* (51.91- 82.14) [62.03- 68.86]	**73.33** [a b] *6.42* (62.16- 83.74) [171.15- 179.0343]
Stature (cm)	**157.78** [a b] *7.64* (143.82- 175.26) [154.10- 161.46]	**163.04** [a b] *5.04* (153.01- 172.20) [160.68- 165.39]	**168.24** [a b] *7.20* (156.32- 186.72) [164.87- 171.62]	**175.38** [a b] *5.04* (153.01- 172.20) [171.57- 179.20]

The four sex-population groups are abbreviated in Table 1 as follows: 1= black females; 2= white females; 3= black males; and 4= white males. The number per group is indicated by N values. The mean (mm) values are indicated in **bold.** The standard deviation is indicated in *italics,* the range is shown within the round (brackets) and the 95% confidence intervals values are indicated within the square [brackets].

[a] Indicates a significant difference in the mean values between population groups within sex groups
[b] Indicates a significant difference in the mean values between sex groups within population groups
[c] The interaction between stature and the various measurement

The estimated reliability of the mean was high for all the measurements taken.

4.2.1. Comparisons between populations within sexes

Seven out of the fourteen measurements considered were significantly larger in white females ($p \leq 0.05$):

- Pubic symphysis length (F-G)
- Distance between the most superior point on the pubic symphysis and the obturator canal (F-B_L)
- Distance between the most inferior point on the pubic symphysis and the obturator canal (G-B_L)
- Pelvic inlet antero-posterior (AP) diameter (F-H)
- Pelvic inlet transverse diameter (I_R-I_L)

- Pelvic outlet interspinous diameter (J_R-L_L)
- The stature

Three out of the six measurements that showed no significant difference between females, were related to the dimensions of the pubis and obturator foramen, and extend from medial to lateral. These include the interobturator foramina distance (measurement C_R-C_L) and the distances between the most inferior point on the ischial tuberosity to both the superior and inferior points on the pubic symphysis (measurements F-E_L and G-E_L respectively).

The other three measurements included the pelvic outlet AP diameter (measurement K-G), the outlet intertuberous diameter (measurement E_R-E_L) and the distance between the left ischial spine and the left lateral border of the sacrum (measurement J_L-L_L).

The calculated subpubic angle measurements did not differ significantly between populations.

Both black and white females, shared a correlation to stature in one distance; between the most inferior point on the pubic symphysis and the obturator canal (measurement G-B_L). The distances related to dimensions of the pelvic inlet (measurements F-H and I_R-I_L) as well as the pelvic outlet interspinous diameter (measurement J_R-J_L) all showed a correlation to stature in black females only. White females showed a correlation to stature in the pubic symphysis length (measurement F-G) and the distance between the most superior point on the pubic symphysis and the obturator canal (measurement F-B_L).

Mean values for all fourteen measurements were overall greater in white males when compared to black males. However, only thirteen measurements were significantly larger in white males ($p \leq 0.05$). The only measurement that showed no significant difference when comparing the populations was the:

- Distance between the most inferior point on the pubic symphysis to the most inferior point on the ischial tuberosity (measurement G-E_L)

Black males showed a correlation to stature in four of the measurements. This included the distances extending from the obturator canal to both the most superior and inferior points on the pubic symphysis (measurements F-B_L and G-B_L respectively) as well as measurements relating to the pelvic inlet (measurements F-H and I_R-I_L) Even though white males presented with larger pelvic sizes including the stature, they showed no correlation to stature in any of the measurements.

4.2.2. Comparisons between sexes within population

Ten of the measurements showed a significant difference when comparing black females to black males ($p \leq 0.05$). Out of these measurements, eight of the mean values were greater in black females. These are:

- Interobturator foramina distance (C_R-C_L)
- The distance between the most superior point on the pubic symphysis to the obturator canal (F-B_L)
- Pelvic inlet transverse diameter (I_R-I_L)
- Pelvic outlet interspinous diameter (J_R-J_L)
- Pelvic outlet ischial tuberosity diameter (E_R-E_L)
- Pelvic outlet AP diameter (K-G)
- The distance between the left ischial spine to the lateral border of the sacrum (J_L-L_L)
- The subpubic angle

The remaining two mean values that were greater in black males were:

- Superior point of pubic symphysis to the most inferior point on the ischial tuberosity (F-E_L)
- The stature

Three out of the four measurements that showed no significance between blacks are related to the dimensions of the pubis and the obturator foramen. These include the pubic symphysis length (measurement F-G), the distance between the inferior point on the pubic symphysis to the obturator canal (measurement G-B_L) and the distance between the most inferior point on the pubic symphysis to the most inferior point on the ischial tuberosity (measurement G-E_L). The fourth dimension is related to the pelvic inlet antero-posterior diameter (measurement F-H).

Although the distances G-B_L and F-H showed no significant difference between the sexes, both of these measurements showed a correlation to stature in both sexes. The pelvic inlet transverse diameter also showed a correlation to stature in both sexes. The pelvic outlet interspinous diameters showed a correlation to stature in black females only. Black males showed a correlation to stature in the distance between the most superior point of the pubic symphysis and the obturator canal only.

Eight out of the fourteen measurements showed a significant difference when comparing white females to white males ($p \leq 0.05$). Out of these measurements, five of the mean values were greater in white females. These are:

- Interobturator foramina distance (C_R-C_L)
- Pelvic outlet interspinous diameter (J_R-J_L)
- Pelvic outlet ischial tuberosity diameter (E_R-E_L)
- The distance between the left ischial spine and the left lateral border on the sacrum (J_L-L_L)
- The subpubic angle

The three measurements significantly larger in white males were:

- Pubic symphysis length (F-G)
- Distance between the most superior point on the pubic symphysis to the most inferior point on the left ischial tuberosity (F-E_L)
- The stature

Three out of the six measurements that showed no significant difference between the sexes describe the dimensions of the pubic symphysis and the obturator foramen. This includes the distance between the most inferior point on the pubic symphysis to the most Inferior point on the left ischial tuberosity (measurement G-E_L); and the distances between the obturator canal to both the most superior and inferior point on the pubic symphysis (measurements F-B_L and G-B_L respectively).

The next two measurements are related to the pelvic inlet AP and transverse diameters (measurements F-H and I_R-I_L respectively). The last measurement is related to the pelvic outlet AP diameter (measurement K-G).

The length of the pubic symphysis (measurement F-G) and the distances between the obturator canal to both the most superior and inferior point on the pubic symphysis (measurement F-B_L and G-B_L respectively) are the only measurements that showed a correlation to stature in white females. White males did not show a correlation to stature in any of the measurements.

Summary of findings

The interobturator foramen distances (measurement C_R-C_L), was significantly different between sexes and between black and white males but showed no significant differences when comparing females to each other. White females presented with the largest interobturator foramina distance, followed by black females, white males and lastly black males. This showed no correlation to stature in all four groups.

The measurement describing the length of the pubic symphysis (measurement F-G), was significantly different between populations and between sexes within the white population. The pubic symphysis length was found to be the longest in white males, then white females and black males and lastly black females. This measurement only showed a correlation to stature in white females.

The measurements describing the width of the obturator foramen that extend from medial to lateral (i.e. measurement F-B_L and G-B_L), were significantly different between population groups and F-B_L was also significantly different between sexes in the black population. These measurements showed a correlation to stature in females and black males. White males showed no correlation to stature in any of the above measurements. These are illustrated in figure 27 and 28.

Figure 27. Summary of results for intact pelvic measurements

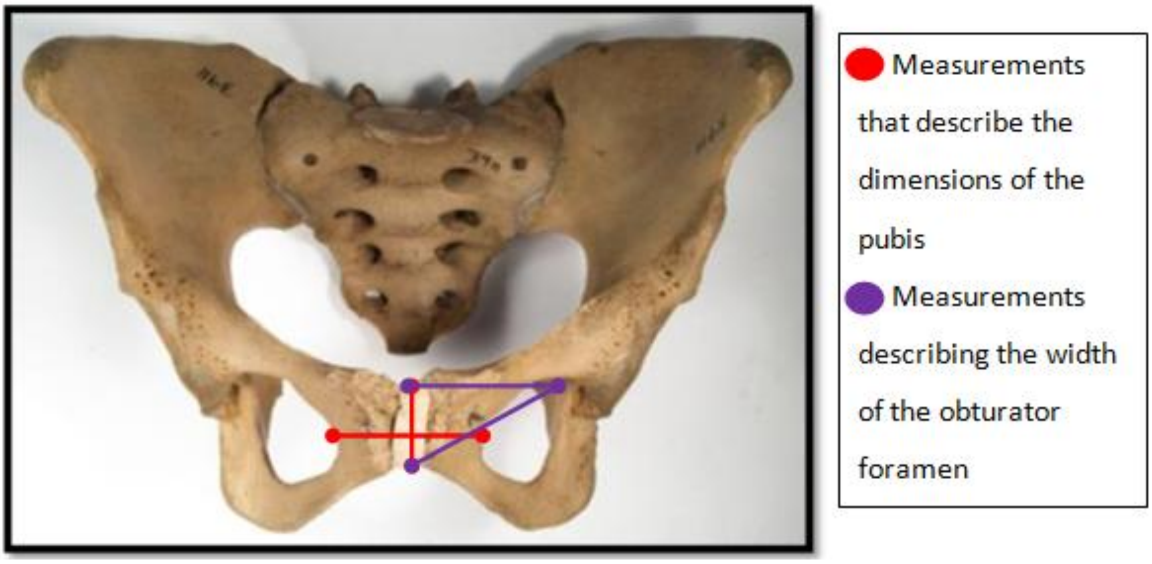
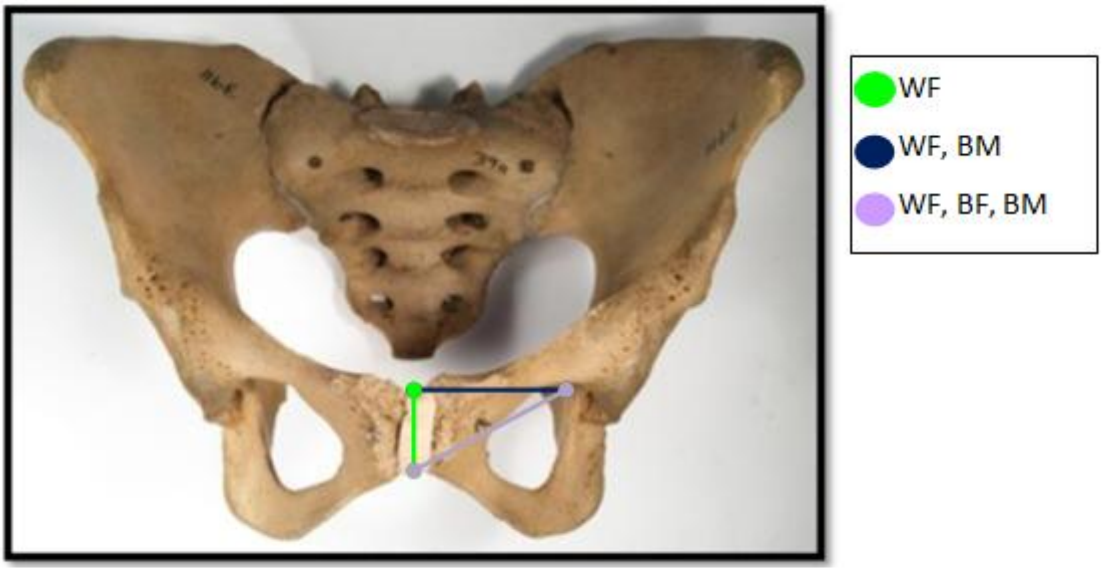


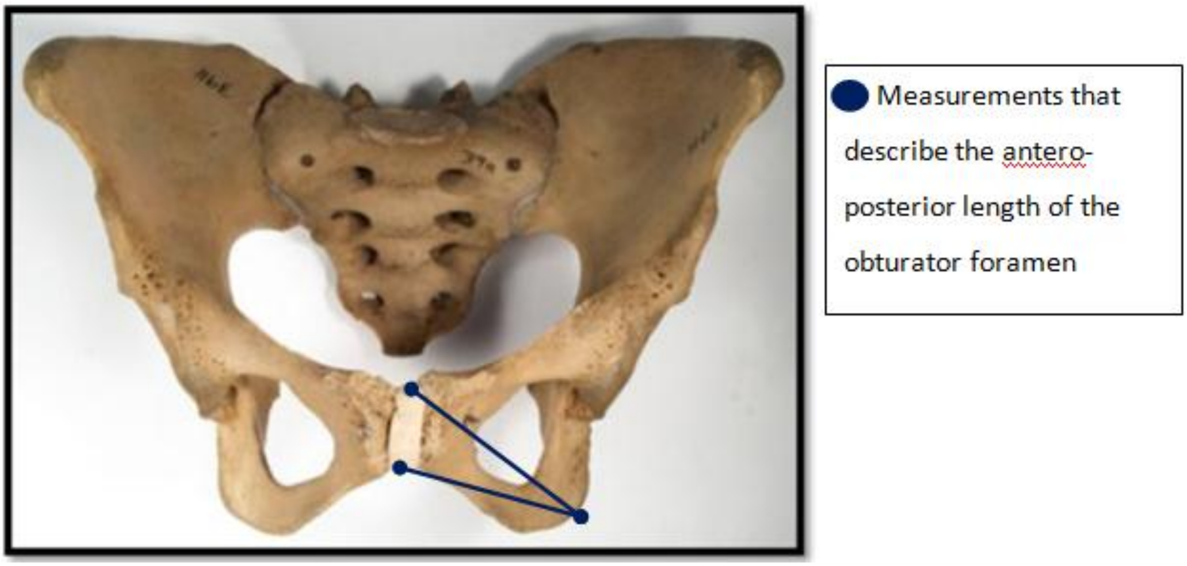
Figure 28. Summary of results relating the influence of stature to the four groups, for intact pelves



Measurements related to the antero-posterior length of the obturator foramen are illustrated in figure 29. Measurement F-E_L did not show a significant difference when comparing black and white females to each other only, but was significantly different between sexes and between black and white males. Measurement G-E_L showed no significant difference when comparing all four groups.

Both of these measurements showed no correlation to stature in all four groups.

Figure 29. Summary of results related to the vertical length of the obturator foramen for intact pelvic measurements



The pelvic inlet measurements are represented in figure 30. These measurements both showed a significant difference when comparing sexes within their population groups. Measurement F-H showed no significant difference when comparing the populations within the sex groups.

Measurement I_R-I_L only showed a significant difference when comparing black females to black males. Both of these measurements were largest in white females, followed by white males, then black females and lastly black males. Also, both of these measurements showed a correlation to stature in the black population. This is represented in figure 31.

Figure 30. Summary of results related to the pelvic inlet for intact pelvic measurements

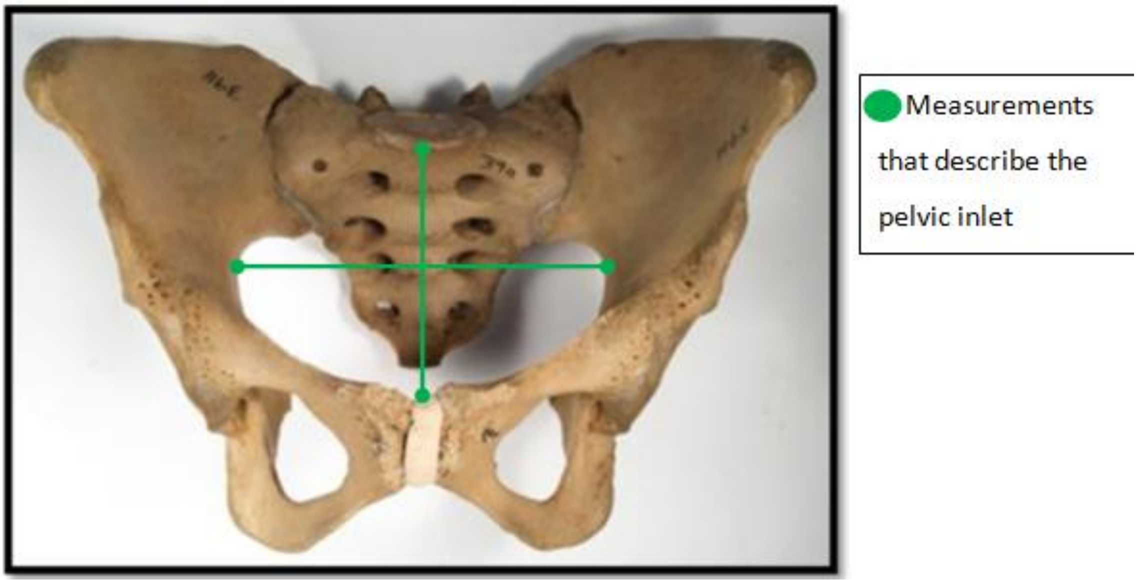
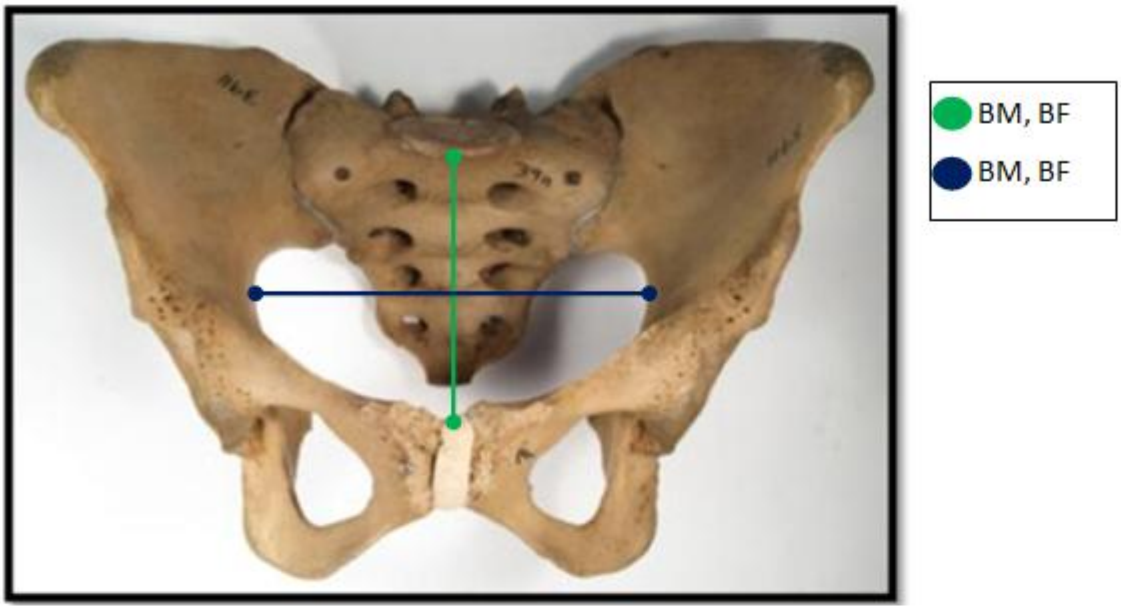


Figure 31. Summary of results relating the influence of stature to the four groups in intact pelves



Pelvic outlet dimensions are shown in figure 32. Measurement J_R-J_L showed a significant difference when comparing all four groups. This measurement was largest in white females, followed by black females, then white males and lastly black males. Black females showed a correlation to stature with this measurement (Figure 33).

Measurement E_R-E_L showed no significant difference when comparing females only. White females presented with the largest mean value, second was black females, thirdly white males and lastly black males.

Measurement K-G only showed a significant difference when within the black populations, and when comparing males. Once again, white females present with the largest measurement, followed by black females, white males and lastly black males.

White females present with the widest pelvic inlet and outlet dimensions in all four groups, while black males present with the smallest measurements.

Figure 32. Summary of results related to the pelvic outlet for intact pelvic measurements

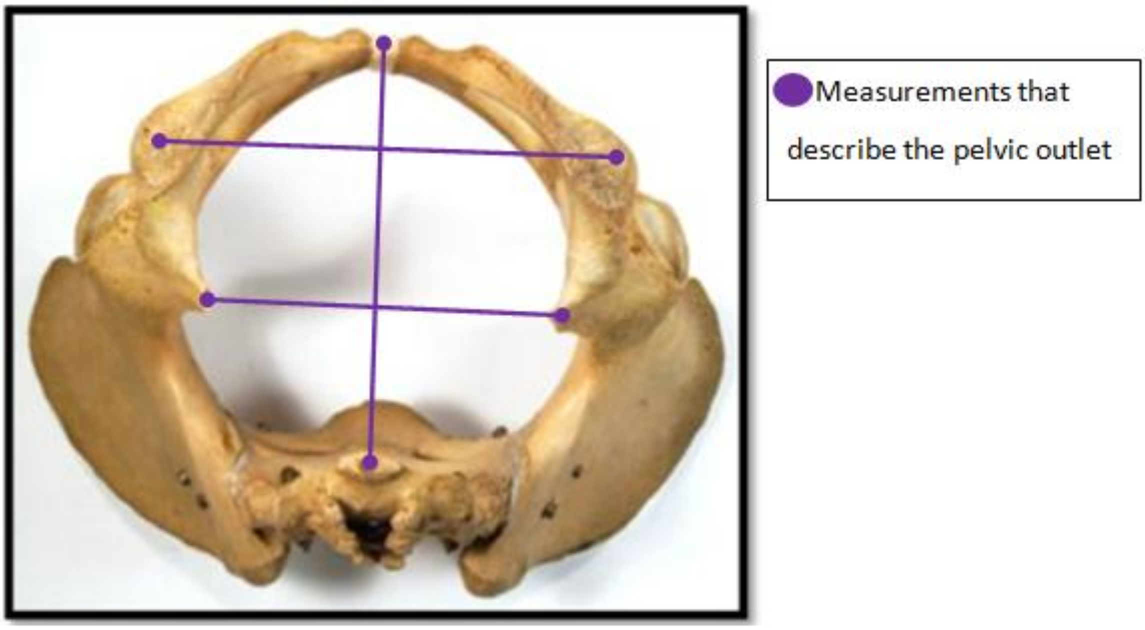
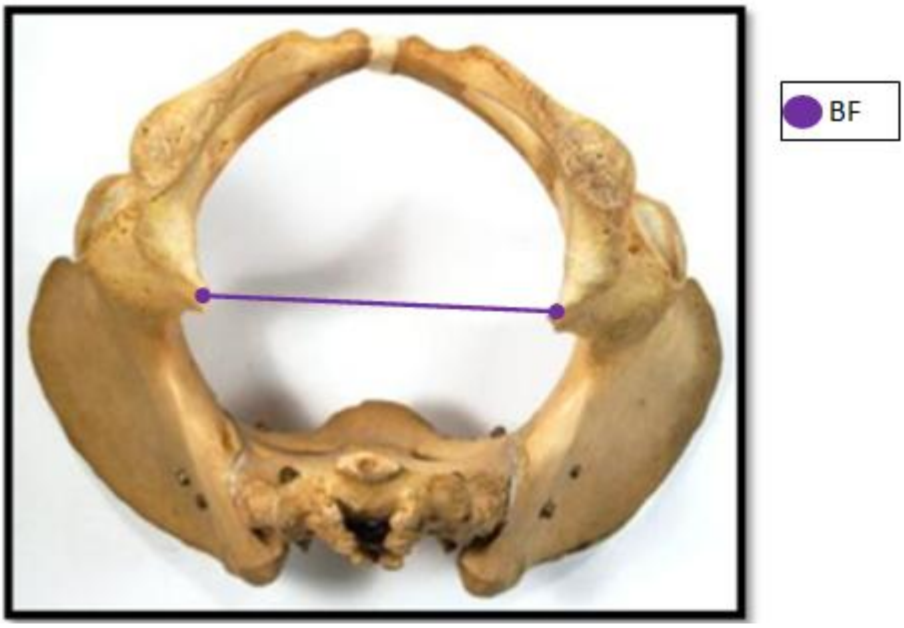
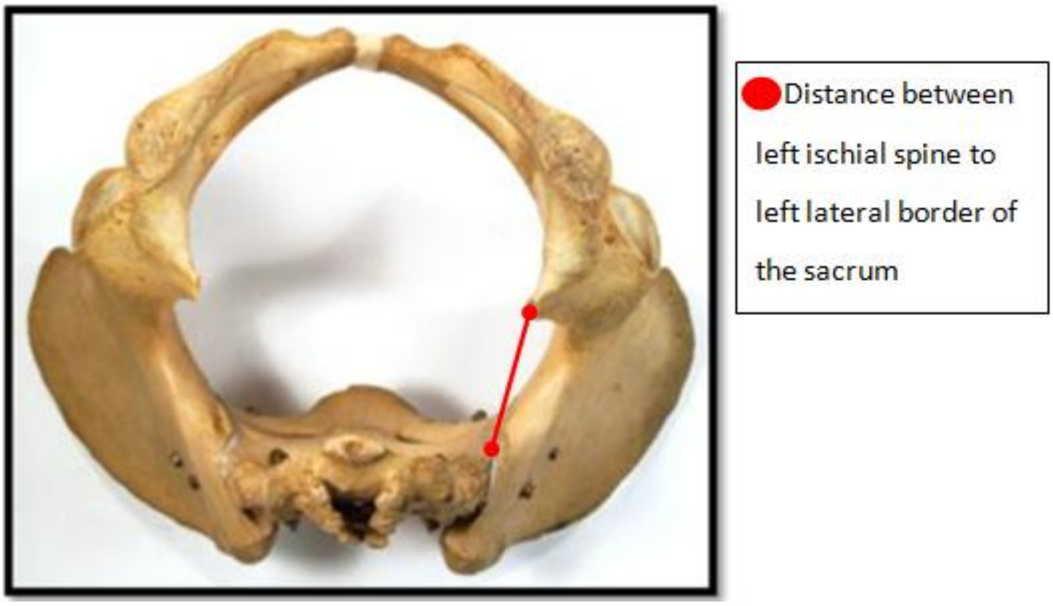


Figure 33. Summary of results relating the influence of stature to the four groups in intact pelves



The distance between the left ischial spine to the left lateral border of the sacrum (measurement J_L-L_L) did not show a significant difference when comparing females only. This measurement was not influence by stature in all four groups and is shown in Figure 34.

Figure 34. Summary of results related to the pelvic outlet for wet intact pelves



The calculated subpubic angle measurement, showed a significant difference when comparing black and white males but not between black and white females. None of these measurements showed a correlation to stature.

4.2.3. Pelvic inlet shape classification according to pelvic brim index

The pelvic brim indexes as determined by: AP inlet diameter ÷ Transverse inlet diameter X 100 of the current study as described by Turner[77] are represented in table 18.

Table 18. Turner's classification of pelvic shapes

	Dolichopellic	Mesatipellic	Platypellic	**Total**
Black females	16	4	0	**20**
White females	16	1	3	**20**
Black males	17	2	1	**20**
White males	15	2	3	**20**
Total	**64**	**9**	**7**	**80**

Pelvic brim index:
≥95= Dolichopellic
91-94= Mesatipellic
≤90= Platypellic

Correlation of the pelvic brim size to stature was made, by the method described by Baird[85]. Female individuals with statures below 155 cm, and 155 cm and greater, were correlated to the pelvic brim shape according to Turner's classification and are represented in Table 19.

Table 19. Comparison of pelvic brim indexes (PBI) to height in women

Pelvic type according to PBI		Dolichopellic	Mesatipellic	Platypellic	**Total**
Height	< 155cm	6	1	0	**7**
	≥ 155cm	26	4	3	**33**
Total		**32**	**5**	**3**	**40**

Our results show that 65 % of all the females considered were ≥155cm in stature. Majority of the women in both stature groups presented with a pelvic brim index over ≥95 and were categorised as dolichopellic. The three of the pelves that were categorised as platypellic were white females.

4.3. Shape analysis using Geometric Morphometics

4.3.1. Bony landmarks as implicated in transobturator procedures

The peri-obturator area described in this study; is defined by the landmarks chosen around the obturator foramen, on the pubic symphysis and ischial tuberosity as they are considered essential for the performance of transobturator procedures (figure 35).

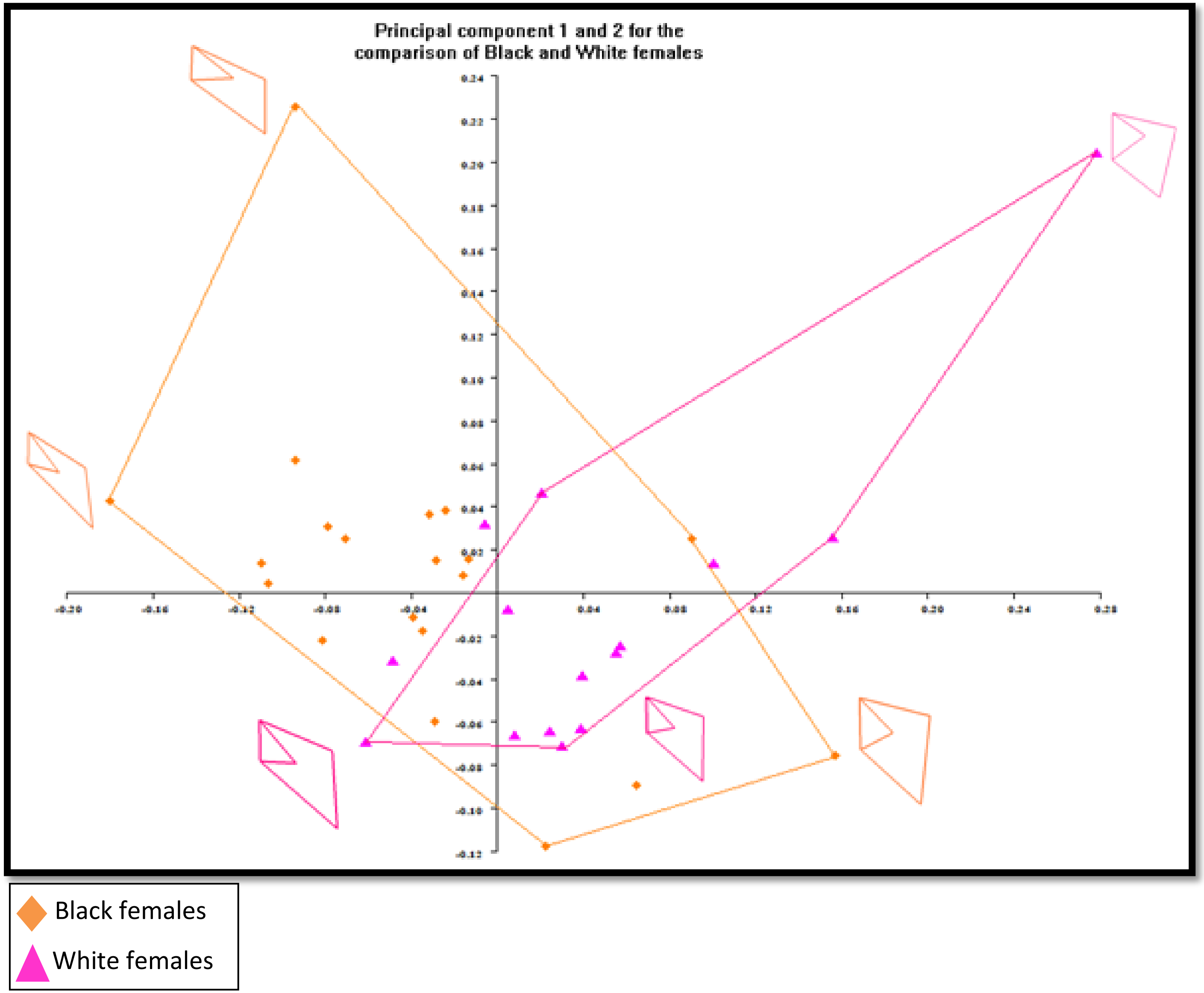
Figure 35. Points taken around obturator region

1. F- Most superior point in the midline of the pubic symphysis
2. G- Most inferior point in the midline of the pubic symphysis
3. C_L. Most medial point of the obturator foramen (left)
4. B_L - Most superior point of the obturator canal
5. E_L- Most inferior point on the ischial tuberosity (left)

4.3.1.1. Comparison of peri-obturator shape between populations within sexes

Firstly, the variations in the peri-obturator area between the populations within sex group are noted. In figure 36, analysis of variance along principle components 1 and 2 can be seen comparing black and white females. Analysis of variance along principle components 1 and 2 can be seen comparing black and white males in figure 38.

Figure 36. Principal component 1 and 2 for the peri-obturator shape in the comparison of black and white females



Although the populations overlap to a great extent, black females tend to represent the extremes on the upper left quadrant of the graph, while white females tend to represent the extremes on the upper right quadrants of the graph. Black females also show a clustering in the left half of the graph, white females are clustered in the right half. The p value for inter-population variation = 0.011 was considered significant, as determined by two group multivariate permutation by Past soft ware.

In the right half of the graph, where most white females are found, there is a relative lengthening in the distance between the obturator canal (B_L) and the most inferior point of the left ischial tuberosity (E_L). In this half of the graph, there is also relative decrease in the distances G-E_L (distance between the most inferior point on the ischial tuberosity to the most inferior points on the pubic symphysis). The length of the pubic symphysis is also relatively longer.

These shape changes, contributes to a peri-obturator area that is elongated antero-posteriorly relative to the dimensions from side to side. When compared to those, mostly black females, in the left half of the graph.

The relative distance of the length of the pubic symphysis is shorter in the left half of the graph. The relative distances between the obturator canal (B_L) and the most inferior point of the left ischial tuberosity (E_L) remains unchanged throughout the left half of the graph. In this half of the graph, there is also relative increase in the distances G-E_L (distance between the most inferior point on the ischial tuberosity to the most inferior points on the pubic symphysis). These shape changes, contributing to a peri-obturator area that is shortened antero-posteriorly, but widened from side to side when compared to those, mostly white females, in the right half of the graph.

Using principal component 1 and 2, the mean pelvic inlet shape of black and white females were found separately. In figures 37 below, the determined mean shapes for black and white females are compared to each other. The two shapes are then superimposed onto each other, to observe shape differences.

Figure 37. Comparison of the mean shapes of black and white females

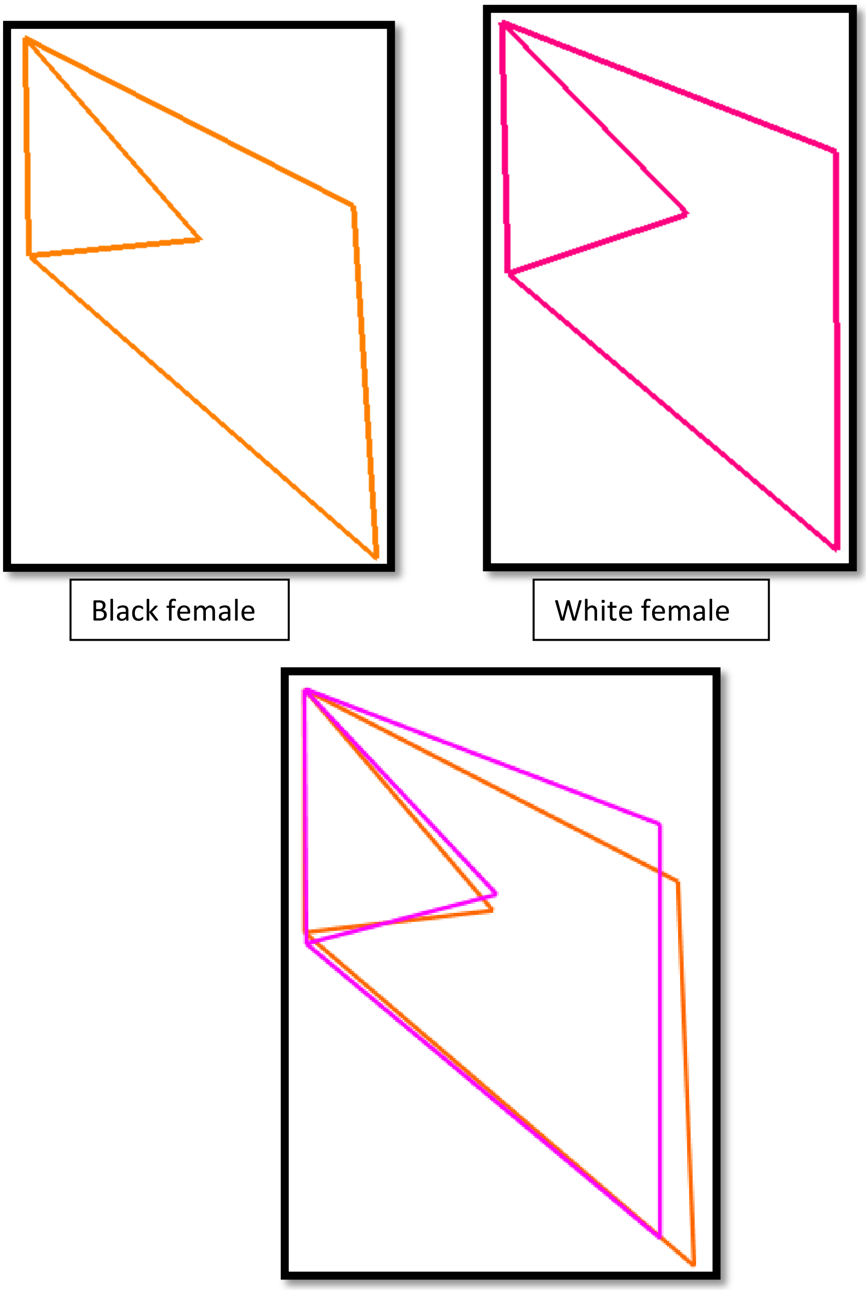
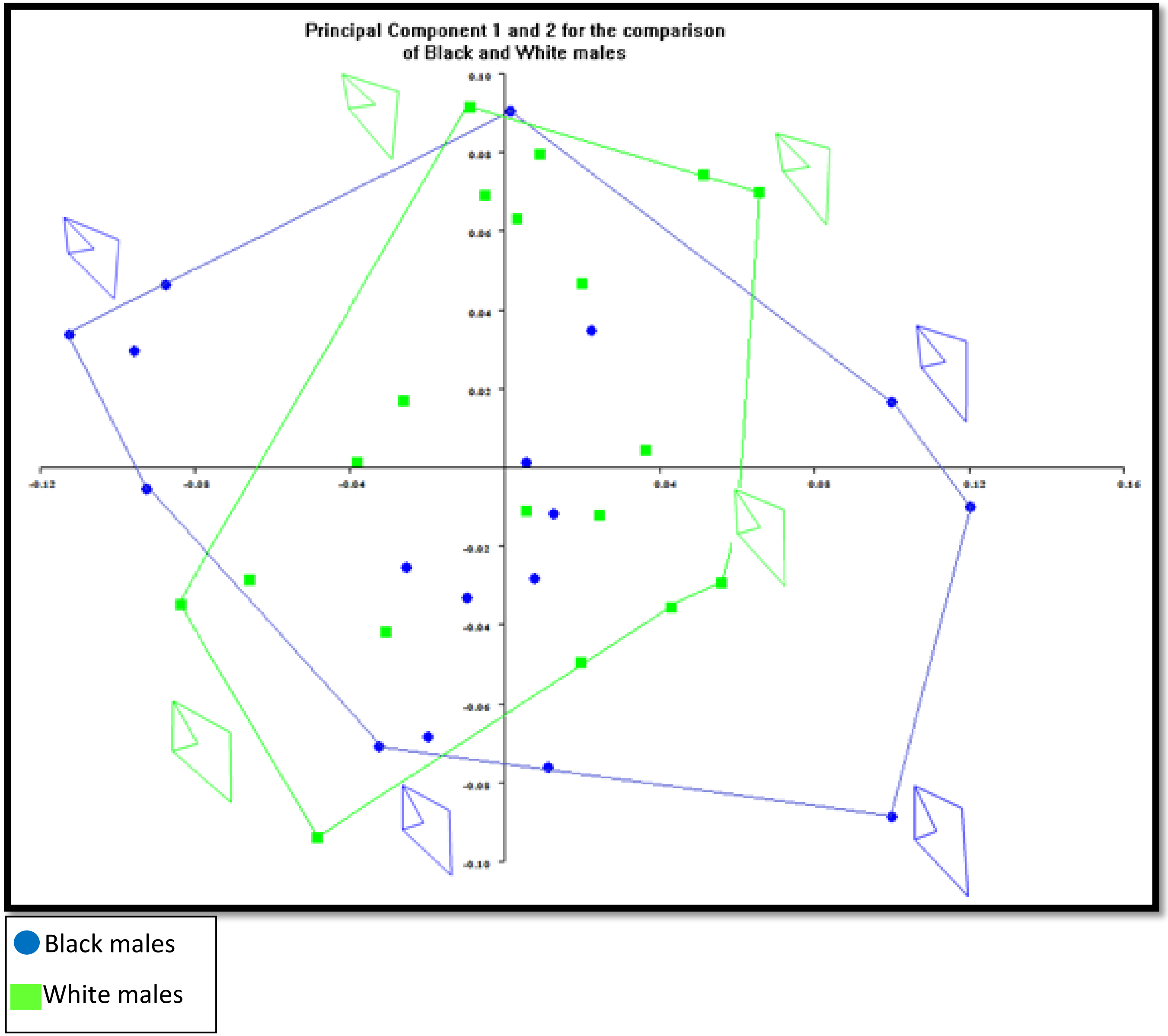


Figure 38. Principal component 1 and 2 for the peri-obturator shape in the comparison of black and white males

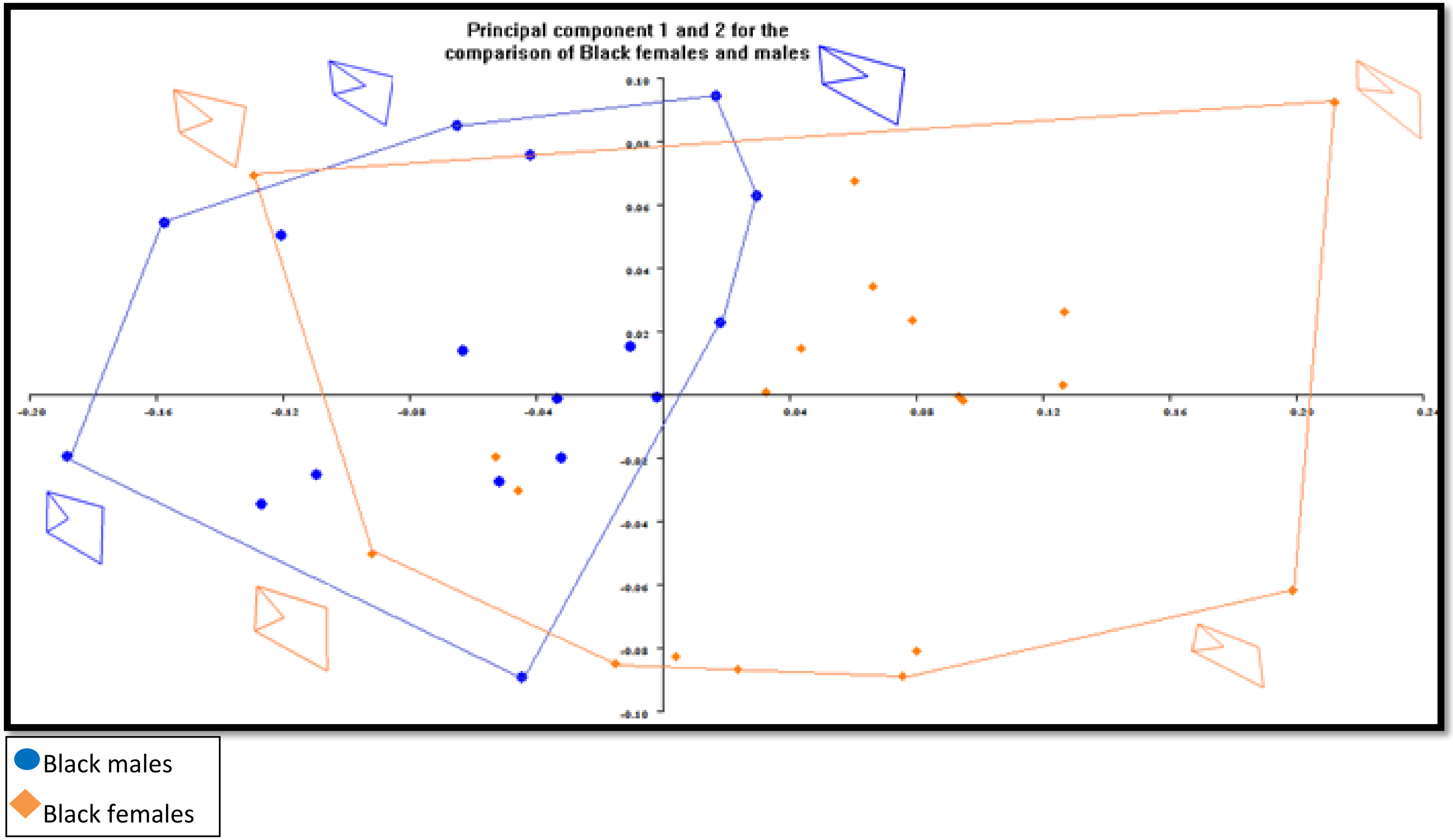


Although the populations overlap to a great extent, black males tend to represent the extremes on the upper left and lower right quadrants of the graph, while white males tend to represent the extremes on the upper right and lower left quadrants of the graph. The p value for inter-population variation = 0.887, was determined by two group multivariate permutation by Past soft ware.

4.3.1.2. Comparison of peri-obturator shape between sexes within populations

The peri-obturator shapes between sexes within the population group are compared. In figure 39, analysis of variance along principle components 1 and 2 can be seen comparing black females and males. Analysis of variance along principle components 1 and 2 can be seen comparing white females and males in figure 41.

Figure 39. Principal component 1 and 2 for the peri-obturator shape in the comparison of black males and females



Although the sexes overlap to some extent, black females tend to represent the extremes on the right half, while black males seem to dominate the extremes on left half of the graph. The p value for inter-sex variation in blacks = 0.0135 was determined by two group multivariate permutation by Past software.

The shapes observed in the left side of the graph, show a relative decrease in the distance between the most superior point on the pubic symphysis to the obturator canal (measurement $F\text{-}B_L$) and the medial point of the obturator foramen seems to be closer to the superior point on the pubic symphysis on the left side of the graph. In this half of the graph, there is also relative decrease in the distances $G\text{-}E_L$ (distance between the most inferior point on the ischial tuberosity to the most inferior points on the pubic symphysis).

The relative distance of the length of the pubic symphysis remains unchanged throughout the graph. The peri-obturator area on the left hand side of the graph as compared to the right hand side of the graph seems to narrow from side to side and lengthen antero-posteriorly.

The females present in the right half of the graph, have a peri-obturator area that is relatively shortened antero-posteriorly, but widened from side to side.

Using principal component 1 and 2, the mean pelvic inlet shape of black females and males were found separately. In figures 40 below, the determined mean shapes for black females and males are compared to each other. The two shapes are then superimposed onto each other, to observe shape differences.

Figure 40. Comparison of the mean shapes of black females and males

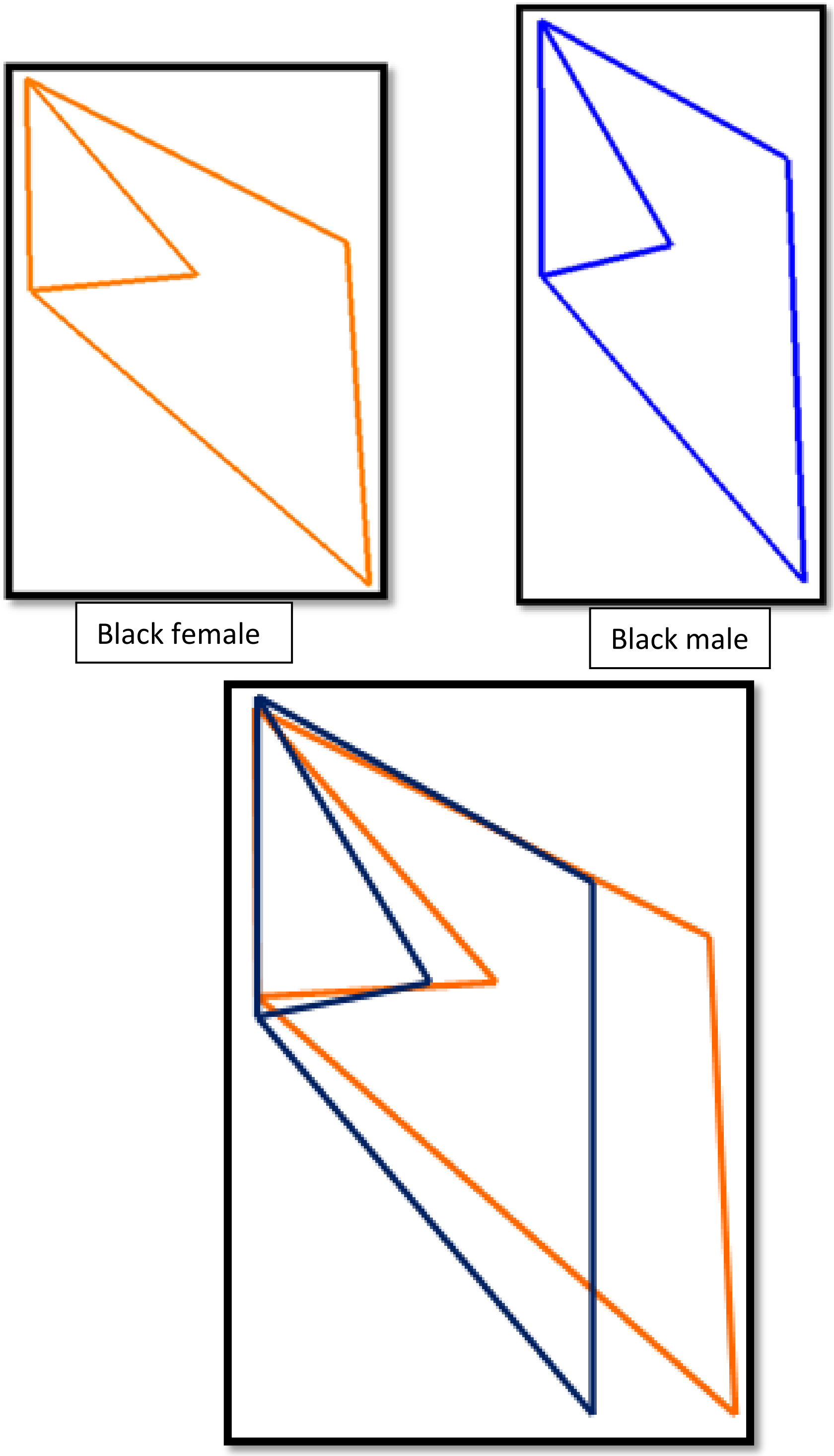
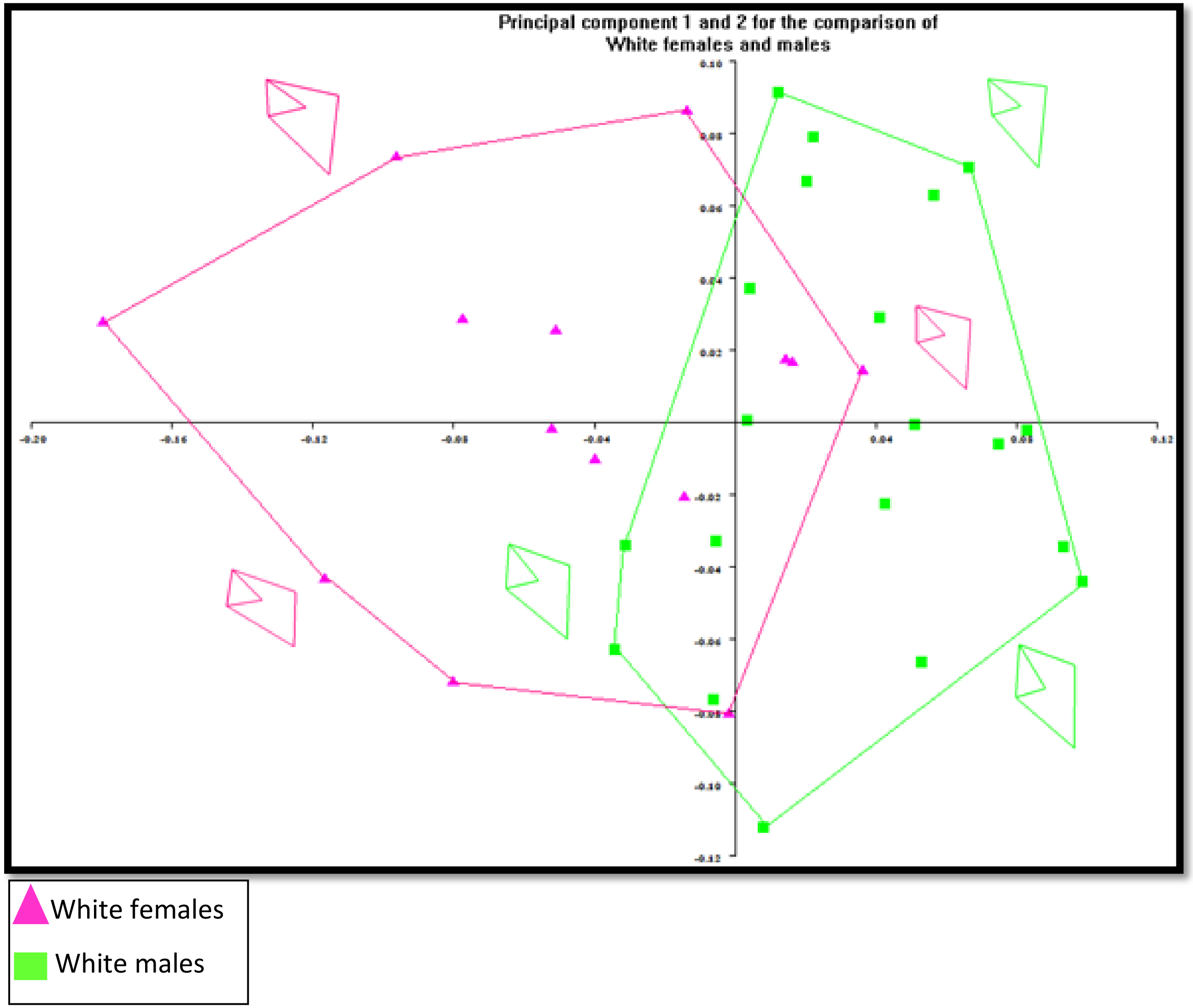


Figure 41. Principal component 1 and 2 for the peri-obturator shape in the comparison of white males and females



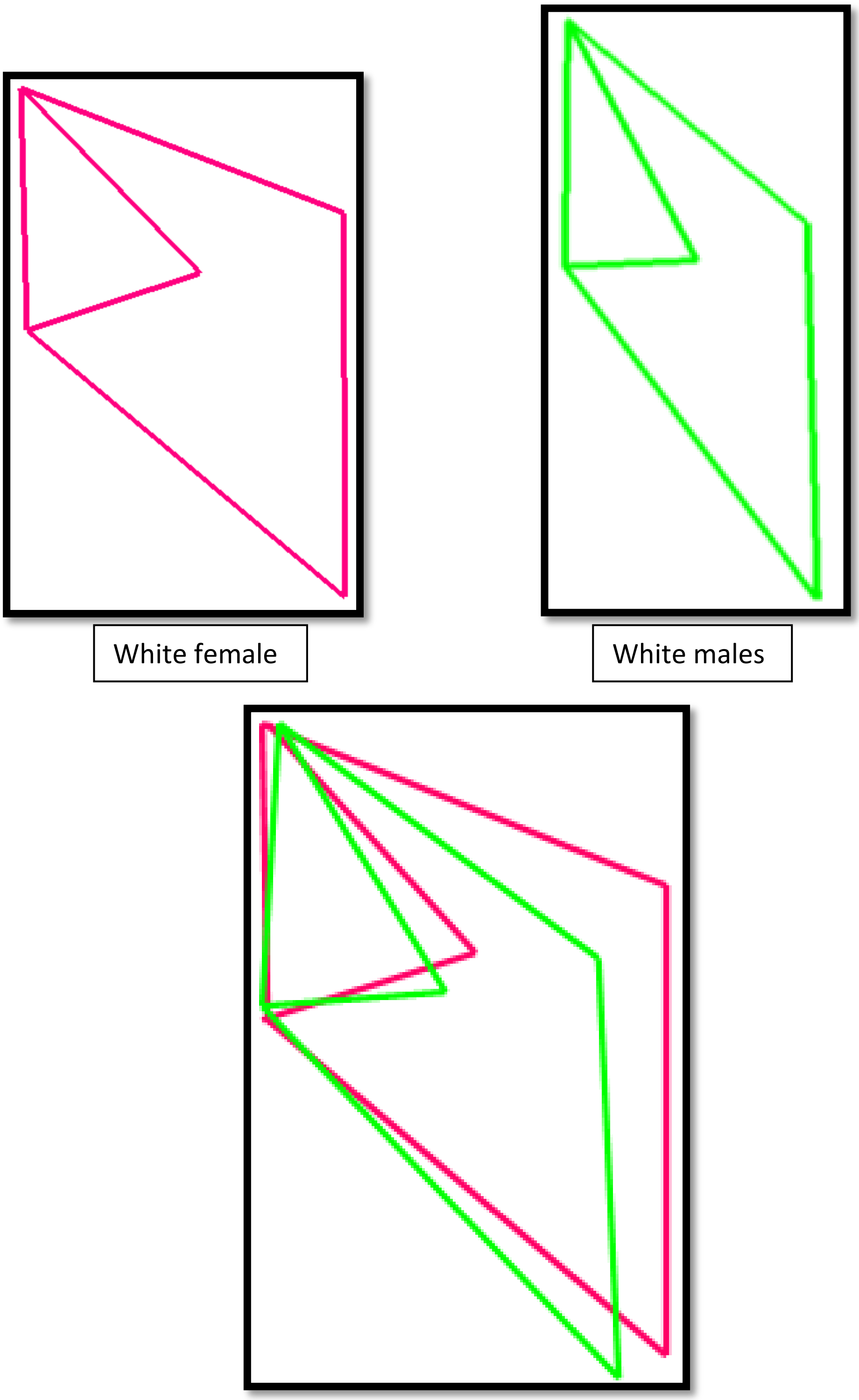
Although the populations overlap to some extent, white males tend to represent the extremes on the right half, while white females seem to dominate the extremes on left half of the graph. The p value for inter-sex variation = 0.0025 was determined by two group multivariate permutation by Past software.

The relative length of the pubic symphysis, as well as the relative distances between the obturator canal (B_L) and the most inferior point of the left ischial tuberosity (E_L) do not increase from the right to the left half of the graph.

The females present in the left half of the graph, have a peri-obturator area that is relatively widened from side to side. In a few extreme left hand side of the graph outliers the distance between the superior point on the pubic symphysis and the medial point of the obturator foramen seems to be relatively greater. The obturator canal is situated more posteriorly than that of white females.

Using principal component 1 and 2, the mean pelvic inlet shape of white females and males were found separately. In figures 42 below, the determined mean shapes for white females and males are compared to each other. The two shapes are then superimposed onto each other, to observe shape differences.

Figure 42. Comparison of the mean shapes of white females and males



Integration of peri-obturator shape analyses with metric findings

The absolute distances, extending antero-posteriorly as well as the distance across the pubic ramus were significantly smaller in black females vs. white females and females vs. males while those extending from side to side were similar.

These impressions were in line with the shape changes observed. In addition, the obturator canal and the medial point of the obturator foramen were relatively closer to the inferior pubic symphysis in black females vs. white females and females vs. males.

Although the absolute distance between the obturator canal to the medial of the obturator foramen did not differ significantly, the shortened distance across the inferior pubic ramus, and the relative position of the obturator canal situated more posteriorly in black females, could approximate the obturator canal to the perineal area in black females vs. white females and males.

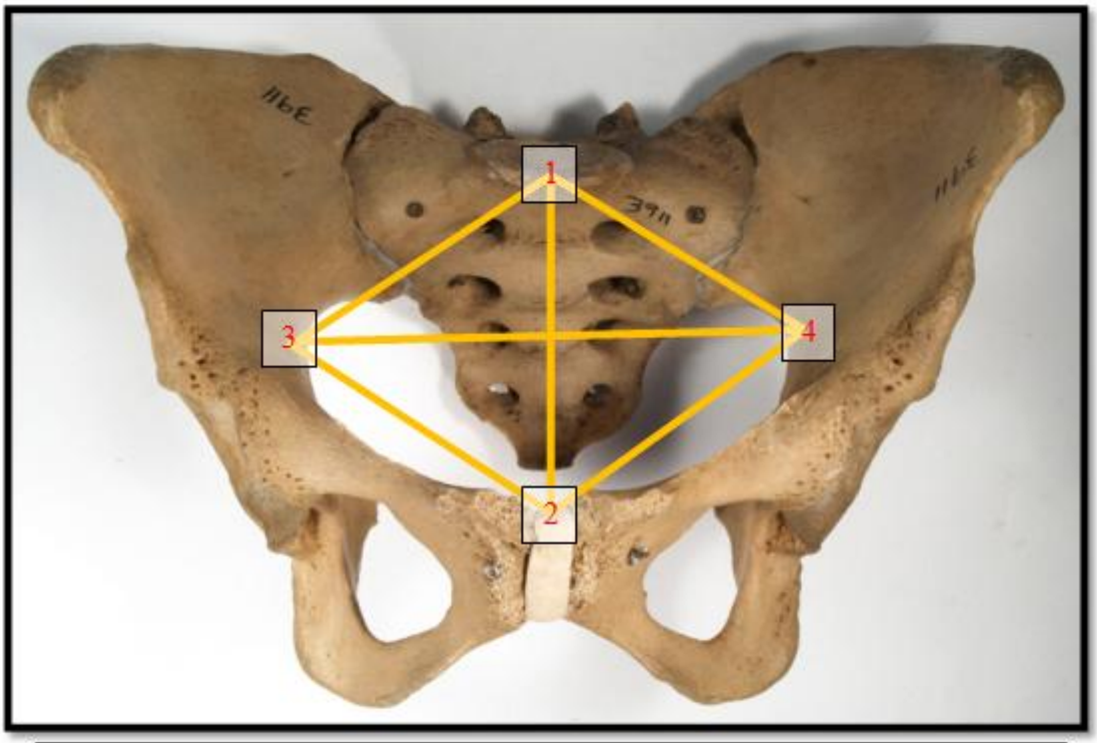
All unilateral measurements on dried os coxae were significantly smaller in black males compared to white males, apart from the distance between the obturator canal to midpoint of obturator foramen. The distances that did not differ and those that were smaller, did not contribute to a significant difference in shape and a great extent of overlap existed between black and white males.

4.3.2. Pelvic inlet

Geometric shape analysis was performed to classify and compare the pelvic inlet shape amongst the four sex- population- groups.

The points marked on the pelvic inlet are shown below (figure 43).

Figure 43. Points marked on the pelvic inlet

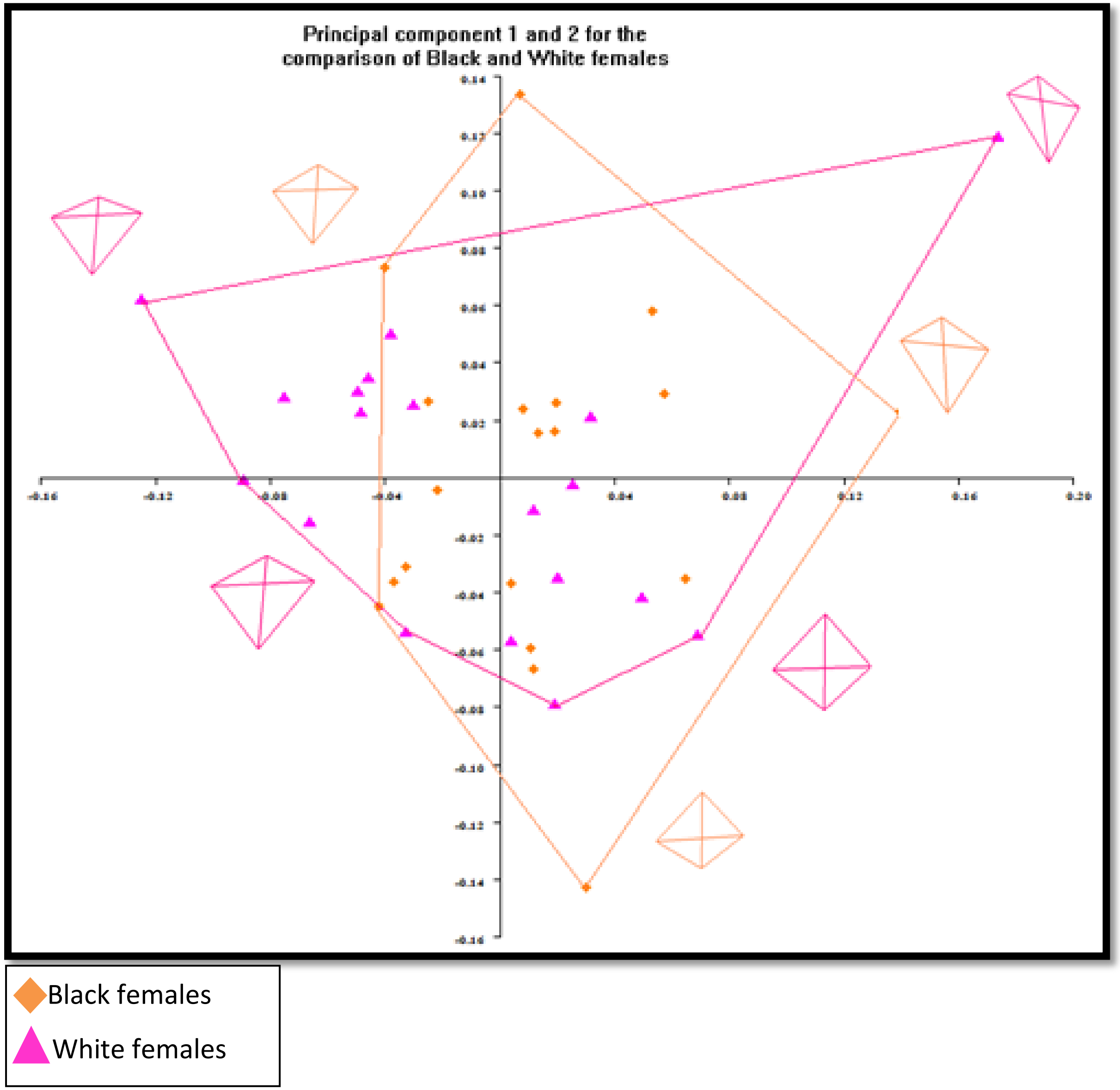


1. H- Midpoint on sacral promontory
2. F- Most superior point in the midline of the pubic symphysis
3. I_R- Most widely separated points in the diameter of the pelvic inlet (right)
4. I_L- Most widely separated points in the diameter of the pelvic inlet (left)

4.3.2.1. Comparison of pelvic inlet shape between populations within sexes

Firstly, the pelvic inlet shapes between populations within sex group are compared. In figure 44, analysis of variance along principle components 1 and 2 can be seen comparing black and white females. Analysis of variance along principle components 1 and 2 can be seen comparing black and white males in figure 45.

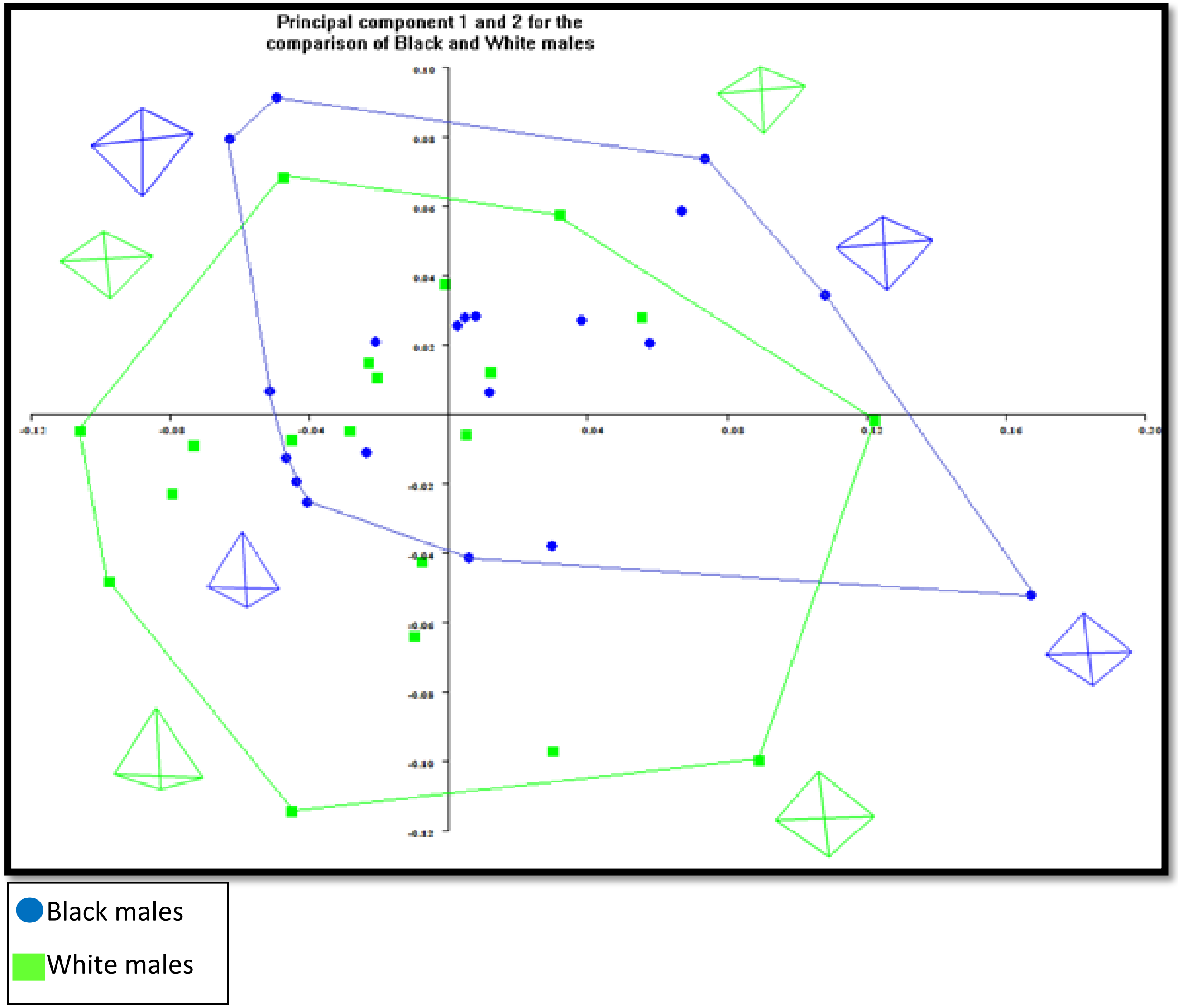
Figure 44. Principal component 1 and 2 for the pelvic inlet in the comparison of black and white females



Although the populations overlap to a great extent, black females tend to represent the extremes on the right lower quadrant of the graph, while white females tend to represent the extremes on the left and right upper quadrants of the graph. The p value for inter-population variation = 0.5565 was determined by two group multivariate permutation by Past soft ware.

Representatives of all 4 pelvic inlet shapes are seen: gynaecoid (mesatipellic) where the AP and transverse diameter axes intersect in approximately the midline; android (brachypellic) where the transverse axis crosses the AP axis more posteriorly; anthropoid (dolichopellic) where the transverse inlet axis crosses the AP axis anteriorly and the longer AP approaches the transverse dimension or platypelloid (platypellic) where the transverse axis is elongated.

Figure 45. Principal component 1 and 2 for the pelvic inlet in the comparison of black and white males



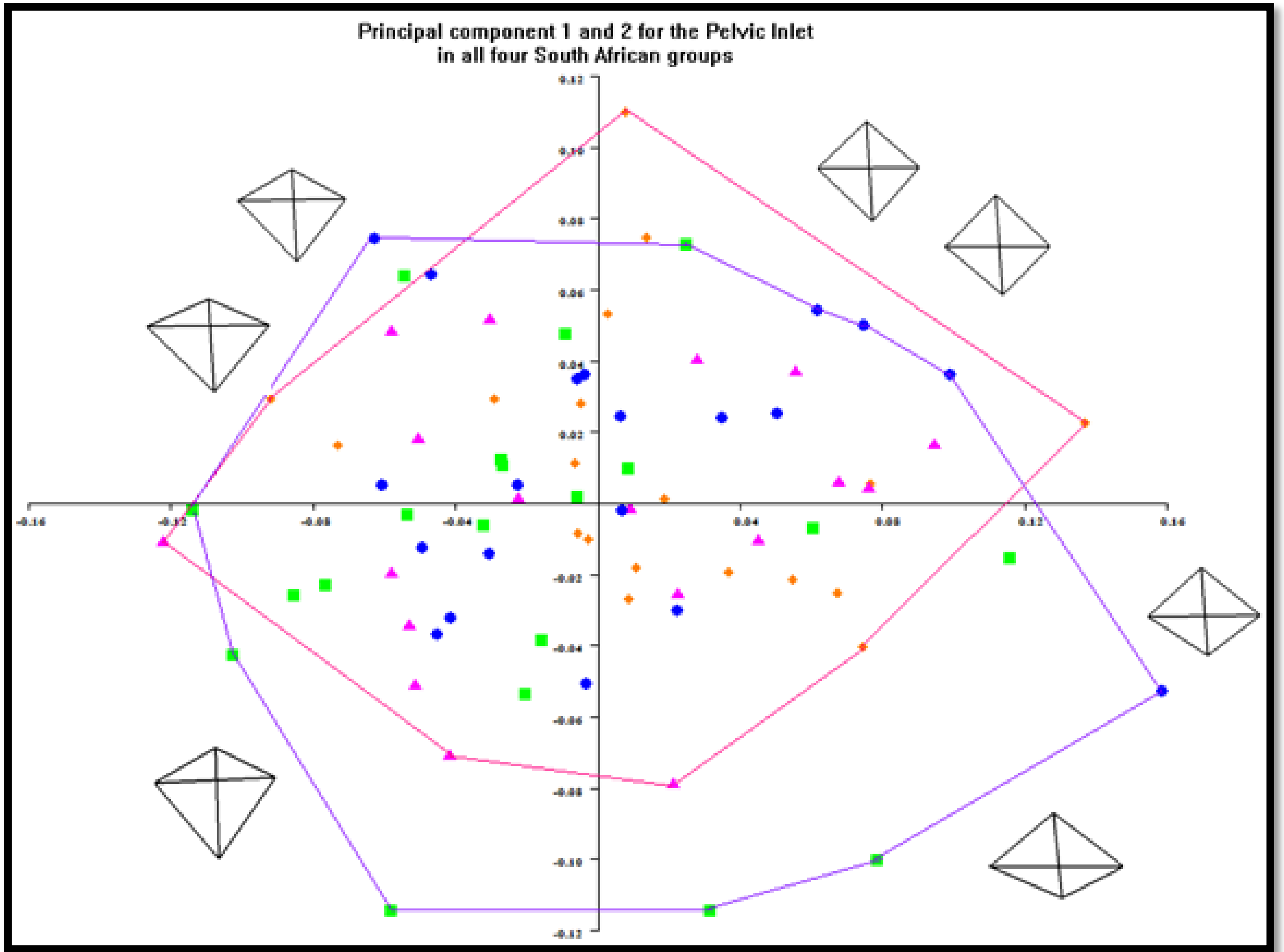
Although the populations overlap to a great extent, the distribution of the graph tends toward black males dominating the upper quadrants especially the left side of the graph and white males the lower quadrants. The p value for inter-population variation = 0.2845 was determined by two group multivariate permutation by Past soft ware. Representatives of all 4 pelvic inlet shapes are seen.

Since there were no significant shape differences when comparing the populations within each sex, as determined by two group multivariate permutation, comparisons between the pelvic inlet shapes of the two sexes were made.

4.3.2.2. Comparison of pelvic inlet shape between sexes

In figure 46 below, the analysis of variance along principle components 1 and 2 can be seen comparing females with males.

Figure 46. Principal component 1 and 2 for the pelvic inlet in the comparison of males and females



Females	White males	Black males	
Males	White females	Black females	

Although the distributions of the groups are widespread over the graph, more females shapes are represented on the right hand side of the graph. Three female individuals are found in the upper quadrants not conforming to the overlap described. It seems that males have a more conforming shape as compared to females often representing the extremes in all quadrants. The p value for inter-sex variation = 0.03 was determined by two group multivariate permutation by Past soft ware.

On the right hand side of the graph, these pelvic brim shapes have the widest transverse diameters and a more posteriorly oriented promontory which is in favour of a gynaecoid shape. The clustering of males on the left side of the graph coincides with the more android shape found. A few black females are represented in the left upper quadrant while a few white females are represented in the left lower quadrant with only 2 black females presenting close to the axes.

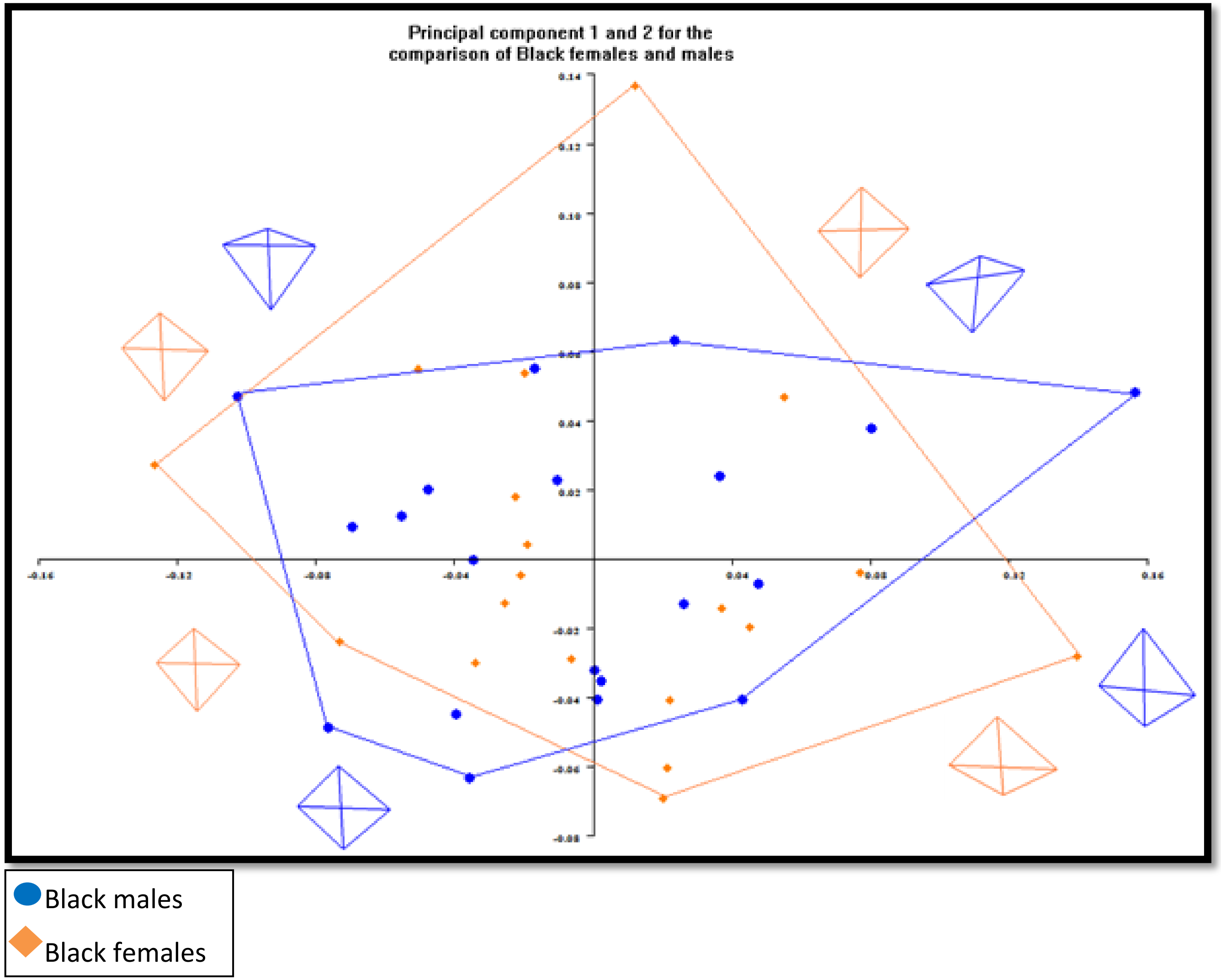
With shape analysis, there was a significant difference between the sexes, but it was not evident that it had much to do with the relationship between the AP distance and the transverse inlet diameters as implicated in Turner's classification, but rather to the relative position of the widest diameter across the pelvic brim. This transverse diameter seemed to shift more anteriorly further away from the sacral promontory in females.

Following the comparison of the pelvic inlet shape between sex groups of both populations, the variation of pelvic shape between sexes within each population group were investigated.

4.3.2.3. Comparison of pelvic inlet shape between sexes within populations

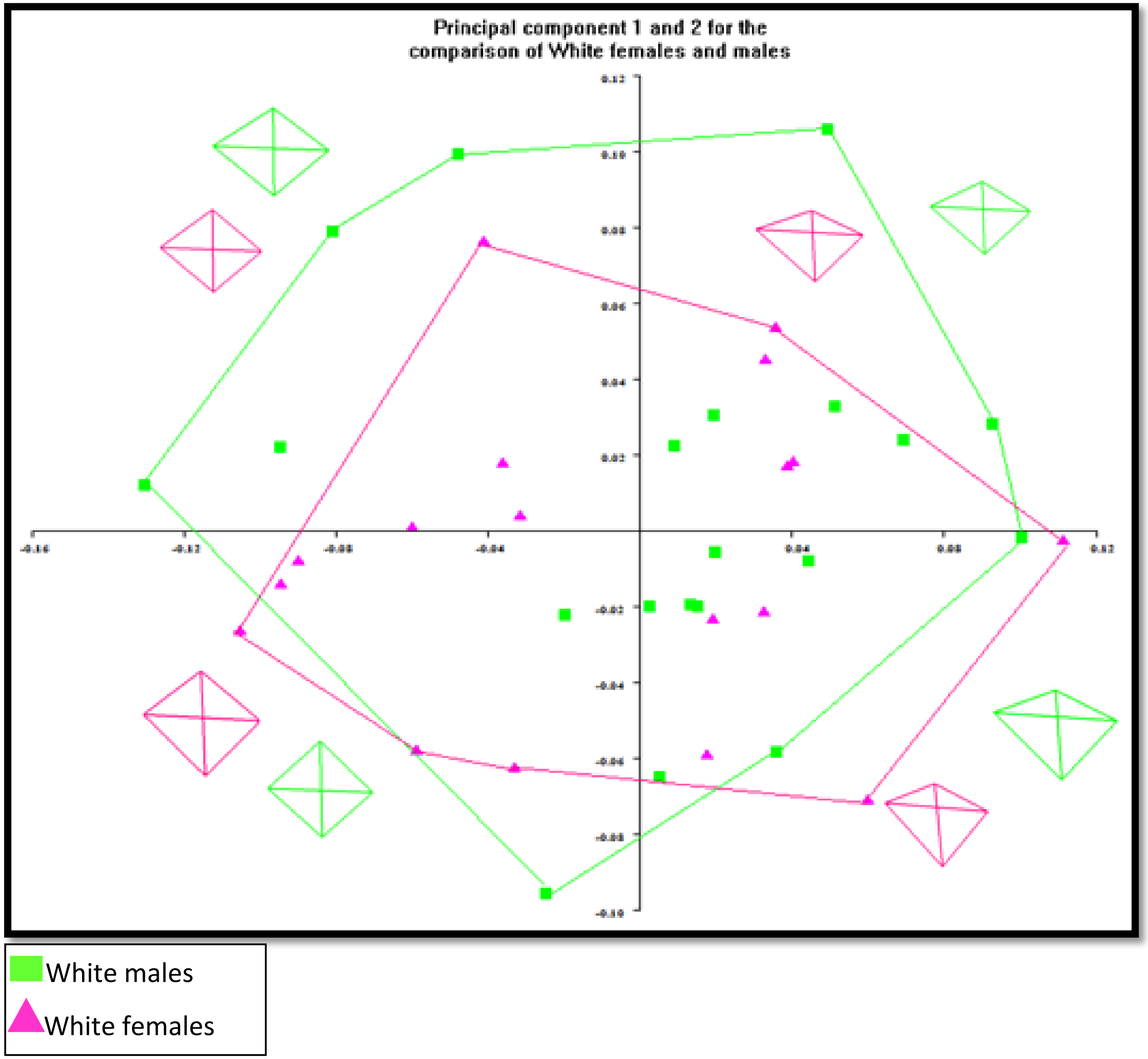
The pelvic inlet shapes between sexes within population group are compared. In figure 47, analysis of variance along principle components 1 and 2 can be seen comparing black females and males. Analysis of variance along principle components 1 and 2 can be seen comparing white females and males in figure 48.

Figure 47. Principal component 1 and 2 for the pelvic inlet in the comparison of black males and females



Although the sexes overlap to a great extend, black females tend to represent the extremes on the right lower quadrants of the graph while black males seem to dominate the extremes on the upper left quadrant. The p value for inter-sex variation = 0.7455 was determined by two group multivariate permutation by Past soft ware. Representatives of all 4 pelvic inlet shapes are seen.

Figure 48. Principal component 1 and 2 for the pelvic inlet in the comparison of white males and females



Males represent the upper half of the graph, while females represent the extremes on the lower right quadrant. Females are predominantly found on the right half of the graph, where AP and transverse diameters are of similar length, and apart from a few extremes cross midway as is consistent with a gynaecoid pelvis.

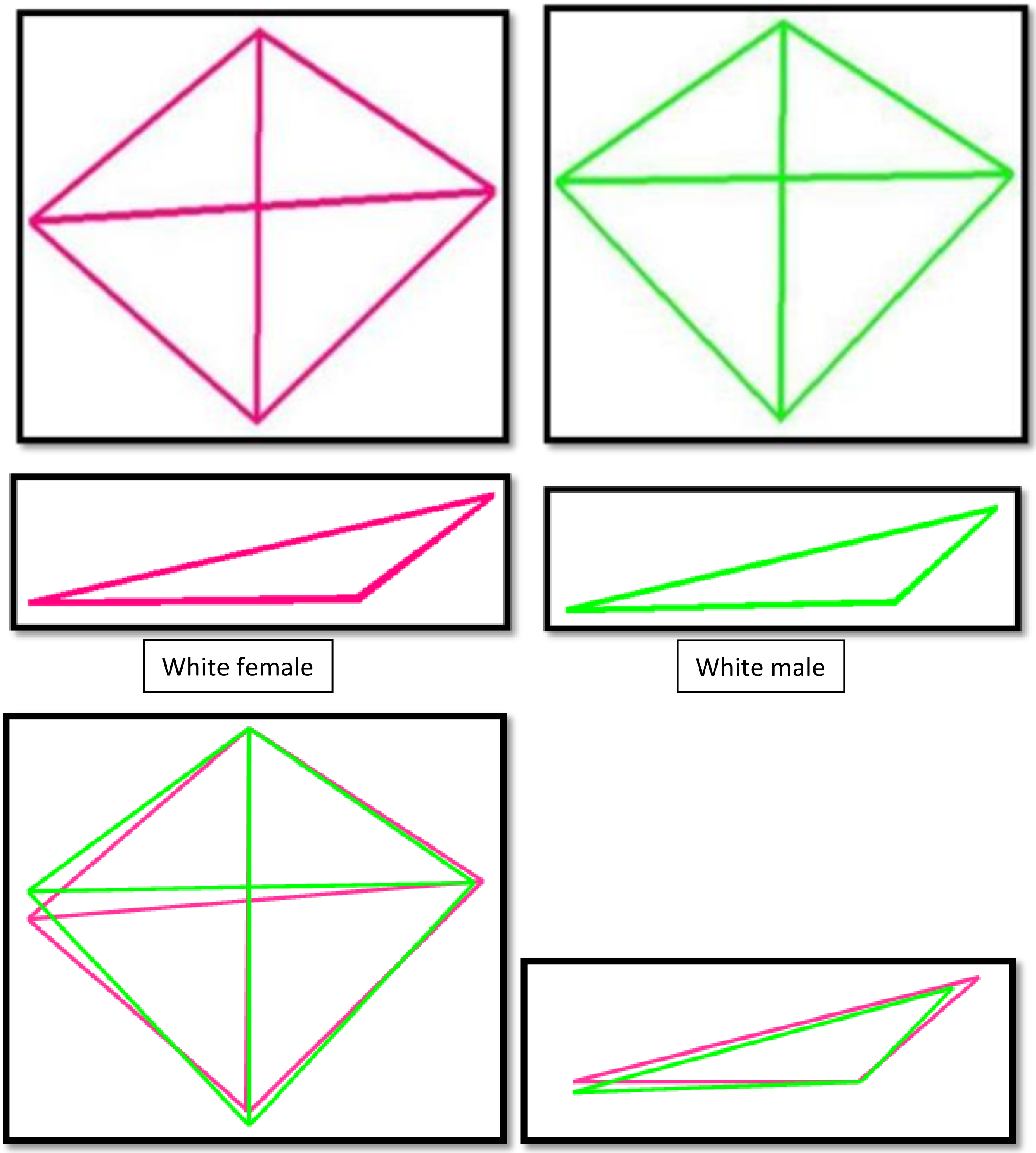
Although the sexes overlap to a great extend, white males tend to represent the extremes on the right upper and left lower quadrants of the graph, while white females seem to dominate the extremes on the right lower quadrant. An extreme female outlier can be seen in the left upper quadrant. The p value for inter-sex variation = 0.0425 was determined by two group multivariate permutation by Past soft ware.

As determined by PAST, there is a significant difference when comparing the pelvic inlet shape between the sexes within the white population.

The shapes observed in the right side of the graph, are characteristic of a heart shaped brim as a result of the AP and transverse diameter axis that intersect more posteriorly, creating a more android shaped pelvis. However, in the left upper quadrant of the graph, the transverse axis crosses the AP axis more anteriorly.

Using principal component 1 and 2, the mean pelvic inlet shape of white females and white males were found separately. In figures 49 below, the determined mean shapes for white females and males are compared to each other. The superior as well as lateral views are shown. The shapes are then superimposed onto each other, to observe shape differences.

Figure 49. Comparison of the mean shapes of white females and males



Pelvic brim	Female	Male
Anterior view	Transverse and AP diameter, with similar dimensions, transect approximately in the centre	Transverse and AP diameter transect more posteriorly
Lateral view	Sacral promontory is more posteriorly orientated than in the male	Sacral promontory is more antero-superiorly orientated than in the female
Classification	Gynaecoid	Android

The shape difference observed in the morphometric analysis, takes into account the relative position of the intersection of the AP to the transverse inlet diameter, which lies more anteriorly in white females, giving it a gynaecoid appearance. This intersection lies more posteriorly in white males, characteristic of an android shaped pelvic inlet. Other factors, such as the relative position of the promontory also contributes to the shape differences observed.

Integration of pelvic inlet shape analyses with metric findings

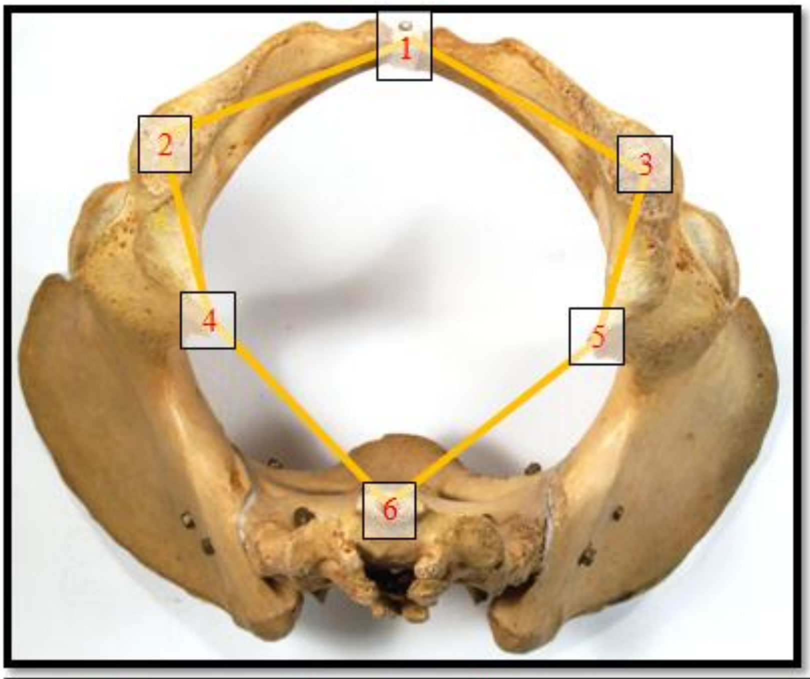
As both the AP dimension and transverse dimension were significantly larger in whites as compared to blacks, the relationship between the AP distance and the transverse inlet diameters as implicated in Turner's classification were similar. This impression was confirmed with shape analysis as no significant shape differences were noted amongst the populations.

Although white females had larger absolute values in the AP and transverse inlet diameters (measurements F-H and I_R-I_L respectively), there were no significant metric differences that existed between white females and males. In the comparison between white males and females, significant shape differences did exist. These differences were not reflected in Turner's classification of pelvic shapes (Table 18), as it only reflects the relationship of the AP diameter to the transverse diameter, but rather in the relative position of the widest diameter across the pelvic brim. This transverse diameter seemed to shift from a more posterior position in white males (heart shaped, android) to more anterior position further away from the sacral promontory in white females, affording a more oval shape (gynaecoid).

4.3.3. Pelvic outlet

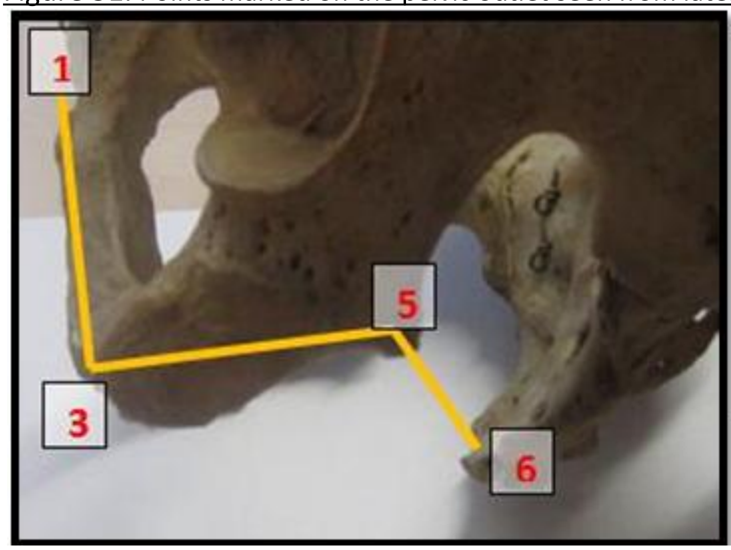
The points that were marked on the pelvic outlet are shown in figures 50 and 51. Figure 50 represents a posteroinferior view, while the figure 51 demonstrates a lateral view.

Figure 50. Points marked on the pelvic inlet seen from inferior



1. G- Most inferior point in the midline of the pubic symphysis
2. E_R- Most inferior point on the ischial tuberosity (right)
3. E_L- Most inferior point on the ischial tuberosity (left)
4. J_R- Ischial spine (right)
5. J_L- Ischial spine (left)
6. K- Lowest limit of coccyx

Figure 51. Points marked on the pelvic outlet seen from lateral

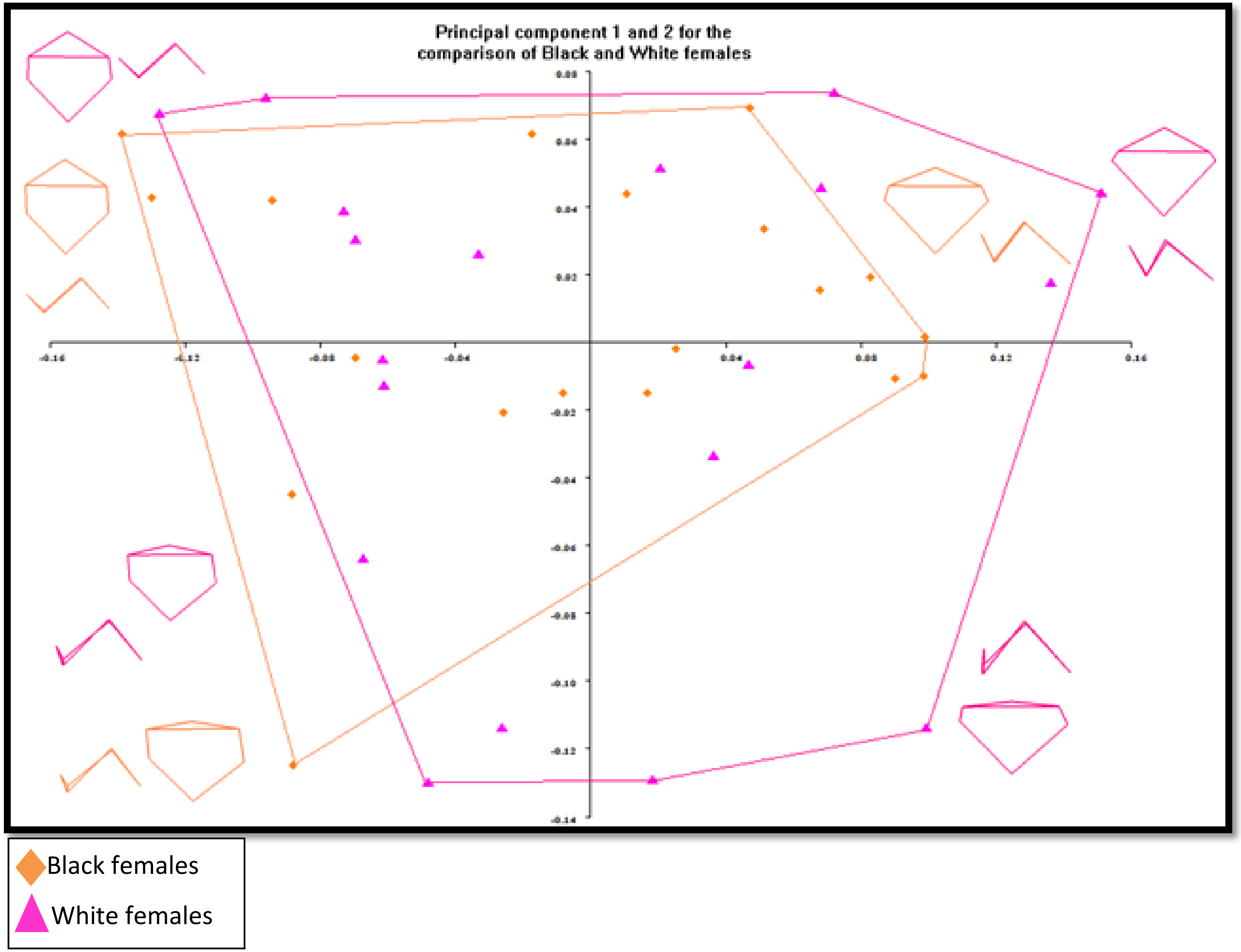


1. G- Most inferior point in the midline of the pubic symphysis
3. E_L- Most inferior point on the ischial tuberosity (left)
5. J_L- Ischial spine (left)

4.3.3.1. Comparison of pelvic outlet shape between populations within sexes

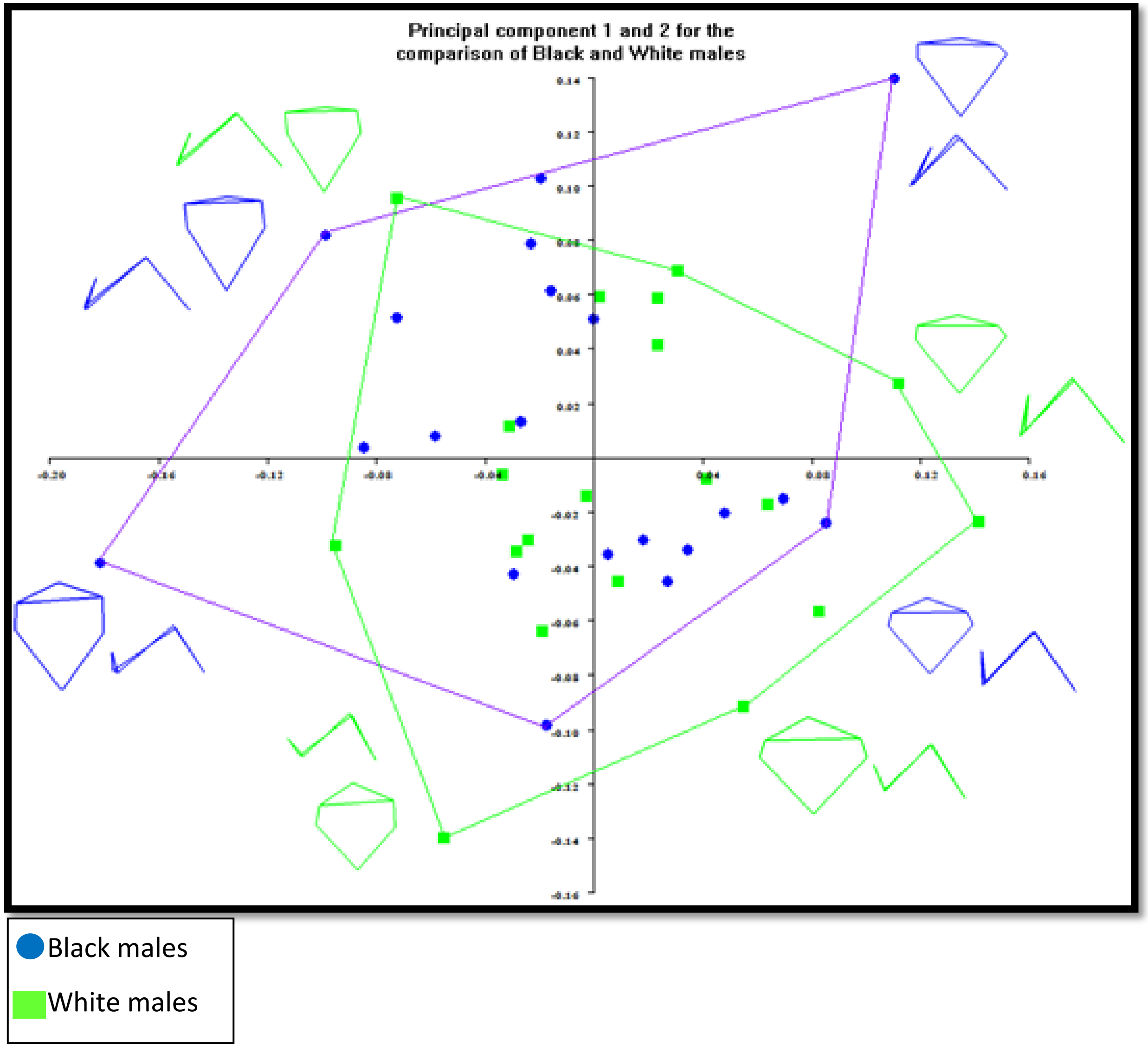
In figure 52, analysis of variance along principle components 1 and 2 can be seen comparing black and white females. Analysis of variance along principle components 1 and 2 can be seen comparing black and white males in figure 53.

Figure 52. Principal component 1 and 2 for the pelvic outlet in the comparison of black and white females



The populations overlap to a great extent, and the p value for inter-population variation = 0.1375 was determined by two group multivariate permutation by Past soft ware.

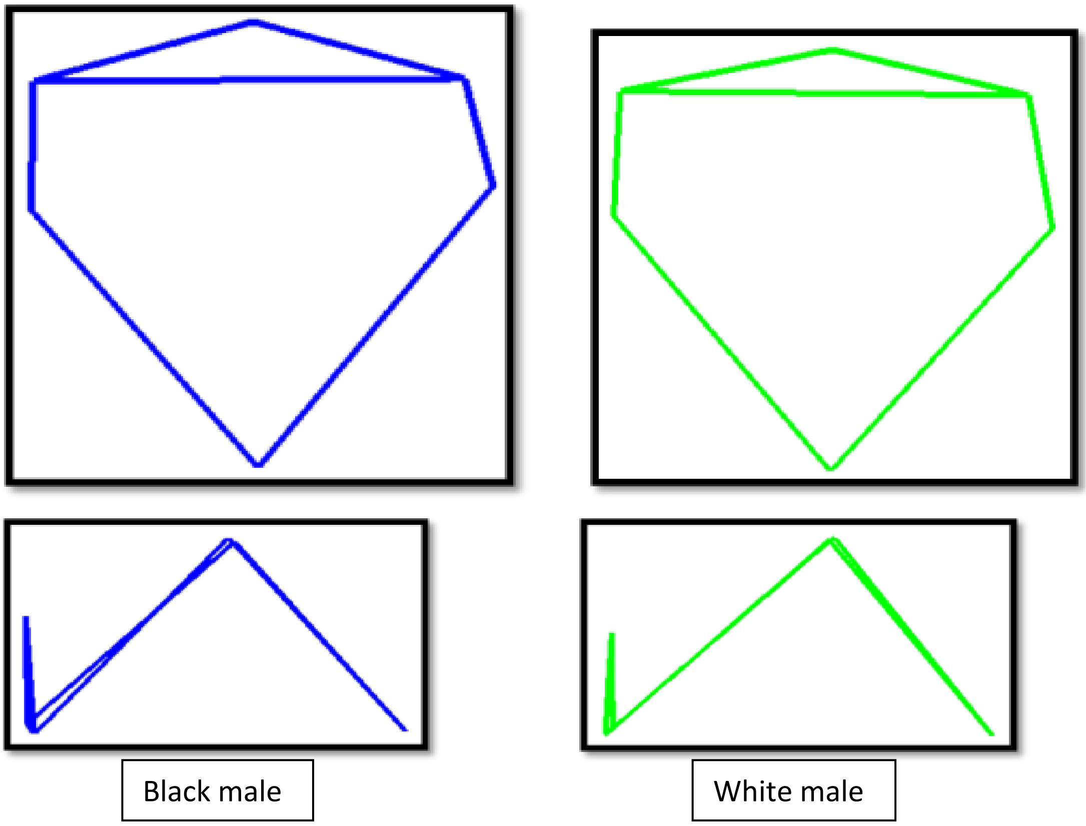
Figure 53. Principal component 1 and 2 for the pelvic outlet in the comparison of black and white males

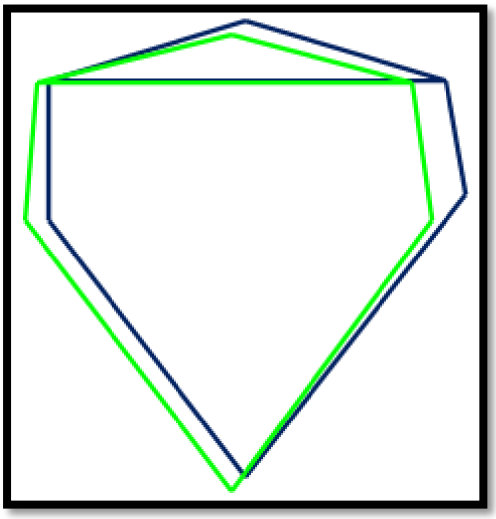


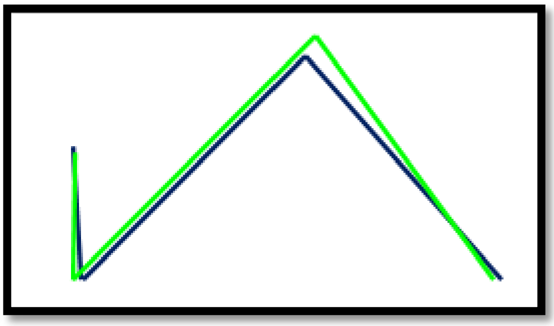
Although there is a great deal of overlap, black males tend to represent the extremes in the upper two quadrants, while white males represent the extremes in the lower quadrants. The p value for inter-population variation= 0.035 was determined by two group multivariate permutation by Past soft ware.

As determined by PAST, there is a significant difference when comparing the pelvic outlet shape between the populations in males. Using principal component 1 and 2, the mean pelvic outlet shape of white and black males were found separately. In figures 54 below, the determined mean shapes for white and black males are compared to each other.

Figure 54. Comparison of the mean shapes of black and white males





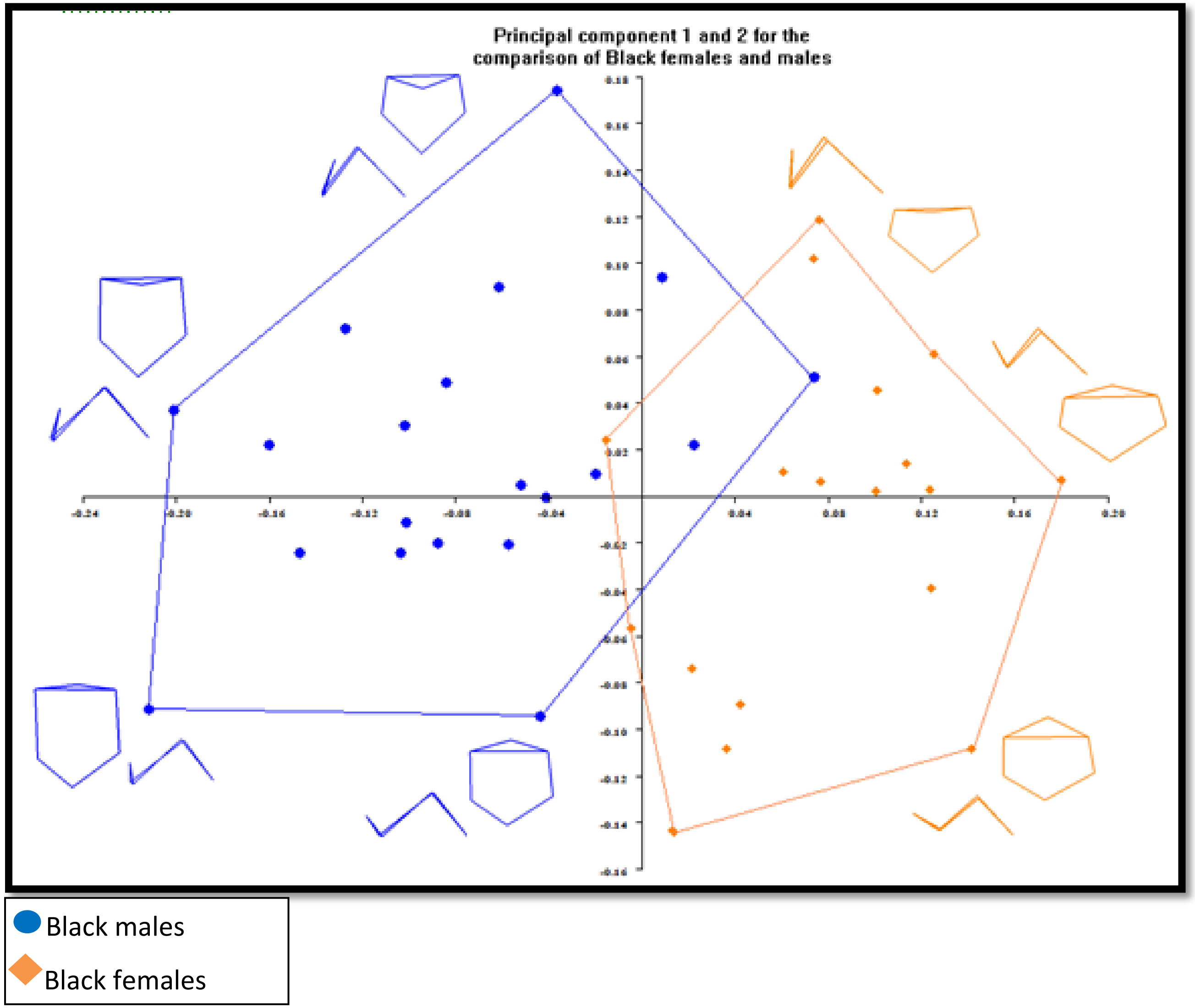


	Black males	White males
Postero-inferior and lateral view	The pelvic outlet is encroached by the urogenital triangle which appears relatively larger.	The urogenital triangle occupies a relatively smaller and flattened part of the entire pelvic outlet.

4.3.3.2. Comparison of pelvic outlet shape between sexes within populations

In figure 55, analysis of variance along principle components 1 and 2 can be seen comparing black females and males. Analysis of variance along principle components 1 and 2 can be seen comparing white males and females in figure 57.

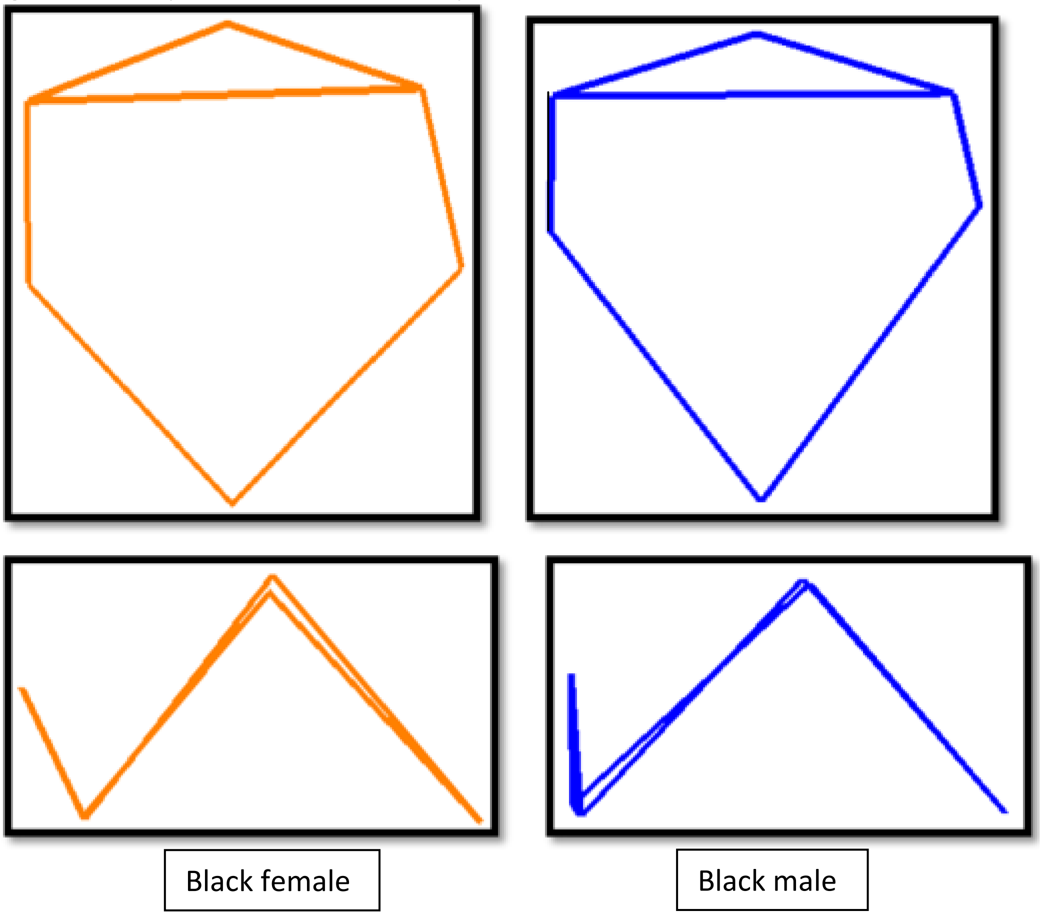
Figure 55. Principal component 1 and 2 for the pelvic outlet in the comparison of black males and females

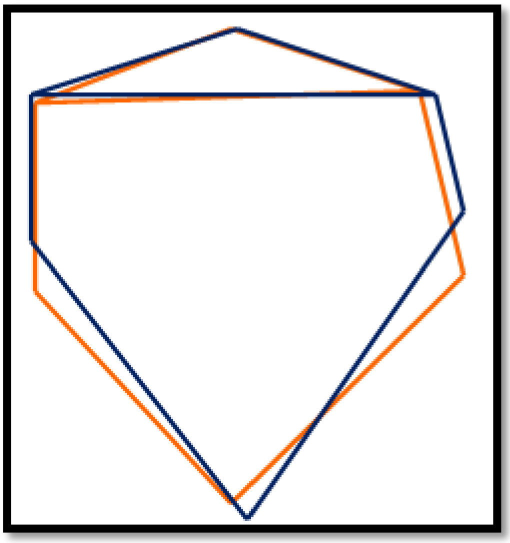


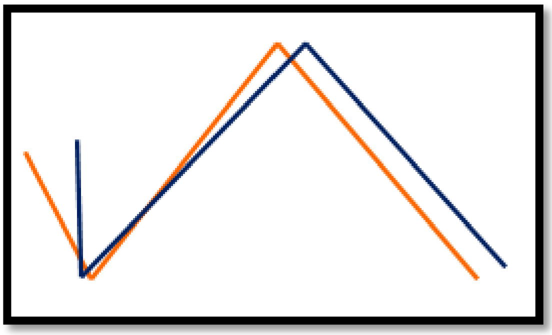
There is almost no overlap of the two groups. Black males dominate the left half of the graph, while black females are abundant in the right half of the graph. The p value for inter-sex variation <0.0005 was determined by two group multivariate permutation by Past soft ware.

As determined by PAST, there is a significant difference when comparing the pelvic outlet shape between the sexes in blacks. Using principal component 1 and 2, the mean pelvic outlet shape of black females and males were found separately. In figures 56 below, the determined mean shapes for black females and males are compared to each other

Figure 56. Comparison of the mean shapes of black females and males

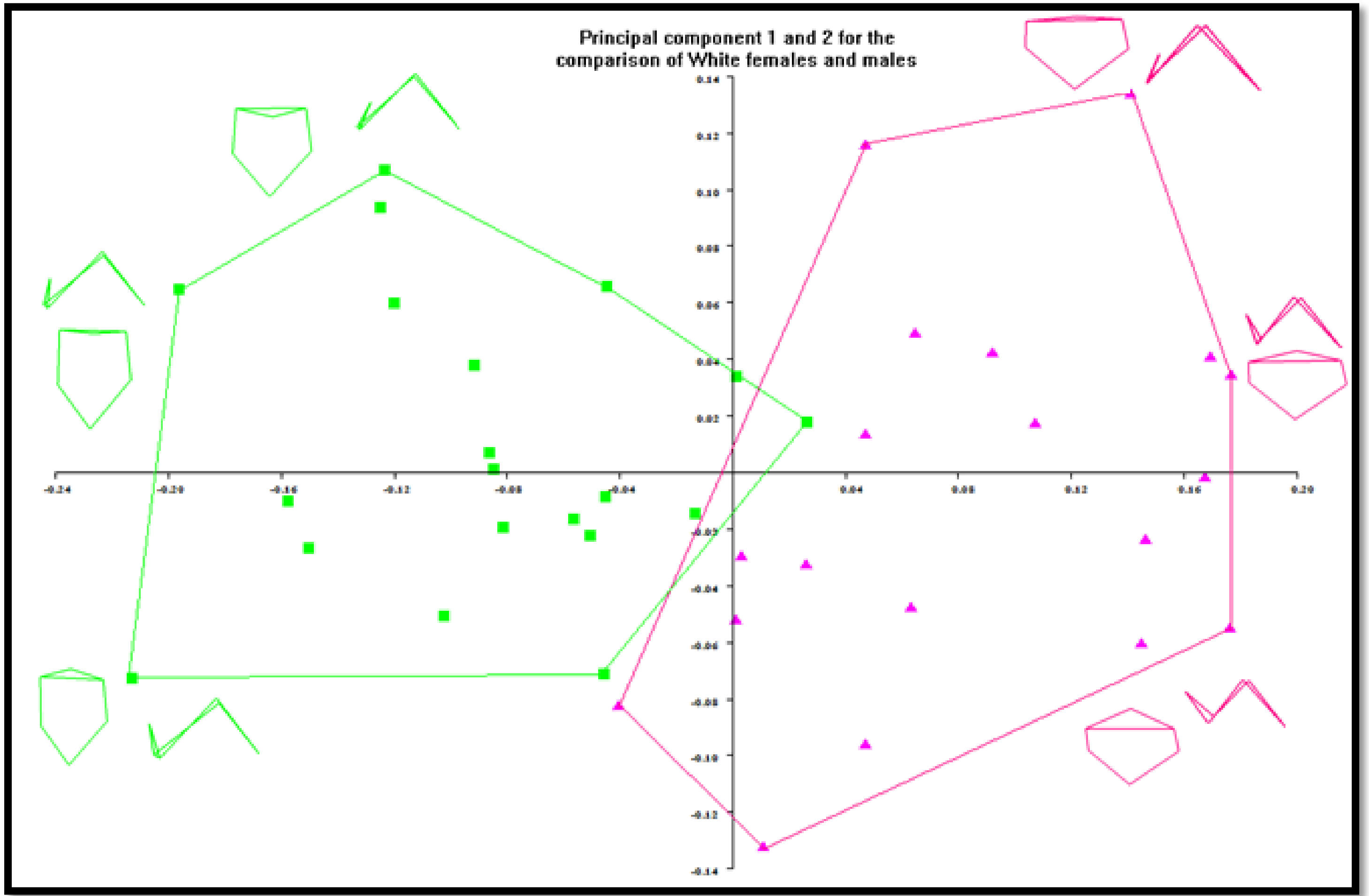






	Black females	Black males
Postero-inferior view	Urogenital triangle is slightly larger.	Urogenital triangle is slightly smaller.
Lateral view	Further distance from pubic symphysis to ischial tuberosity directed more posteriorly.	Shorter distance from pubic symphysis to ischial tuberosity directed more vertically.

Figure 57. Principal component 1 and 2 for the pelvic outlet in the comparison of white females and males

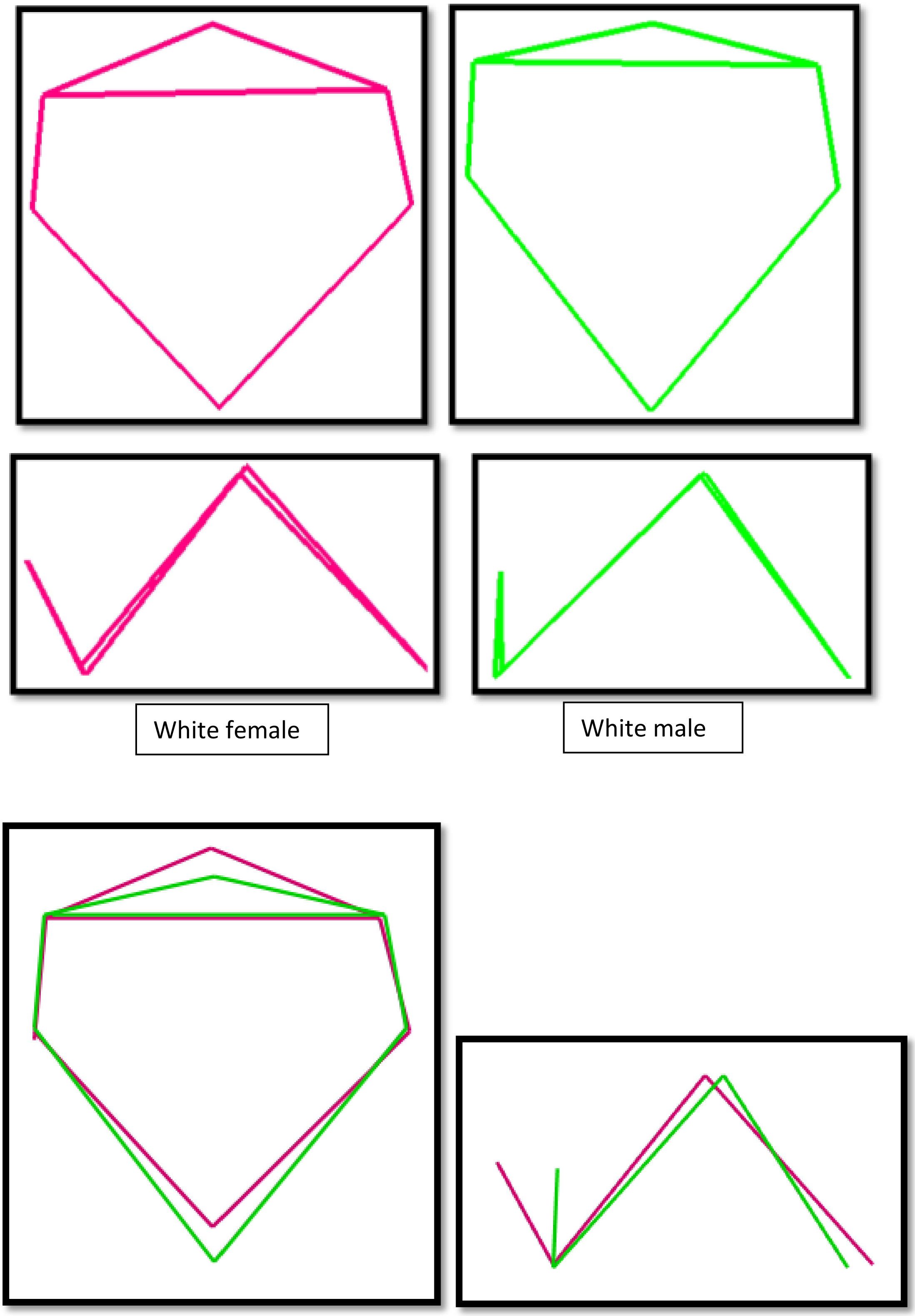


White males
White females

There is some overlap of the two groups. White males dominate the left half of the graph as well as the lower right quadrant. White females represent the extremes in the upper right quadrant. The p value for inter-sex variation = <0.0005 was determined by two group multivariate permutation by Past soft ware.

As determined by PAST, there is a significant difference when comparing the pelvic outlet shape between the sexes in whites. Using principal component 1 and 2, the mean pelvic outlet shape of white females and males were found separately. In figures 58 below, the determined mean shapes for white females and males are compared to each other

Figure 58. Comparison of the mean shapes of white females and males

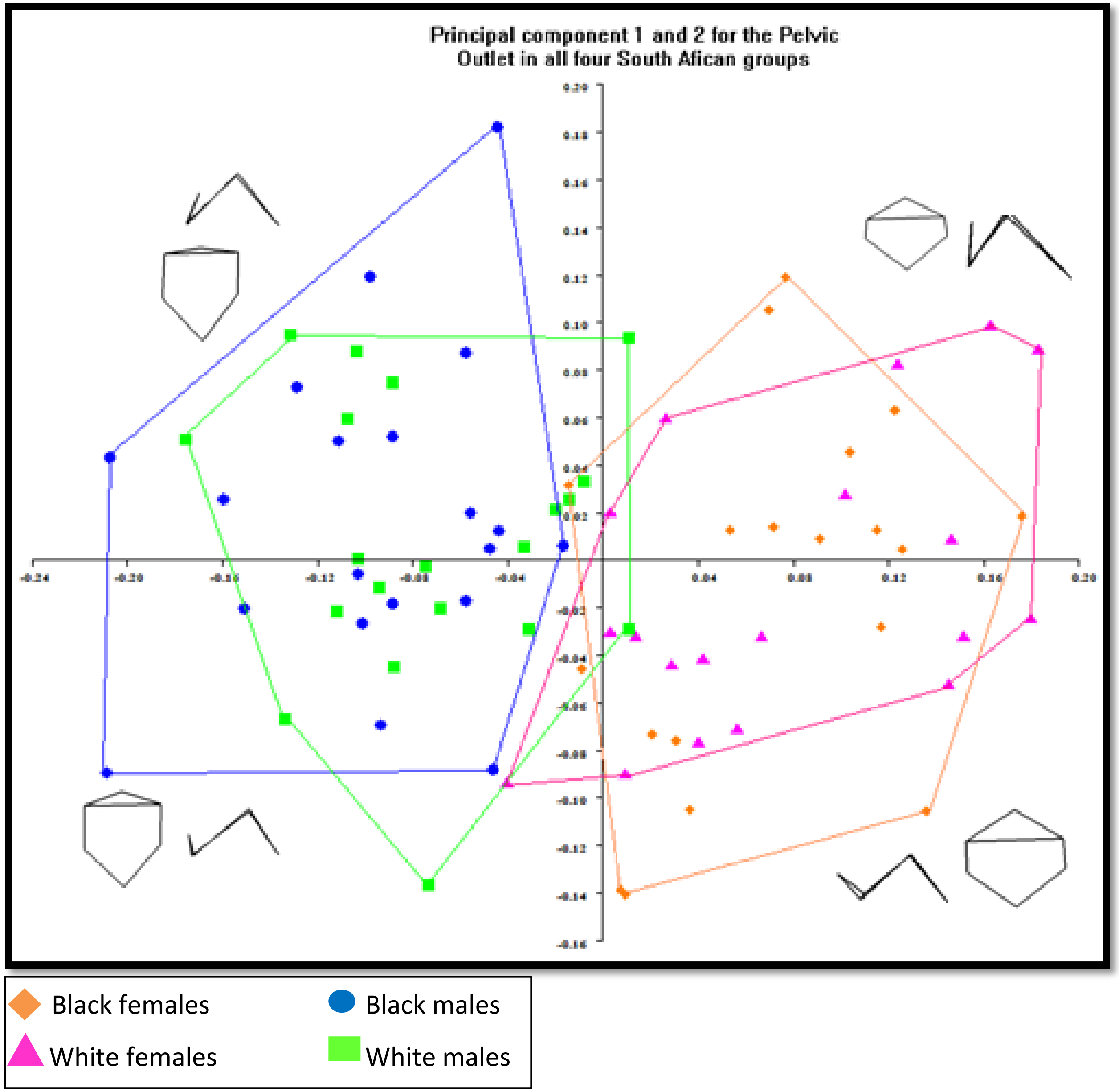


	White females	**White males**
Postero-inferior view	Urogenital triangle is larger Outlet is wider in its transverse diameter than in its AP diameter.	Outlet is greater in its AP diameter than in its transverse diametre.
Lateral view	Further distance from pubic symphysis to ischial tuberosity directed more posteriorly	Shorter distance from pubic symphysis to ischial tuberosity directed more vertically

4.3.3.3. Comparison of pelvic outlet shape between all four sexes-population groups

Lastly an analysis of variance along principle components 1 and 2 were performed to compare all four sex-population groups as seen in figure 59 below. This gives a representation of the distribution of each group in relation to each other.

Figure 59. Principal component 1 vs. 2 of the pelvic outlet shape in all four groups



There is a distinct separation in the two sex groups; with females dominating the right half of the graph and males the left half. There is only a slight overlap of the four groups in the centre of the graph.

The relative size of the urogenital triangle is larger on the right hand side of the graph and therefore in females. The relative transverse diameters to the AP diameter increase as well on the right hand side of the graph (females) so as to make the outlet shape broader than on the left (males).

Integration of pelvic outlet shape analyses with metric findings

The impression of the shape of the pelvic outlet to be similar in black and white females is also reflected in the metric analyses of pelvic outlet diameters, which showed no significant difference, apart from the interspinous diameter. The interspinous diameter although significantly larger in white females, was not great enough to cause the shape changes to be significantly different.

Apart from the distance between the pubic symphysis and the ischial tuberosity, all dimensions across the pelvic outlet were significantly larger in whites and black females than black males. This was especially so in the transverse diameters (interspinous and intertuberous) creating a wider pelvic outlet shape in white males and in black females.

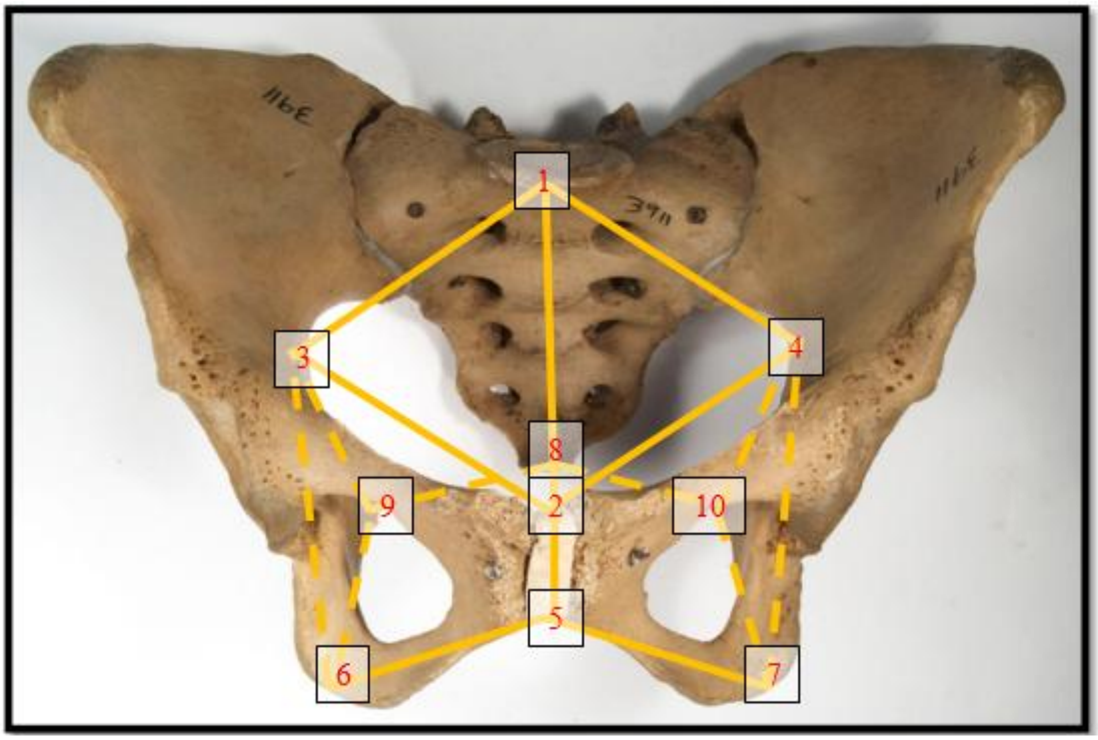
So although the urogenital triangle appeared relatively larger in the antero-posterior dimensions in black males, this was because the actual transverse diameter was so much smaller than in whites and black females. The relative size of the outlet in black males was smaller and narrower.

In both black and white females, the urogenital triangle was larger and the outlet wider in its transverse diameter than in its AP diameter. The distance from the pubic symphysis to ischial tuberosity was directed more posteriorly, this is also reflected in the metric dimensions.

4.3.4. Pelvic canal

The pelvic canal, described in this study, comprised of both the points used in the boundaries of the pelvic inlet as well as the pelvic outlet. Using a wire frame to connect the points on Morphologika software a “continuous canal” was created between pelvic inlet and outlet. Figure 60 and 61 represents the canal from an antero-inferior and lateral view respectively.

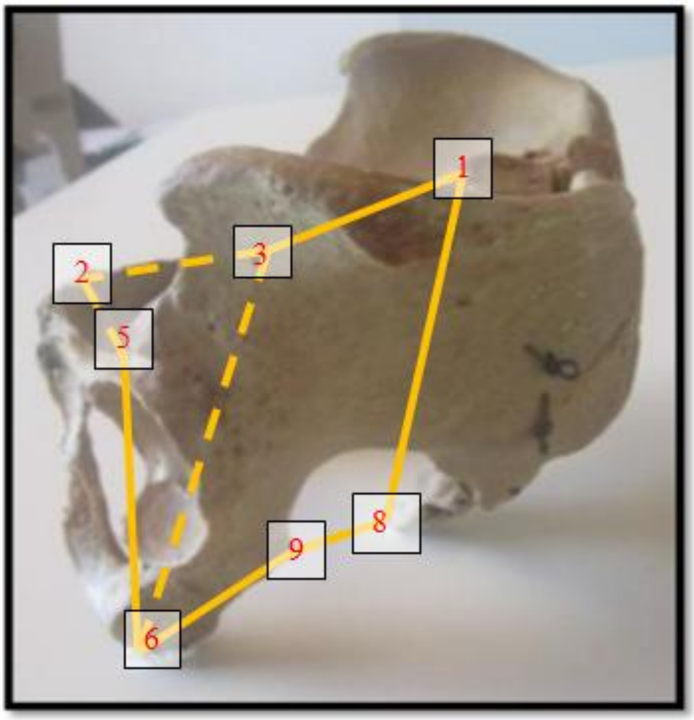
Figure 60. Pelvic canal shown from an antero-inferior view



1. H- Midpoint on sacral promontory
2. F- Most superior point in the midline of the pubic symphysis
3. IR- Right point where widest transverse diameter transects the pelvic inlet
4. IL- Left point where widest transverse diameter transects the pelvic inlet
5. G- Most inferior point in the midline of the pubic symphysis
6. E_R- Most inferior point on the ischial tuberosity (right)
7. E_L- Most inferior point on the ischial tuberosity (left)
8. K- Lowest limit of coccyx
9. J_R- Ischial spine (right)

10 J_L- Ischial spine (left)

Figure 61. Pelvic canal shown from a lateral view



1. H- Midpoint on sacral promontory
2. F- Most superior point in the midline of the pubic symphysis
3. I_R- Most widely separated points in the diameter of the pelvic inlet (right)
5. G- Most inferior point in the midline of the pubic symphysis
6. E_R- Most inferior point on the ischial tuberosity (right)
8. K- Lowest limit of coccyx
9. J_R- Ischial spine (right)

4.3.4.1. Comparison of pelvic canal shape between populations within sexes

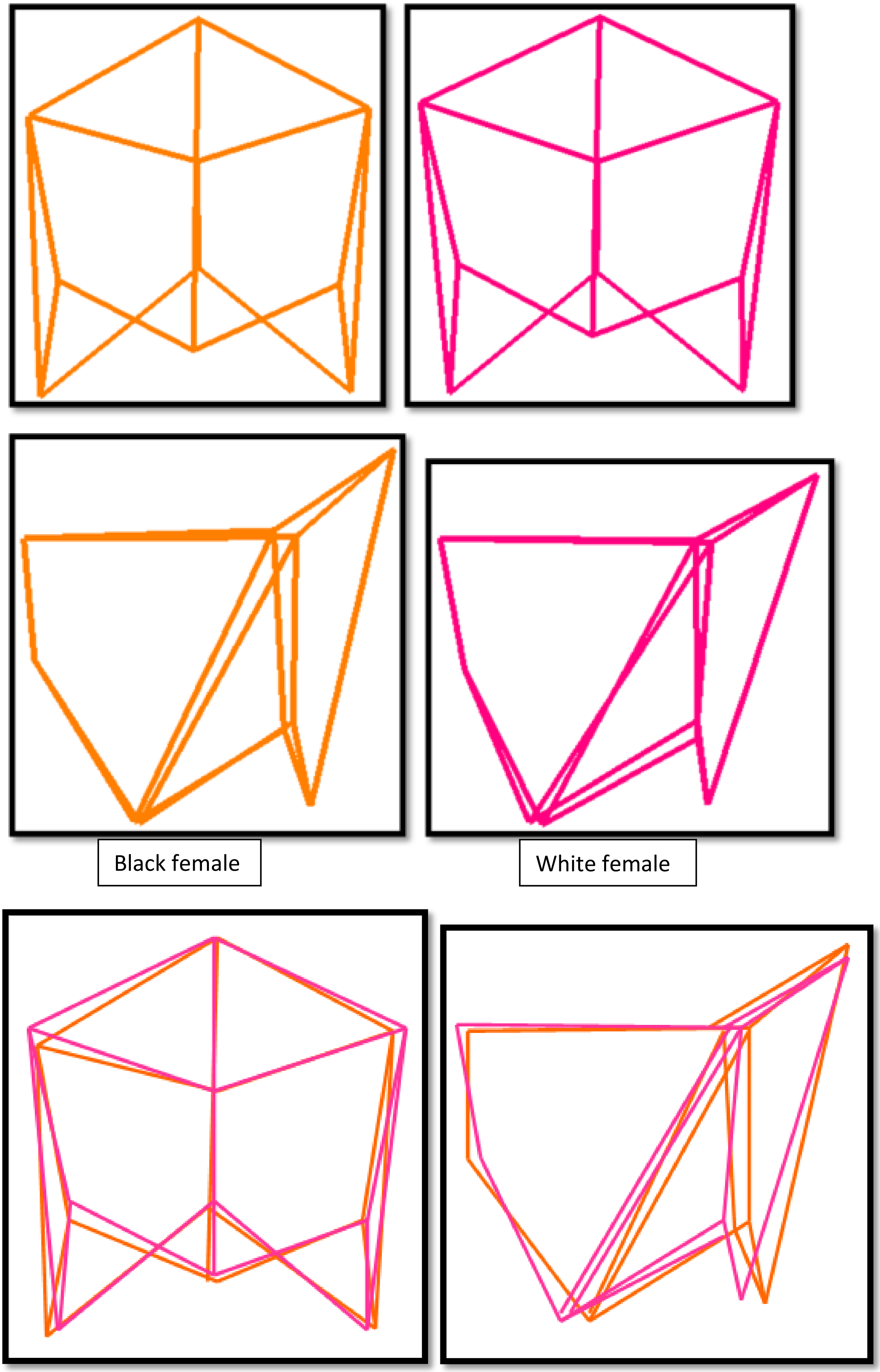
Firstly, the pelvic canal shapes between populations within sex group were compared. In figure 62, analysis of variance along principle components 1 and 2 can be seen comparing black and white females. Analysis of variance along principle components 1 and 2 could be seen comparing black and white males in figure 64. An antero-inferior, lateral and postero-inferior views of the canal are represented.

Figure 62. Principal component 1 and 2 for the pelvic canal in the comparison of black and white females

Although the distributions of the females were evenly spread over the graph and a great extend of overlap could be visually detected between the populations, especially around centre of the graph, the p value for inter-population variation = 0.0395 as determined by two group multivariate permutation by Past soft ware was significant.

Using principal component 1 and 2, the mean pelvic canal shape of black and white females were found separately. In figures 63 below, the determined mean shapes for black and white females are compared to each other. The antero-inferior as well as lateral views are shown.

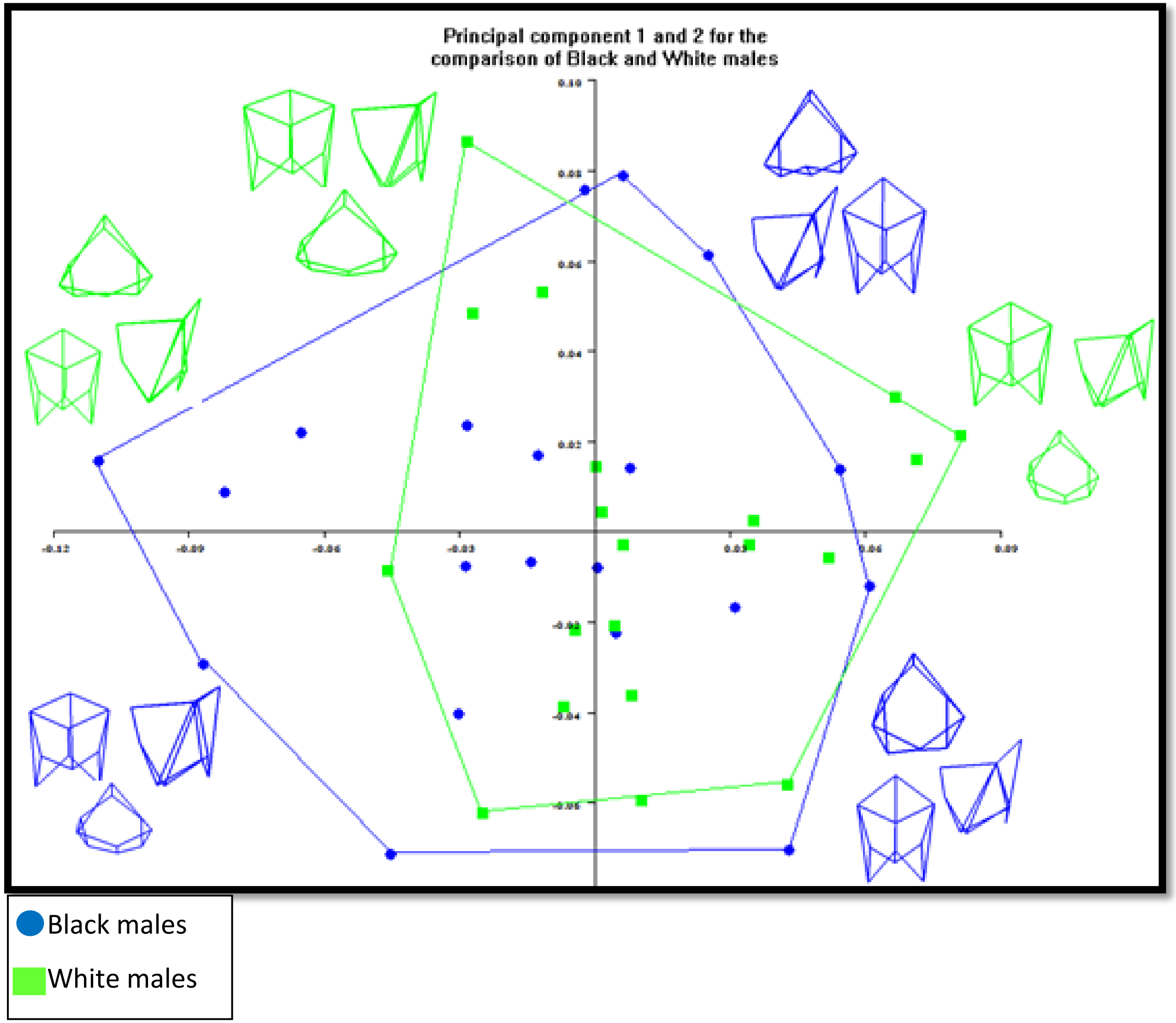
Figure 63. Comparison of the mean shapes of black and white females



	Black females	**White females**
Antero-inferior and Lateral view	Pubic symphysis is relatively shorter and more vertically directed.	Pubic symphysis is relatively longer and slanting inwards in a posterior direction

The slanting inwards of the pubic symphysis in a posterior direction, may be explained by a relatively longer AP distance across affecting the inlet more than the outlet in the white females.

Figure 64. Principal component 1 and 2 for the pelvic canal in the comparison of black and white males



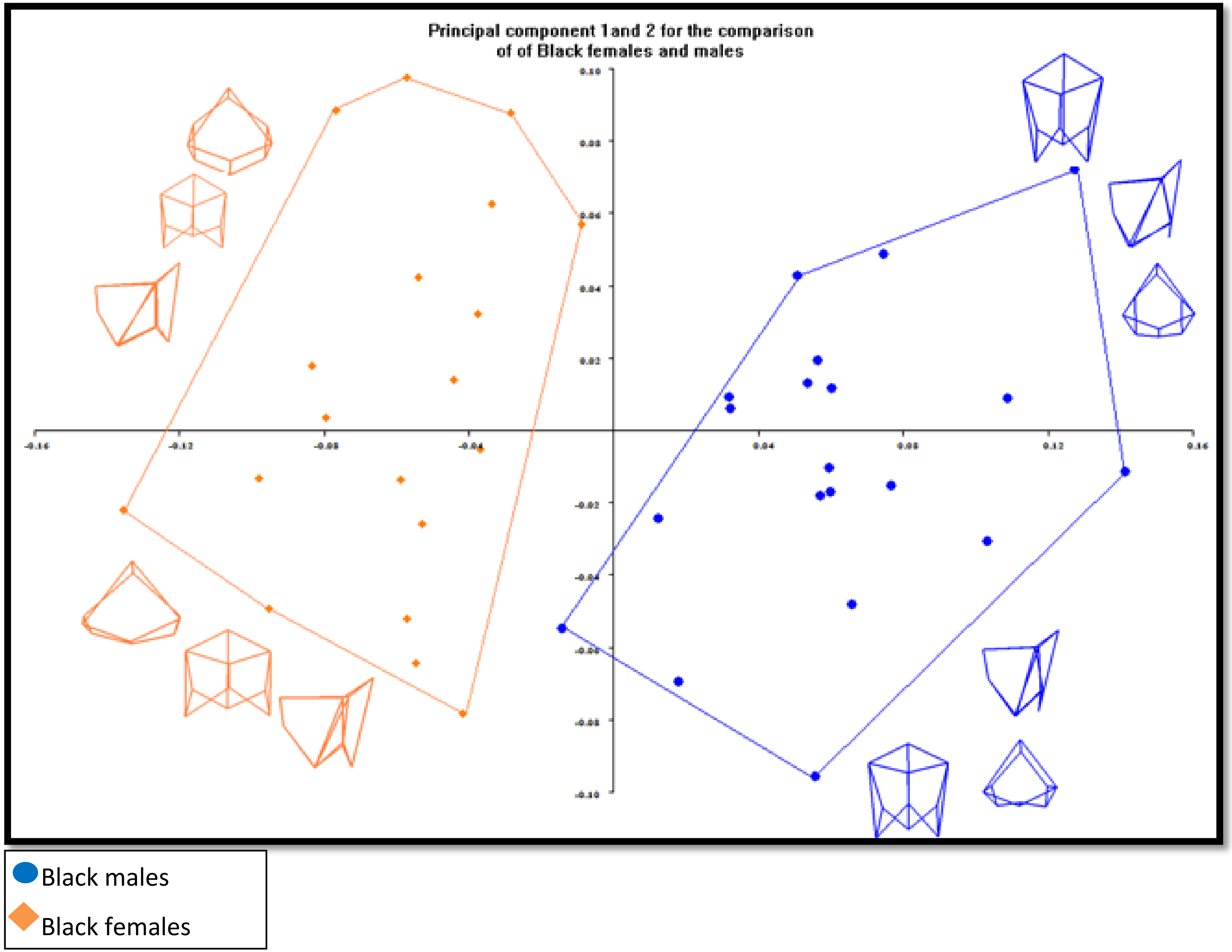
The distributions of males are evenly spread over the graph and a great extend of overlap can be visually detected between the populations. The p value for inter-population variation = 0.29 was insignificant as determined by two group multivariate permutation by Past soft ware.

Although the populations overlap to a great extend, black males tend to represent the far extremes on the left half of the graph, while white males tend to represent the extremes on the right half of the graph.

4.3.4.2. Comparison of pelvic canal shape between sexes within populations

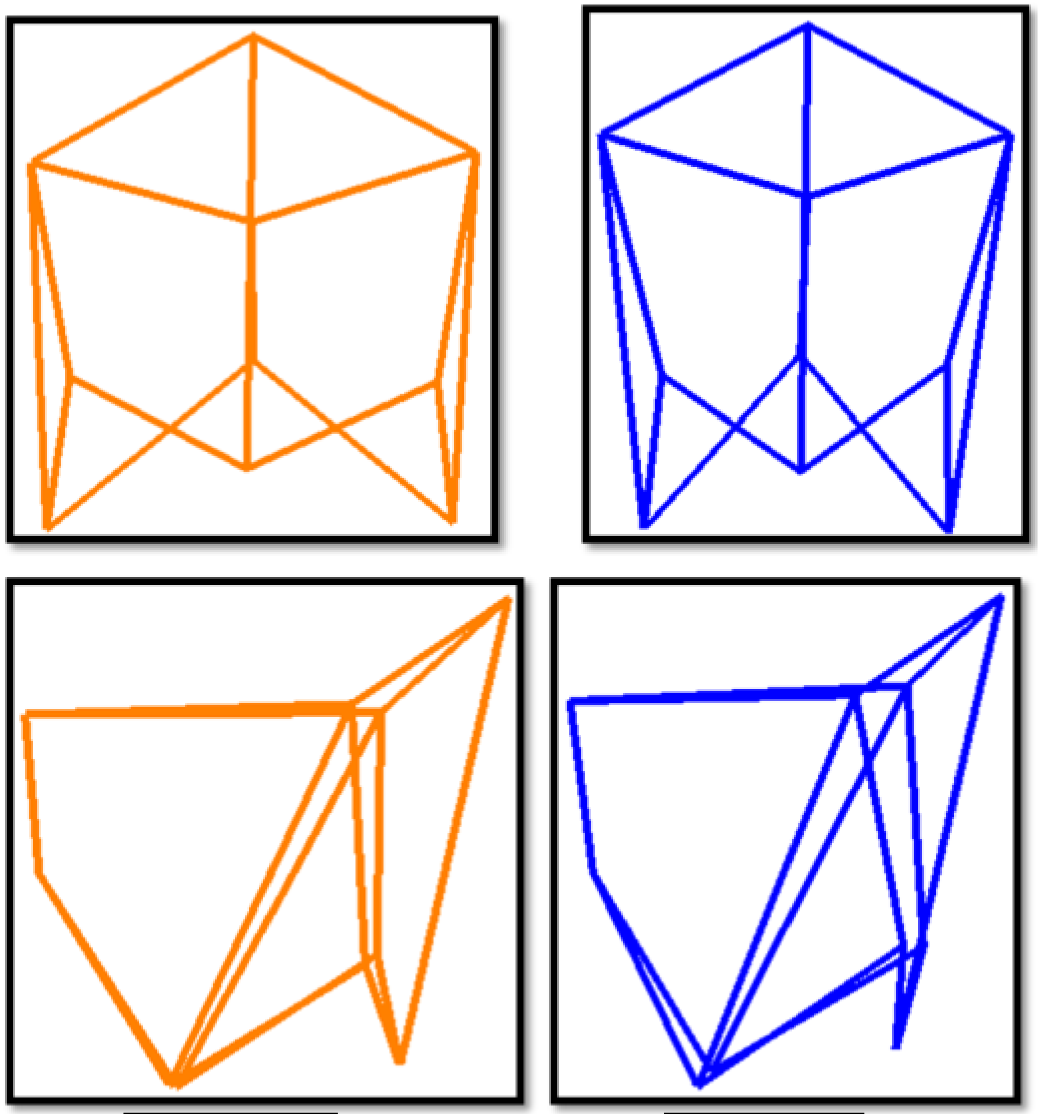
In figure 65, analysis of variance along principle components 1 and 2 can be seen comparing black females and males. Analysis of variance along principle components 1 and 2 can be seen comparing white males and females in figure 67.

Figure 65. Principal component 1 and 2 for the pelvic canal in the comparison of black males and females



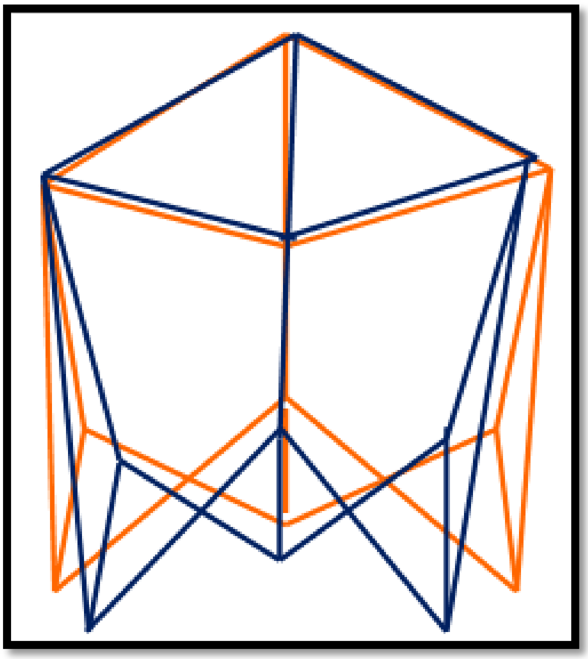
There is a distinct separation of the groups, with no overlap at all. Black females dominate the left side of the graph, and present with pelves that have wider outlets. Their promontories are highest (or more proximal relative to the widest transverse diameter) in the lower left quadrant. The right side of the graph, is dominated by black males who present with narrower pelvis canals. The p value for inter-population variation = 0.0005 was significant as determined by two group multivariate permutation by Past soft ware.

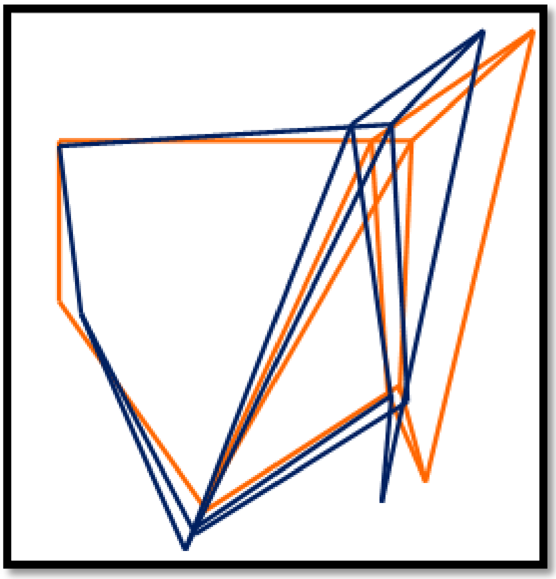
Figure 66. Comparison of the mean shapes of black males and females



Black female

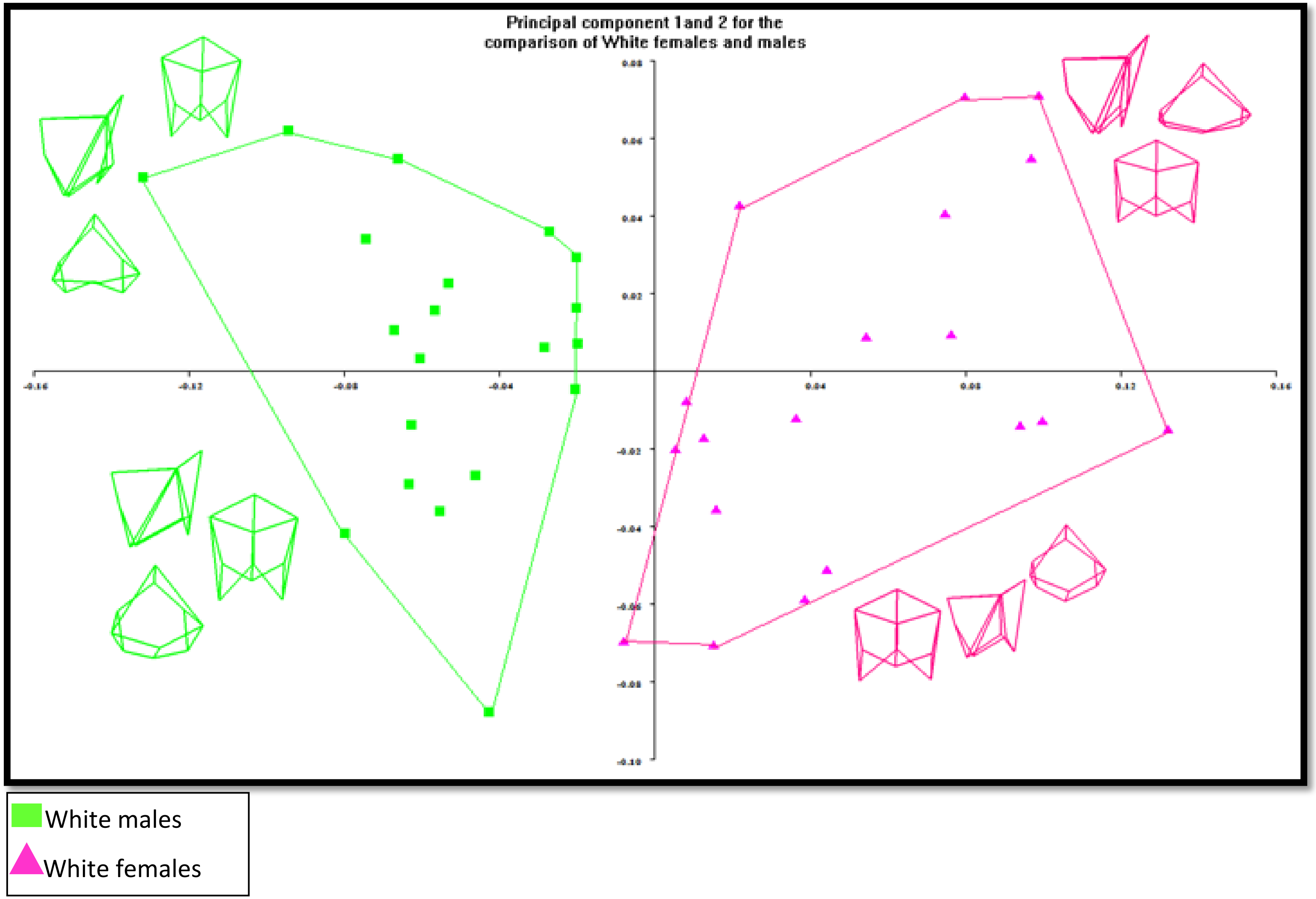
Black male





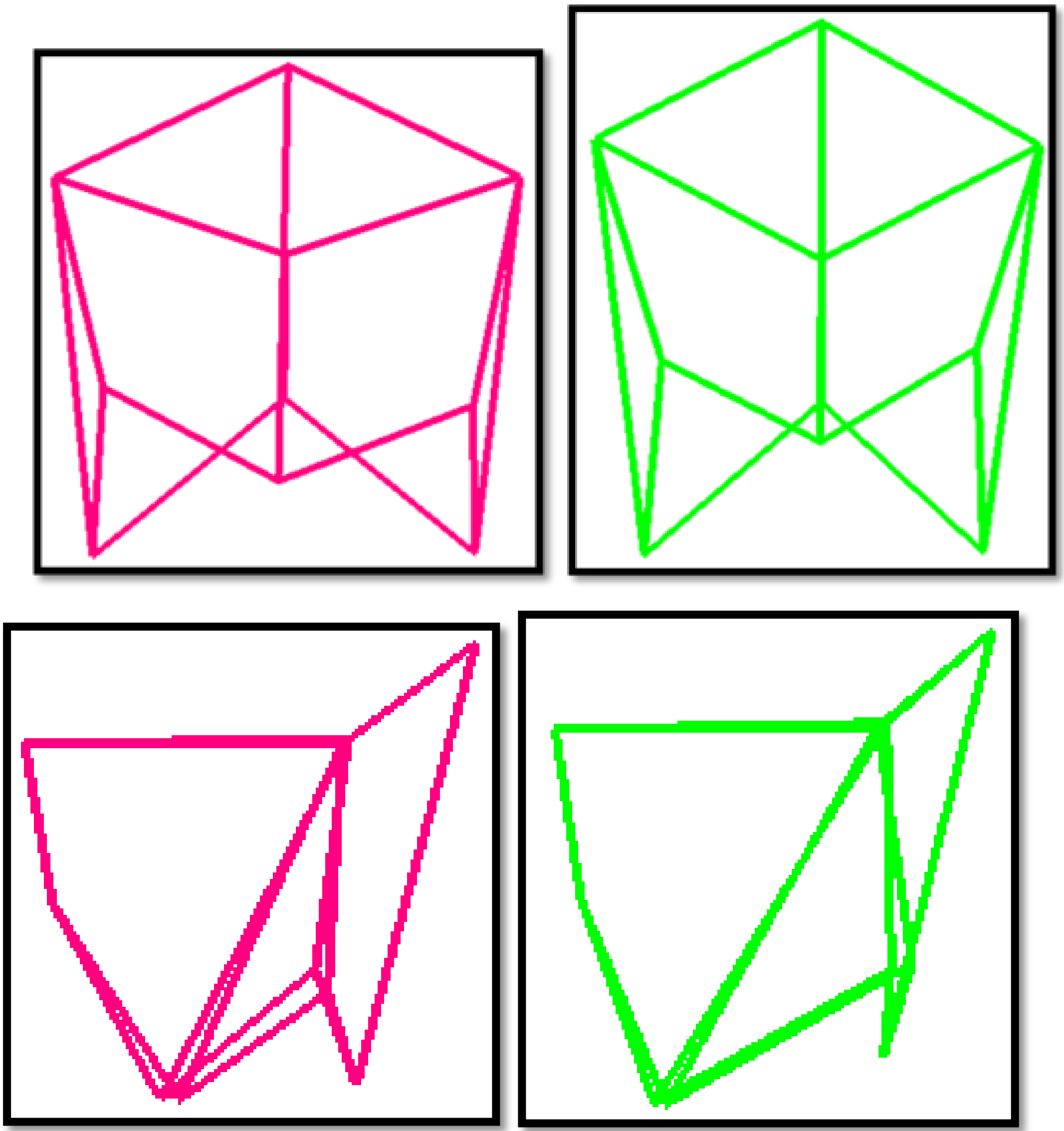
	Black females	Black males
Antero-inferior view	Wider appearance. Ischial spines as well as ischial tuberosities lie further apart.	The walls are narrower. Ischial spines as well as ischial tuberosities are inwardly directed
Lateral view	Wider and flattened out appearance	Coccyx more turned inward

Figure 67. Principal component 1 and 2 for the pelvic canal in the comparison of white males and females



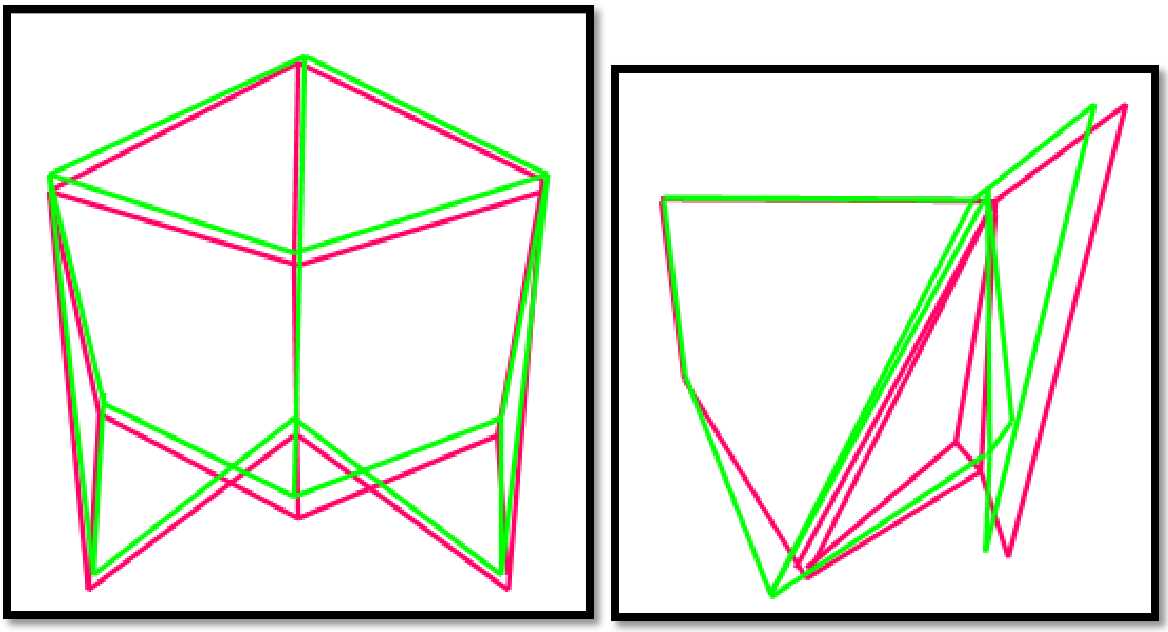
As with the black population, a distinct separation of the groups is found, with no overlap at all. White females dominate the right side of the graph, and white males the left half. These females have pelves that have wider outlets. The left side of the graph is dominated by black males who present with narrower pelvic canals. As with the black population, the p value for inter-population variation = 0.0005 was significant as determined by two group multivariate permutation by Past soft ware.

Figure 68. Comparison of the mean shapes of white males and females



White female

White male

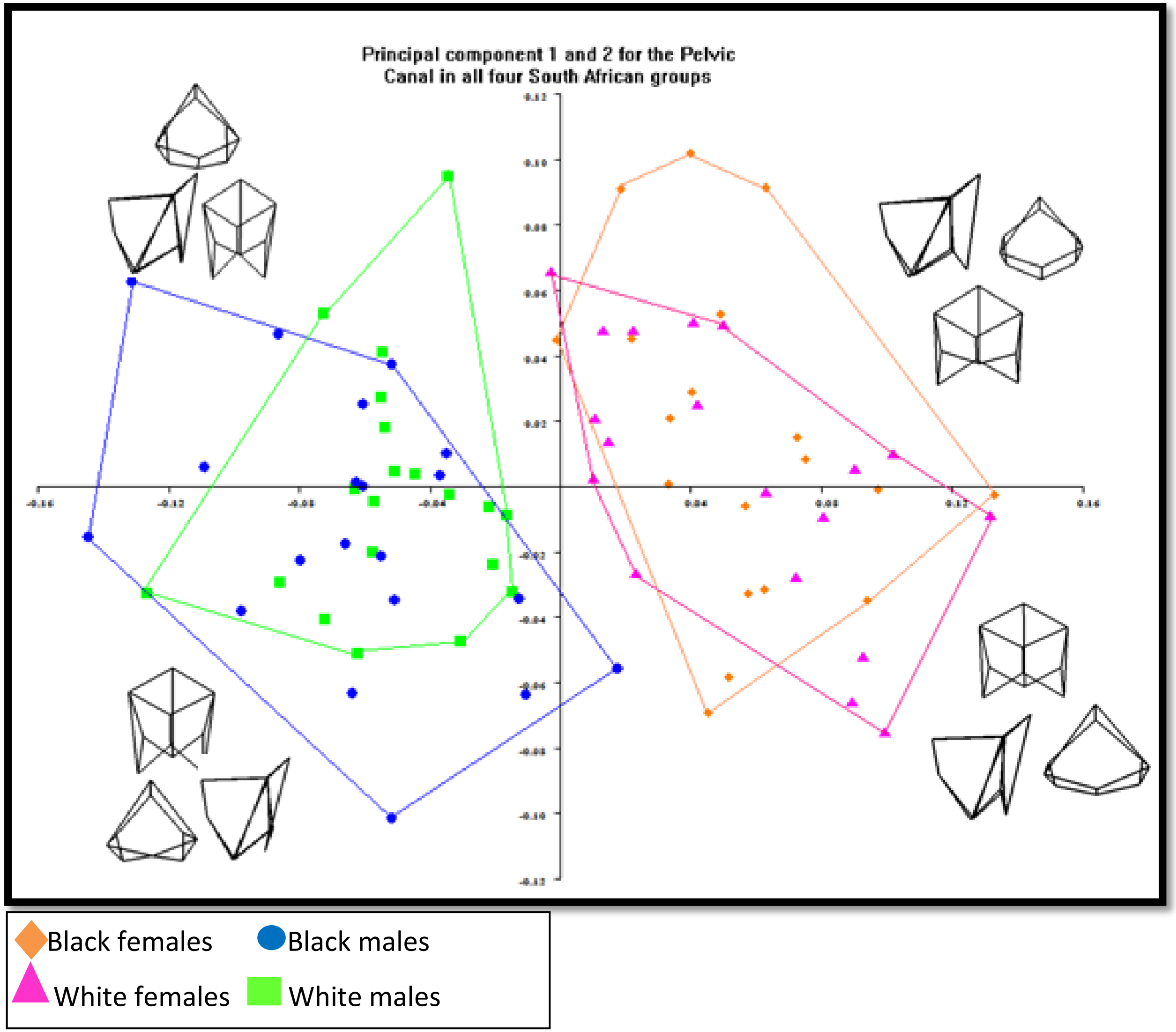


	White females	White males
Antero-inferior view	Wider appearance. Ischial spines as well as ischial tuberosities lie further apart.	The walls are narrower. Ischial spines as well as ischial tuberosities are inwardly directed
Lateral view	Wider appearance	Coccyx more turned inward

4.3.4.3. Comparison of pelvic canal shape between each sex-populations groups

Lastly, an analysis of variance along principle components 1 and 2 were performed, to compare all four sex-population groups as seen in figure 69 below. This gives a representation of the distribution of each group in relation to each other.

Figure 69. Principal component 1 vs. 2 of the pelvic canal shape in all four groups



The distributions of the groups are widespread over the graph, with males notably dominating the left half, and females dominating the right half of the graph. The left side of the graph represents pelves that present with a narrow canal, and increased distances between their most inferior points on the ischial tuberosities thereby, creating smaller subpubic angles. These pelves also have higher and more prominent sacral promontories. The coccyx and ischial spines projects inwardly, creating a smaller pelvic outlet.

The right side of the graph is made up of pelves with a wider canal; due to the outward projection of the ischial spines and coccyx. This also creates a wider and roomier pelvic outlet.

Integration of pelvic canal shape analyses with metric findings

The significant pelvic shape differences noted amongst the females, may be related to the significantly larger pelvic inlet and interspinous diameters in white females, as compared to black females, whilst the outlet diameters did not differ significantly. This had an influence on the direction of the pubic symphysis and the space available in the anterior part of the pelvis. In addition, the total length of the pubic symphysis was significantly shorter in black females.

The significant difference in pelvic shapes between sexes, may be related to the significant differences between the interspinous distance and the significant differences in the pelvic inlet and outlet dimensions of the black population.

4.4. Implications of results related to the clinical procedures

4.4.1. Perineal incontinence procedures

4.4.1.1. Dissection plane

The ease of performance of perineal incontinence procedures including rectal incontinence procedures in both sexes, may be enhanced by a wider dissection plane. The bony borders of the dissection plane consists of the ischiopubic rami and are therefore influenced by the subpubic angle, the pelvic outlet intertuberous diameter (measurement E_R-E_L) and the distance between the most inferior point on the pubic symphysis to the most inferior point on the left ischial tuberosity (measurement G-E_L).

The expected size of the dissection plane did not differ much between black and white females. However in males, in general and more specifically black males this plane was smaller as a result of a significantly smaller subpubic angle and intertuberous diameter.

Associated with the non significantly longer ischiopubic ramus length (measurement G-E_L) in whites, all measurements that extend across the obturator foramen from anterior to posterior (except measurement A-B_L), were found to be statistically longer. Two of these measurements were also stature dependent.

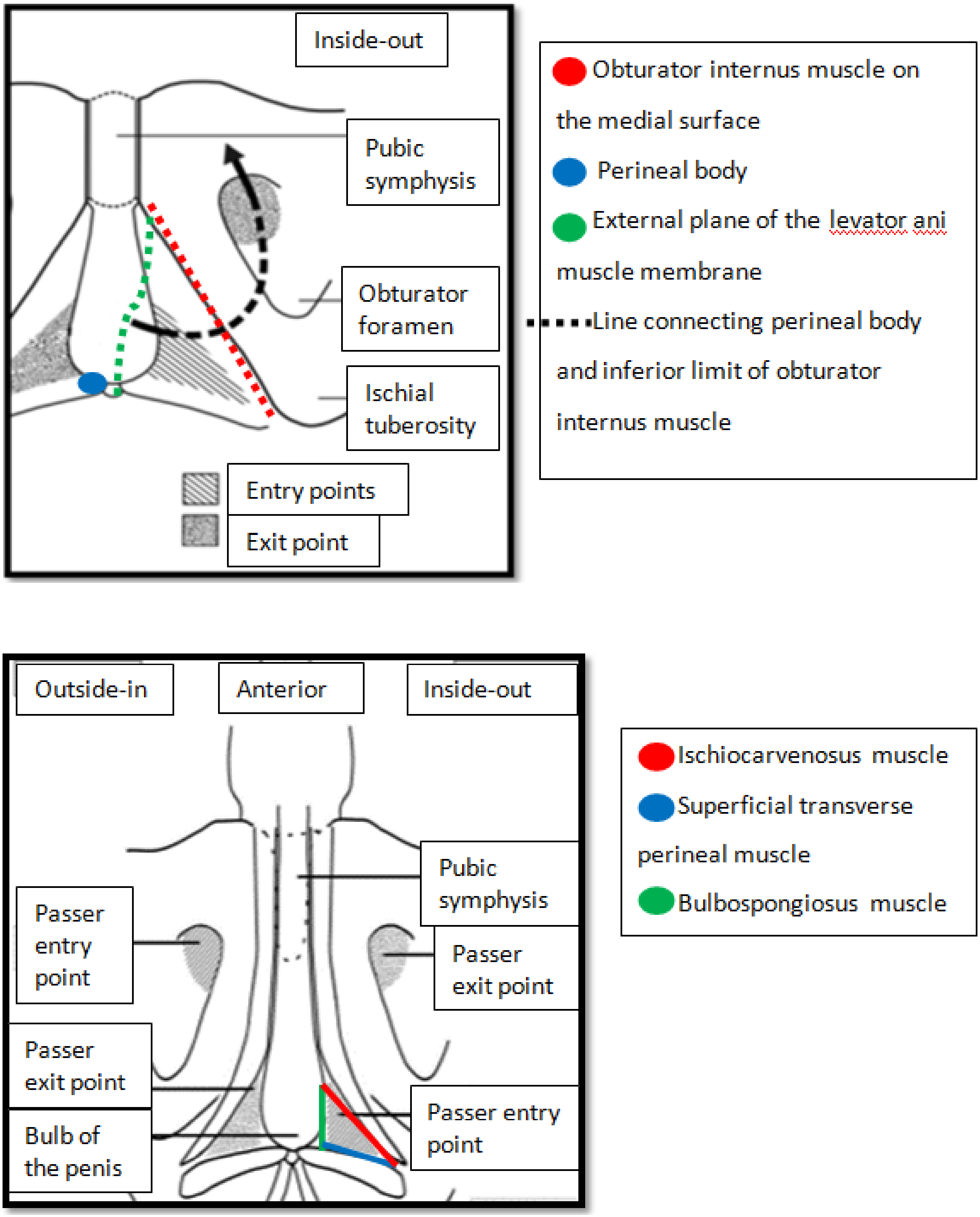
During TOT procedures, this perineal dissection plane involves a triangular space bounded by perineal muscles attached to the ischiopubic rami on either side.

When considering the inside out approach in males, the guide is inserted through the scissor-initiated dissection path. The triangular space is observed, delineated laterally by each ischiocarvenosus muscle and medially by the bulbospongiosus muscle.[27]

In females, during the perineal dissection for the insertion of the passer, the vulvar vestibulum is exposed and a triangular space is so created. This space is limited in its external border by the internal obturator muscle. Once the upper part of the ischio-pubic ramus is reached and bone contact is perceived the obturator membrane is perforated.[24]

Both of these dissection planes, as well as the muscles involved in both sexes are compared in figure 70 below.

Figure 70. Representation of the triangular space observed and the muscles involved in females (left) and males (right)



As a result of the significantly wider subpubic angle and intertuberous distance, exposure of the ischiocarvenosus muscle will require a dissection that extends more laterally in comparison to black males, producing a wider, more open dissection area which may aid the surgeon in performing the procedure in white males.

In black males with a smaller dissection plane, care should be taken that the trajectory of the passer encroaching on the inferior pubic ramus should not endanger related structures e.g. the branches of the pudendal nerve.

A deeper dissection might be necessary in white males, and especially taller white females, as the ischiopubic ramus was wider. When a mini-arc-anterior repair procedure, monarc TOT sling or other similar TVT slings in white females are placed, it might be at a deeper dissection level than black females.

In addition to this; in females, the triangular space created will be influenced by the dimensions of the obturator foramen as well, which were longer in the antero-posterior dimension in white and taller females

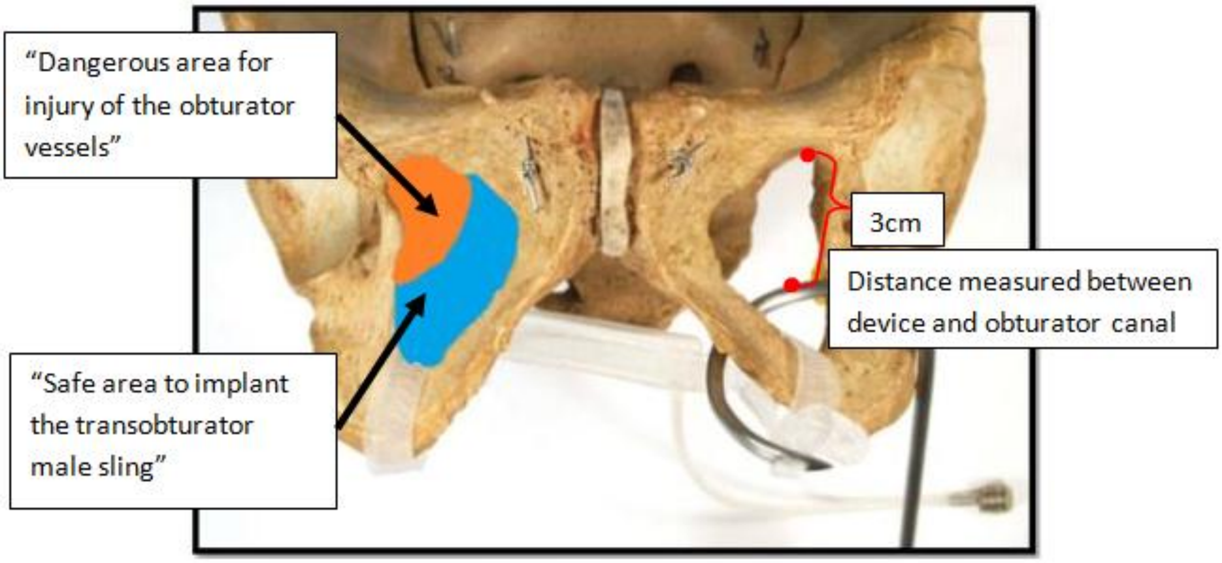
Rectal incontinence procedures

As in the case of females, wider dissection plane observed around the anus and perineum may facility the perineal approach in the repair of rectal prolapse.

4.4.1.2. Introducers used for TOT placement

The use of a transobturator circular needle with a diameter of 3 cm, was associated with an obturator canal of nearly 3 cm away from the devise, as it passed through the obturator foramen.[24, 37] Bauer et al.,[12] also found distance of 3 cm between the tape and the obturator canal. These authors then divided this distance into two segments referred to as the “dangerous area for injury of the obturator vessels” and “safe area to implant the transobturator male sling” (Figure 71).

Figure 71. Indication of the “dangerous area for injury of the obturator vessels” and “safe area to implant the transobturator male sling” as adapted from Bauer



Distance B_L-C_L, which is the distance between the most superior point of the obturator canal and the most medial point on the obturator foramen, did not have a significant difference between the populations or sexes. All South Africans, presented with mean values of approximately 2.5 cm in this measurement. Taking into account the 3 cm distance from the obturator canal to the device measured, South Africans could be more exposed to possible injury to the obturator neurovascular bundle with the TOT outside-in technique than predicted. These differences might require the adjustment of the technique or instrumentation to perform the procedure safely. A passer with a smaller open circular segment than 3 cm radius may for instance be required to prevent obturator nerve injury.

The use of instrumentation with a fixed dimension as described, may not take into account the variability in the relevant pelvic dimensions e.g. the broadness of the inferior pubic ramus and the subpubic angle observed in the different populations and sexes considered. These differences might further necessitate the adaptation of the technique or instrumentation to perform the procedure successfully.

When considering the more slender inferior pubic width in blacks and its association with stature, as well as the narrower subpubic angle in black males; an introducer with a smaller open circular segment than 3 cm radius, might facilitate the procedure in blacks or shorter individuals.

4.4.1.3. Course of the needles

Tension-free vaginal tape (TVT) and bone anchors

When considering trajectories where the needle passes retropubic, it should be noted that in black females, the rotation of the passer should be sharper to accommodate the shorter pubic symphysis and to prevent damage to internal structures. Although the mean values did not differ that much, the ranges differed to a greater extend: in black females as short as 33.89 mm and in white females up to 56.83 mm.

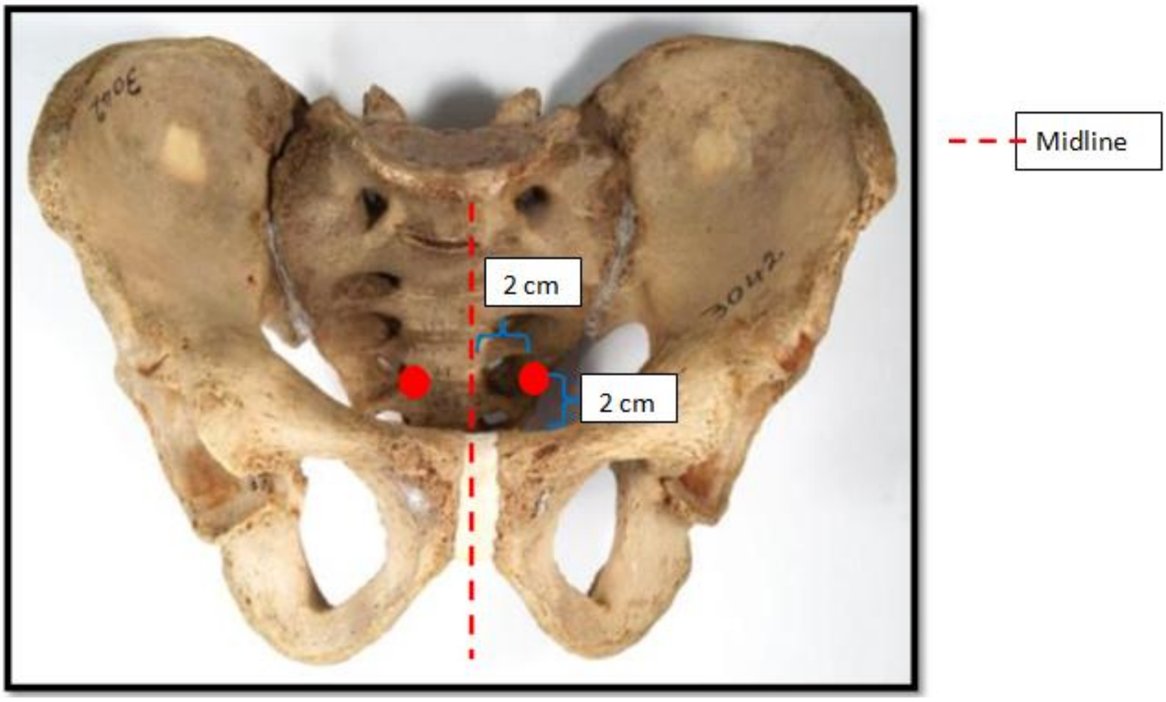
An overestimation of the pubic symphysis length which may occur in black and shorter females, may possibly lead to the placement of the needles too far superior to the upper border of the pubic symphysis. This may cause the diversion of the needles in the retropubic space, putting large blood vessels and nerves in the pelvis at potential injury as well as perforation of the bladder.[21, 37, 47, 52, 53] On the other, hand underestimation may cause difficulty in the performance of the procedure.

Although the interobturator foramina distance of just under 6 cm on average did not show significant differences between groups, it conforms to the 4-5 cm distance between the abdominal incisions. Some black females present with interobturator distances of less than 4 cm. This might lead to placement of the needles too far laterally, which might endanger intrapelvic structures.

"Four-Armed" male sling system

According to the Coloplast Virtue Male Sling System[50], an incision is made 2 cm above the pubic symphysis and 2 cm lateral to the midline on either side (figure 72). The introducer is passed pre-pubically through the pubic incision and out through the perineal incision lateral to the urethra.

Figure 72. Position of the pre-pubic arm placement



Although white males presented with a significantly longer mean interobturator foramina distance (measurement C_R-C_L) and a longer pubic symphysis length (measurement F-G), both measurements in both populations approximated 5 cm. It is however important to note, that the interobturator foramina distance might be less than 4 cm and the pubic symphysis length may be as small as just more than 3 cm in some black individuals.

These dimensions may influence the correct placement of the pre-pubic arms. An incorrect estimation may cause diversion of the introducers too far into the abdomen causing damage to underlying vessels.

Needle trajectory for TOT placement

As the inferior pubic ramus forms part of the obturator needle pathway, the broadness was considered.(10) Although the mean values in both populations and sexes ranged from 1 to 1.5c m, statistical significant differences existed between the groups, and it was more than 2 cm in some individuals. In addition, the distance between the most inferior point on the pubic symphysis to the obturator canal (measurement G-B_L) were also significantly different between populations, and reached values of more than 7 cm in whites which was more than 2 cm longer than some black individuals.

Although the distance between the obturator canal and the most medial point on the obturator foramen (measurement B_L-C_L) did not show any significant differences between groups, the obturator canal were closer to the perineal dissection plane in blacks. The obturator canal was also brought closer to the midline in black males as the subpubic angle was statistically significantly smaller.

As the antero-posterior distance of the peri-obturator area was relatively much shorter, in relationship with the side to side diameter; with the associated position of the obturator canal lying more posteriorly in black females; it brought the obturator canal closer to the perineal area. It needs therefore to be considered that as soon as the needle is directed superiorly, that the available distance to the obturator canal is diminished, and therefore the obturator neurovascular bundle might be more endangered compared to white individuals.

In males as opposed to females, the inferior pubic rami were wider and the subpubic angle smaller, affording a more difficult procedure because of a smaller dissection plane and a wider curved route around the inferior pubic ramus.

These differences need to be taken into account, as over or under-estimation, may cause incomplete circumventing of the inferior pubic rami or diversion of the introducers into the pelvic space or closer to the obturator vessels. Care must therefore be taken to guide the passer along a smaller more curved route in blacks, females and shorter individuals as compared to whites, males or taller individuals not to injure intrapelvic structures or the obturator neurovascular bundle.

Bulbourethral sling

Certain authors emphasize that care should be taken to maintain contact with the pubic bone at all times during passage of the needle, and to exit the needle through the perineal membrane as far under the pubic arch and as medially as possible.[7] Lateral placement is likely to damage branches of the perineal nerve.

Similar dimensions regarding the dissection plane in the transobturator inside-out and outside-in procedures, as well as the length of the pubic symphysis (measurement A-B) will be of importance.

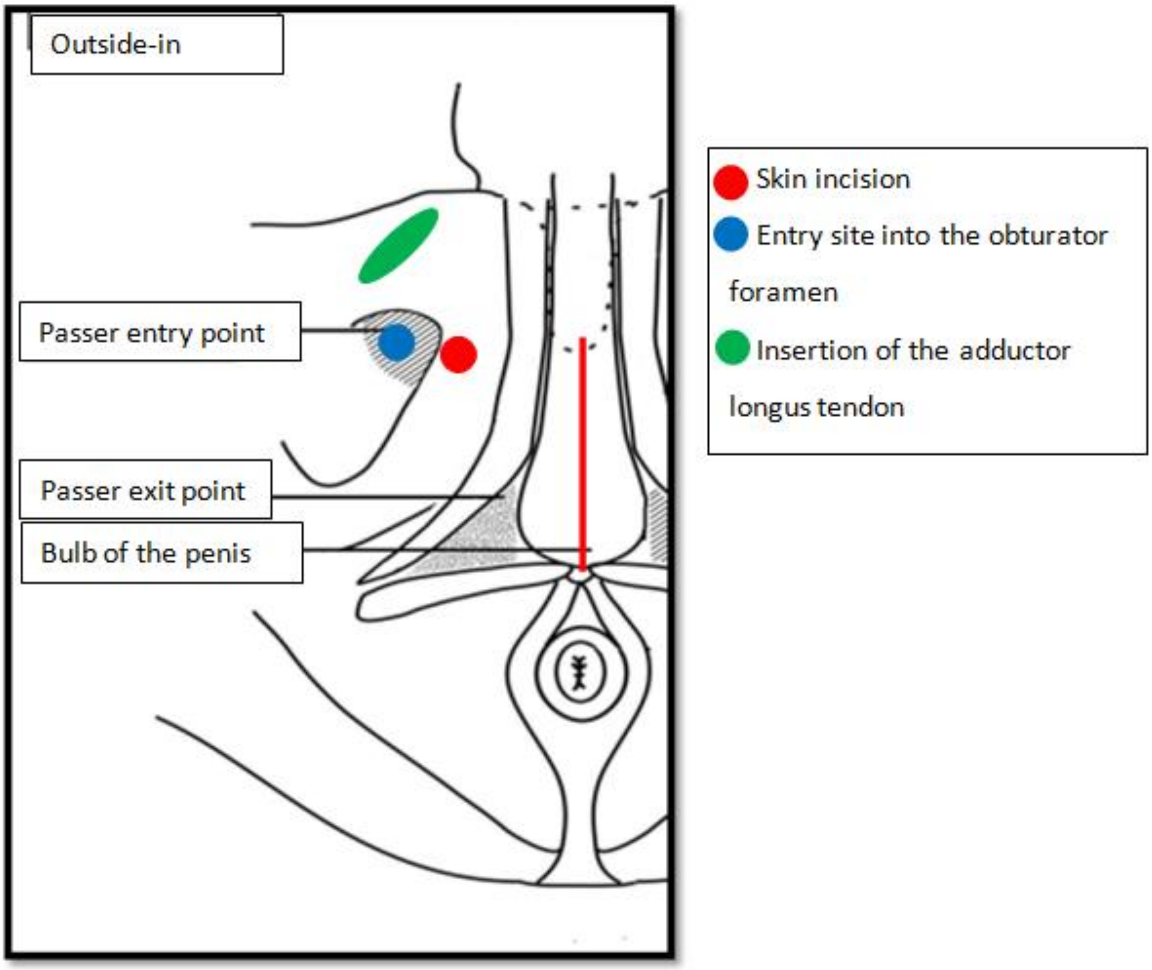
4.4.1.4. Procedures for the transobturator tape placement

According to a study performed by Zahn et al.,[9] the trajectory of the needle in the inside-out method was significantly closer to the obturator canal and further from the ischiopubic ramus than the outside-in approach. Especially in black females with a significantly smaller inferior pubic ramus, the trajectory of the needle might come even closer to the obturator canal as it directs further laterally from the slender inferior pubic ramus.

During the inside-out approach for transobturator tape placement, variations in the incisions made, points of entry and exit of the introducer, as well as different landmarks used to direct the incisions and course of the introducer exist, and are reflected in figure 73. Stature is not specifically taken into account when these landmarks were considered; for instance measurements such as a puncture of the root of the thigh, 4 cm from the median line and 4 cm below the adductor longus muscle is used.[27]

As the distance between the ischial tuberosities within populations were significantly different, with a mean value of just above 8 cm in black males and almost 10 cm in white males, these landmarks are not fixed and need to be considered when performing these procedures.

Figure 73. Position of the variations in the entry points for the outside-in TOT



4.4.1.5. Mesh tape used for TOT placement

As the size of the subpubic angle will give a reflection of the available space for the mesh[10], a mesh tape with a fixed distance may result in discrepancy in the tension of the tape around the urethra, due to the differences in the distance of the course of the mesh.

Individuals that have a wider subpubic angle, greater distance between the ischial tuberosities and a longer interobturator foramina distance, as in the case with white males, may result in the mesh tape having a slightly increased route to exit at the expected point.

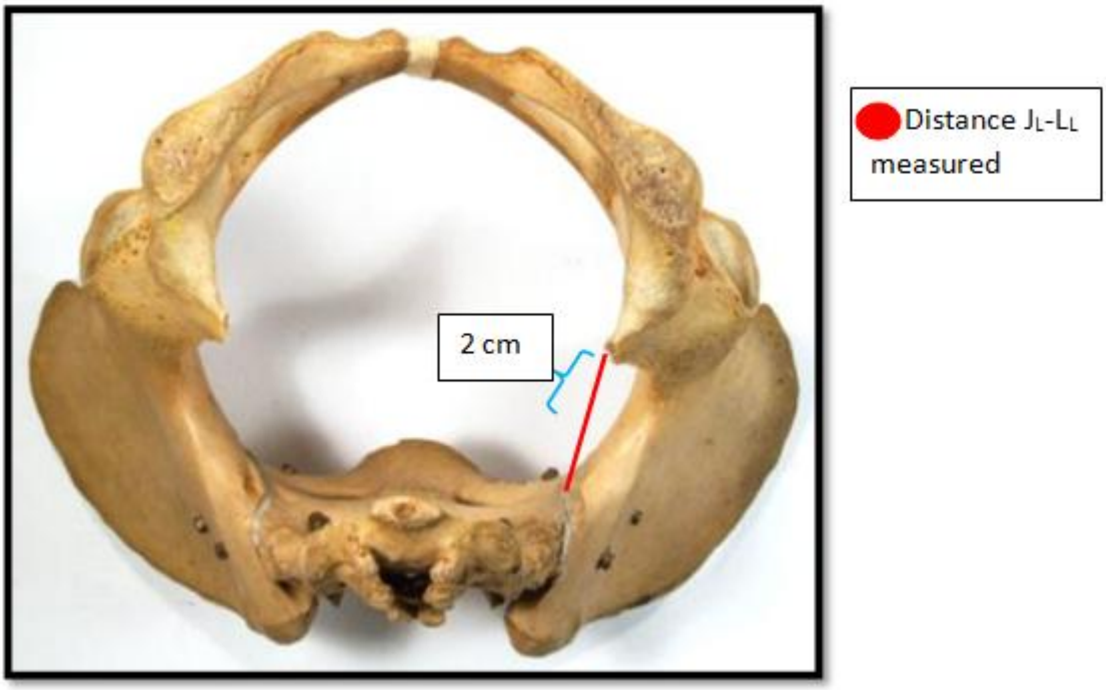
In our study, the distance between ischial tuberosities was approximately 10 cm and the interobturator foramina distance ranged from almost 4 cm to almost 8 cm. These distances were not stature dependent. The mesh tape placed in a pelvis containing a wider set subpubic angle is anticipated to offer less support than those with a narrower subpubic angle, as the mesh tape will course a shorter distance to reach the outer edge of the inferior pubic ramus at its junction with the body of the pubis. Individual variability and population group need to be considered as these measurements showed an overall correlation to stature.

In those with a smaller subpubic angle, intertuberous distance and between obturator foramina as in black males, a mesh tape with fixed dimensions may be associated with folding and prolonged healing of the wound.

4.4.2. Sacrospinous colpopexy

Transvaginal sacrospinous colpopexy involves placing a stitch from the vaginal cuff to the sacrospinous ligament approximately 2 cm medial to the ischial spine to correct the deficient.(66) This is shown in figure 74.

Figure 74. Location of stitch placed in sacrospinous colpopexy



An estimation of 2.5 cm medial to the ischial spine for placement of the stitch in South African females, may not have the potential risk of injuring the inferior gluteal nerve, as the distance between the ischial spine and most distal part of the inferior gluteal nerve is 13.82 mm ± 3.50 mm.[66]

4.4.3. Pelvic procedures

In radical retropubic prostatectomy (RRP) and rectal cancer procedures, the intrapelvic size is an important aspect in the success of surgery.

Surgery for rectal cancer involves adequate vision, maximum retraction, and access to the depths of the pelvis via the pelvis inlet. Thus, major factors influencing the difficulty of safe surgical excision are likely to be the pelvic dimensions and the depth of the pelvis especially for low rectal cancers.[67, 68]

The interspinous distance (measurement J_R-J_L), the intertuberous distance (measurement E_R-E_L) and the widest pelvic inlet transverse diameter (measurement I_R-I_L); are dimensions used to assess the width of the pelvis. Measurement F-H (pelvic inlet AP diameter) as well as measurement K-G (pelvic outlet AP diameter) was used to assess the antero-posterior diameter.

Results showed that white males had a significant greater distance between the ischial spines (mean distance of 98.27 mm; range of 86.86- 108.72 mm) as well as between the ischial tuberosities (mean distance of 99.22 mm; range of 84.18- 119.57 mm), as compared to black males who measure mean distances of 86.08 mm (range of 76.40- 98.83 mm) and 83.64 mm (range of 66.92- 100.47 mm) respectively. These measurements were not influenced by stature.

White males also presented with a significantly larger pelvic inlet AP mean diameter of 127.84 mm (range of 116.7- 142.66 mm), while black males measured a mean value of

115.96 mm (range of 102.22-135.61 mm). This measurement showed a correlation to stature in black males.

Our results show that white females present with the longest mean distance of 131.05 mm across the pelvic inlet AP diameter (measurement F-H). This is followed by white males who measure a mean distance of 127.84 mm, black females who measure 119.28mm and lastly by black males who measure 115.96 mm. All values were significant between population groups within sex groups. Black males and females showed a correlation to stature with this measurement.

The pelvic inlet transverse diameter (measurement I_L-I_R) followed the same trend, with white females presenting with the largest mean distance of 134.18 mm. This is followed by white males who measure a mean distance of 130.40 mm, black females at 118.84 mm and finally black males with a mean measurement of 113.10 mm. All values were significantly different between the population groups within sex group. Black males and females also, showed a significant difference in their value between sex groups within population groups.

Our results support that because of an anatomically narrower pelvis found in blacks and in men in general, this may lead to a technically more challenging operation.

4.4.4. Parturition

The pelvic inlet transverse diameter (measurement I_R-I_L), as well as the pelvic inlet AP diameter (measurement F-H), were significantly smaller in black females. Black females also showed a correlation to stature with these two measurements (Table 20). To approximate the results to include soft tissue, 10 mm is subtracted.[46] In this table the data is sorted according to pelvic inlet AP diameter as this is considered an important determinant for CPD by a number of authors.

Table 20. AP inlet diameter compared to stature in black females

Pelvic inlet AP	Pelvic inlet AP - 10 mm for soft tissue	Pelvic inlet transverse diameter	Stature (cm)
112.86	102.86	106.12	143.8154
112.93	102.93	123	143.8154
118.86	108.86	124.26	147.952302
114.97	104.97	120.3	152.9166
121.47	111.47	112.55	153.1924
113.5	103.5	109.24	154.5713
115.75	105.75	120.83	154.5713
126.29	116.29	123.65	155.3987
127.36	117.36	115.43	155.3987
108.23	98.23	116.57	156.2261
111.43	101.43	115.6	156.2261
116.57	106.57	115.6	156.2261
110.98	100.98	119.23	158.4324
131.19	121.19	120.85	159.5356
108.66	98.66	119.17	161.4661
121.55	111.55	124.54	163.1209
125.83	115.83	112.13	163.6725
126.28	116.28	122.97	163.6725
130.61	120.61	124.86	170.2915
129.79	119.79	135.27	175.2557

These dimensions were not stature dependent, and can be found in table 17. As an AP inlet diameter of 10 cm or less is considered to be associated with CPD in patients, the associated height of less than 163 cm may be a risk for CPD as can be seen in table (table 19).

Black females were significantly shorter when comparing their height to white females. These shorter statures observed in the black population may account for the smaller metric pelvic inlet dimensions, since they are stature dependant. During parturition, white women and taller black women may present with larger inlet dimensions which may facilitate the passage of the fetus.

The typical shape for vaginal delivery is said to be gynaecoid shaped.(13) According to the morphological classification, a gynaecoid shape is represented by a pelvis that has and AP inlet conjugate of 108.5 mm and a transverse inlet diameter of 137 mm.(60, 61) This is however seldom seen in our populations, as 80% presented with a dolichopellic pelvis according to Turner's classification that is classified as an anthropoid shape (table 17 above).(60, 61, 77)

In anthropoid shapes, the AP diameter is relatively elongated as compared to the transverse diameter. In our population groups, the transverse diameter is more affected than the AP diameter, so that the index according to Turner's classification classifies it as anthropoid. Although some cases present with small or borderline acceptable diameters, it is the transverse diameter that is severely shortened and poses a risk for CPD. This is especially so in black females. Fifteen percent of white females though, presents with platypelloid pelves which are defined by a relatively broader transverse diameter.

In the white population, although the pelvic inlet shape and therefore ratio between AP and transverse diameter was not that different to the black counterparts, the absolute dimensions were much larger affording a possible better outcome.

Especially short black women of less than 163 cm, poses a risk for CPD according to established recommendations.

5. Discussion

5.1. Populations and methods used

All the dry disarticulated os coxae, as well as many of the wet intact pelves used in this study were obtained from the Pretoria Bone Collection.[100] The Pretoria Bone collection started with the inception of the Department of Anatomy and the Medical School of the University of Pretoria in August 1942. Since its founding in 1943, the skeletal collection has been utilized as a teaching aid for medical, dental and health care students and staff.

A paper compiled by L'Abbe´ et al., presents information on the composition of this collection.[100] According to the researchers, the collection has grown over the years to a well-documented and well-administered research resource. Those skeletal remains included into the research collection have a known age, sex, and population affinity. Black males are the most represented in this collection, followed by white males, black females and lastly white females.

Other skeletal collections, such as the Coimbra Identified Skeletal Collection in Portugal, house a similar compilation of skeletal matter.[74] These complete skeletons however, comprise of individuals who died between 1904 and 1936. Similar studies performed, utilized The Hamann-Todd Human Osteological Collection housed at the Cleveland Museum of Natural History in Cleveland.[108] This Collection began from 1893-1912 when skeletons were collected from cadavers after dissection.

The Pretoria Bone Collection, in comparison to the others mentioned, houses a more contemporary collection from 1944 until 2011, on which measurements on dried bones were made. The measurements on the intact cadaver pelves were even more recent, and were collected from 2005 to 2007. This therefore, will afford the results to be more applicable to modern populations as opposed to some of the studies mentioned above on the pelvic canal on older collections.[74, 108]

The Pretoria Bone collection therefore offers a great deal of opportunities in skeletal studies, especially on the physical properties of individuals inhabiting South Africa and originating from diverse geographic regions.[(100)]

In traditional, as well as in geometric morphometric studies, the shape of the pelvis is often quantified after the reassembly of the two hip bones and the sacrum.[(10, 82, 93, 108)] However, on dry bones, the morphology of the cartilaginous tissues that form the two sacroiliac joints and the pubic symphysis before death remains unknown, leading to potential inaccuracies and errors during the reassembly process.[(93)]

Bonneau et al., demonstrated a significant effect on quantitative results after reassembly of pelves. Variation in the reassembly process is likely related, first, to the complete absence of cartilaginous tissues on dry bones and, second, to the morphology of the sacroiliac joint which, *in vivo,* allows physiological movements, resulting in different potential positions of the two sacroiliac surfaces relative to one another.[(93)] In our study however, the shape of the intact pelves obtained after dissection of the soft tissues, avoided the inaccuracies reported by other researchers. Our findings are therefore, envisaged to be more relevant to the clinical situation.

Measurements on intact cadaver pelves stripped from its flesh however, are not directly comparable to live patients intra-operatively and radiographically and consideration should be taken to subtract the calculated soft tissue thickness from these measurements.[(46)]

In our measurements on the intact pelves, many of the distances were smaller than those of other studies.[(46, 84, 109).] If considered, that soft tissues could have diminished these distances, it would emphasize our impressions that the inlet diameters were smaller in our black populations as compared to those of other studies.

As the conjugates of the pelvic inlet and outlet were originally described as dimensions to be palpated during physical examination of pregnant women during vaginal examination, the measurement of these distances would also depend on the expertise of the examiner.(109)

The proficiency to conduct a manual pelvic exam is a skill not achieved and accurately performed by all helpers, as these measurements depend on the estimation of the length and width of the examiners fingers. The determination of the conjugates should be considered an estimation. The obstetrical conjugate is computed by subtracting 1.5 to 2.0 cm from the diagonal conjugate, and it is therefore by definition, not an accurate measurement. These shortcomings may yield inconsistencies in the measurements taken.(46)

The true conjugate; between the superior pubic symphysis and the promontory, as well as the transverse inlet diameter are measured on radiographic films. Not all manual measurements could be verified radiographically however. Heyns questioned the value of X-ray measurements on the pelvic brim compared to the true index measured on real bone. It was found that the transverse diameter of the inlet cannot be accurately measured radiographically, as the measurements were consistently smaller than actual dried bone measurements. However, the measurement for the pelvic inlet AP conjugate proved to be more precise radiographically.(110)

Measurements may be done on radiological samples but may not be entirely accurate. Heyns for instance suggests that certain dimensions such as the transverse diameter of the pelvic brim cannot be measured accurately on film. He further states that this diameter, in the females will always be less, never greater on the film than it should be. The dried bone used by Heyns, implies that disarticulation preceded re-articulation of pelves used for measuring dimensions manually and radiographically.(110) This reassembly procedure might lead to errors discussed below.

Other studies have shown that metric measurements on radiographs and photographs are not always accurate(59, 82, 110) as three dimensional shape differences will not always be accurately displayed on X ray as it may affect the position and therefore distance from the X ray source distorting the shape. Various other authors further comments that measurements are interpreted as radial acoustic shadows observed on radiographs, and this may be prone to subjective error.[75, 79] It also seems logical, that measurements made on real three-dimensional object would be closer to the truth and more repeatable than that done on radiographic films. Direct measurements on dried disarticulated bone for peri-obturator dimensions, and as intact cadaver pelves for pelvic canal dimensions were made in this study, to eliminate radiographic error or re-articulation errors of the dried bones.

Intra-operative measurements seem to be the most accurate, and therefore should deliver repeatable results. The number of possible measurements however will be limited to the exposure offered during the surgical procedure.[110]

The subpubic angle, relevant in obstetrics and forensic anthropology, was mathematically calculated as done in other studies from vaginal examination of actual patients, dried reassembled pelves or radiographs.[57] It was however noted on dissections, that this angle does not fully describe the subpubic arch. Especially in females, the subpubic area was commonly associated with a subpubic concavity.[11]

Thoms[111] comments that when evaluating the adequacy of the pelvic outlet, the width of the subpubic angle as well as the shape of the pubic arch are of considerable importance. He illustrates that the degree of the pubic angle in itself may not give a good index to outlet capacity and may even be misleading due to the variations in the downward course of the pubic rami. In his illustration, identical pubic angles are shown with the same intertuberous diameters, yet the available space in the upper part of the two arches is quite different.

Further in the present study, it was found that asymmetrical subpubic arches were the rule rather than the exception. The wedge-shaped appearance of the pubic symphysis seen in many cases at least partly contributed to the width of these subpubic arches.[82]

Studies on disarticulated pelves, done by other researchers[82, 110], could possibly have overseen this contribution of the shape of the pubic symphysis to the width of the subpubic area. Further studies including shape analyses, by geometric morphometrics describing the subpubic area are necessary to elucidate these impressions.

The subpubic angle in our population groups were found to be smaller than in all other studies researched.(10, 14, 110) The closest findings were those of a study done by Oladipo and Hart(59) on Ikwerres and Kalabaris tribes of Nigerian populations.

The reasons for the Nigerian group to have the closest values to the present study cannot be ascribed to a population correspondence, as both South African whites and blacks were affected. Possible reasons for our findings to be smaller could include the impact of reassembly of dried bones, photographic or radiographic errors on measurements.

Calculations from vaginal examinations, although the most obstetric relevant, is possibly flawed as soft tissue dimensions could influence accurate bony landmark estimations.(111, 112) Thoms(111) states that the bi-tuberous diameter between the inner surfaces of the ischial tuberosities could not be measured satisfactorily by any method so far described. He describes a 0.5 cm allowance for the thickness of the soft parts covering the pubic rami in their medial aspect, which represents an average of 93 mm.(111, 113)

Metric analyses of the pelvic cavity and peri-obturator area were supplemented with shape analyses to determine differences amongst groups. For instance, the commonly described tendency for females to present with gynaecoid pelves could not be demonstrated by Turner's method, which uses the ratio between AP and transverse inlet diameters.(77)

The difference between the pelvic inlet was only evident when shape analysis was performed, and it was noted that the transverse diameter seemed to shift more anteriorly further away from the sacral promontory in females, describing a more oval/round shape as compared to the heart shaped inlets of males.

The gynaecoid pelvis (rounded shape) is said to be the expected female type while the android pelvis (heart-shaped) is often designated a male variant.(13) In the present study, no significant inter-sex variation could be found in the pelvic inlet shape for blacks with representatives of all pelvic inlet types. A significant inter-sex variation of a p value of 0.064, was found for the white population. White South African females presented with similar transverse and AP diameter dimensions transecting approximately in the centre, and a sacral promontory orientated more posteriorly than in males which could fit in with the described gynaecoid shape.

Some females presented with variant shapes including android or platypelloid but were the exception rather than the rule. Women with android pelves do not typically present with hyperandrogenism, but was associated with strenuous physical activity during adolescence and when the acquisition of erect posture was delayed beyond the usual age of 14 months, while a platypelloid pelvis was more frequent when erect posture was acquired before 14 months. [(13)]

In this study, six out of the 40 total white pelvic inlets measured presented with an AP to transverse diameter suggestive of a platypelloid shape. Only one out of the 40 total black individuals presented with a platypelloid shape. These findings might point to different cultural rearing of infants e.g. either orientated on the floor or tied to the back.

In addition to being developmentally discriminating, the distribution of the anthropoid pelvis between both sexes and frequency is ethnically discriminating as well. Leong found that there were significant differences in the accuracy of sex determination from pelvic morphology between both males and females, and whites and blacks.[(13)] The pubic bone shape is the easiest to assess and was the most consistently reliable morphological indicator of sex in both sexes and population groups. However, in blacks, the greater sciatic notch form allowed the highest separation. This demonstrates that population differences significantly affect the expression of sexual dimorphism.[(4, 13)]

Repeatability studies for all measurements were high, except for the distance between the pubic tubercle and the ischial tuberosity (measurement A-E_L). This could have been due to inter-observer differences in the interpretation of the defined points on the ischial tuberosity and/or the pubic tubercle. Deductions made on the longitudinal dimensions of the obturator foramen however, did not only include this distance but three other measurements involving the pubic tubercle or the ischial tuberosity and these were in agreement.

5.2. Clinical procedures considered

5.2.1. Perineal procedures

The perineal procedures considered involved procedures designed to alleviate urinary and rectal incontinence or vaginal prolapse in the case of sacrospinous colpopexy.

Stav et al., found that metric pelvic inlet and outlet dimensions were significantly larger in incontinent women. In our study, the pelvic inlet size was significantly larger in white females; this could predispose this group to incontinence.[23] The pelvic outlet size however, seems to be more important in incontinence and was not significantly different between population groups. Further clinical data may be researched to support this hypothesis.

5.2.1.1. TVT and bone anchors in males and females

Despite its relative safety, the tension free vaginal tape (TVT) procedure requires the blind passage of needles through the retropubic space via two small incisions in the abdomen just above the pubic bone. The smaller dimensions, including pubic symphysis length and interobturator distance, seen in some black South Africans, need consideration during these procedures.

A 2-3 cm approximation for placement of the anchors from the urethra (or from the midline),[37] maybe too far apart in certain black females. The 2 cm margin,[31] may be more suitable to avoid to these individuals to misplacement of the anchors into non-osseous tissue.

5.2.1.2. TOT and Mini arc anterior repair system in females

The use of instrumentation with a fixed dimension as described, may not take into account the variability in the relevant pelvic dimensions e.g. the broadness of the inferior pubic ramus, the subpubic angle as well as shape of the obturator region observed in the different populations and sexes considered.

In the present study, all measurements involving the obturator region were statistically significantly larger in males compared to females; apart from the distance between the most medial point on the obturator foramen to the obturator canal (measurement B_L-C_L) which did not differ significantly. This distance extending from side to side, therefore did not differ between sexes, while the AP diameters were larger in males and contributed to a more elongated obturator shape.

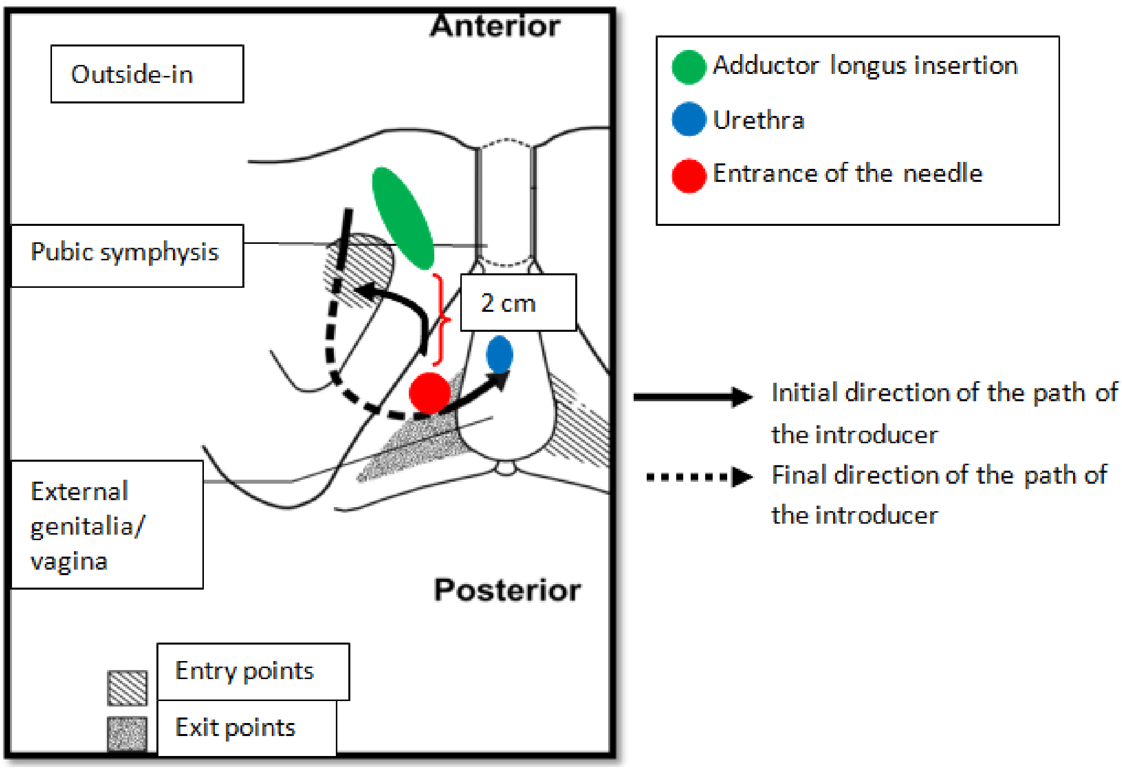
These results were in line with those of Patriquin, who found smaller metric measurements on female South African obturator foramina as compared to males. She found that these foramina were more triangular or circular shaped, compared to males who have a much larger and ovoid shaped foramen.[11] The female obturator foramen is said to be more elliptical shaped according to other authors.[10, 13]

In contrast, three of the four measurements that extended across the obturator foramen from anterior to posterior (i.e. measurements: A-D_L, A-E_L and B-E_L) were significantly larger in the white population. In addition, measurements A-C_L and A-E_L showed a correlation to stature in black males and white males. Measurement A-D_L showed a correlation to stature in white females, black males and white males. These metric impressions were also confirmed by peri-obturator shape analyses, whereby significant inter-population variations when comparing females were found. White women presented with elongated anteroposterior dimensions relative to measurements extending laterally across the foramen. Taller white females may therefore also present with more ovoid and elongated shaped foramina.

Some of the measurements on the pelves of the present study group however, do not always correspond to those of other researchers and study groups. Although sometimes smaller this was not consistently so and similar or greater measurements were also documented. These differences may require the adaptation of the technique or instrumentation to perform the procedure successfully.

The transobturator tape outside-in procedure is illustrated in figure 75. The groin incision is described by various authors, to lie below the level of the urethral opening at 2 cm inferior to the adductor longus tendon insertion which is approximately at the level of the clitoris.[37, 47]

Figure 75. The outside- in TOT in females



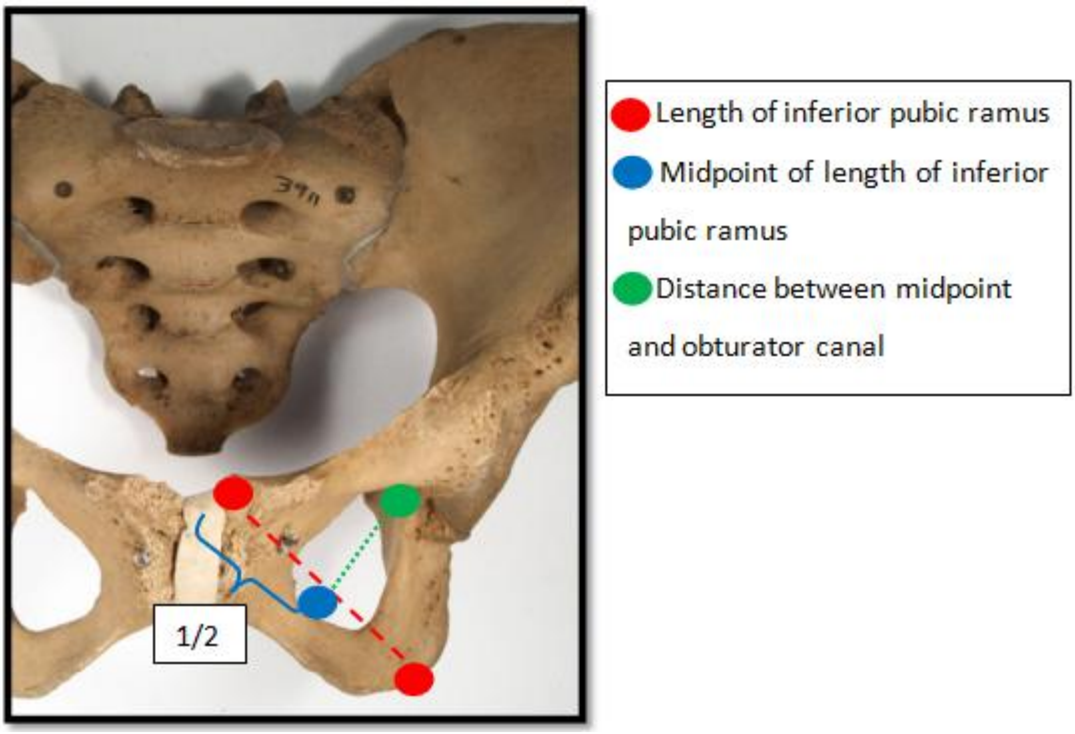
Whiteside and Walters performed the TOT outside-in technique on six frozen cadavers and took the following measurements.[37]

The ischiopubic ramus was measured from the ischial tuberosity to the superior midpoint of the pubic symphysis (described as half the distance between the palpable pubic tubercles).

The midpoint of the ishiopubic pubic ramus was then used as a reference point to measure the relevant muscular and neurovascular structures in the obturator region. This landmark was not well described, and could cause inter-observer discrepancies. It was found that the obturator canal and midpoint of the ischiopubic ramus was approximately 5 cm apart. This is illustrated in figure 76.

The closest measurement of our study to compare with this finding is the distance between the most medial point on the obturator foramen to the obturator canal (measurement B_L-C_L). The distance did not differ between sex-population groups, and was about 2.5cm, ranging between 1.5 and 3.5 cm. The measurement done by Whiteside and Walters however, was performed on dissected specimens, and obstacles such as soft tissues might have obscured the bony landmarks, and could partly account for the larger dimensions when compared to our findings.[37] It is however, important to take note of the smaller distances measured in our groups when performing transobturator procedures as the obturator neurovascular might be endangered.

Figure 76. Distance measured before placement of the sling

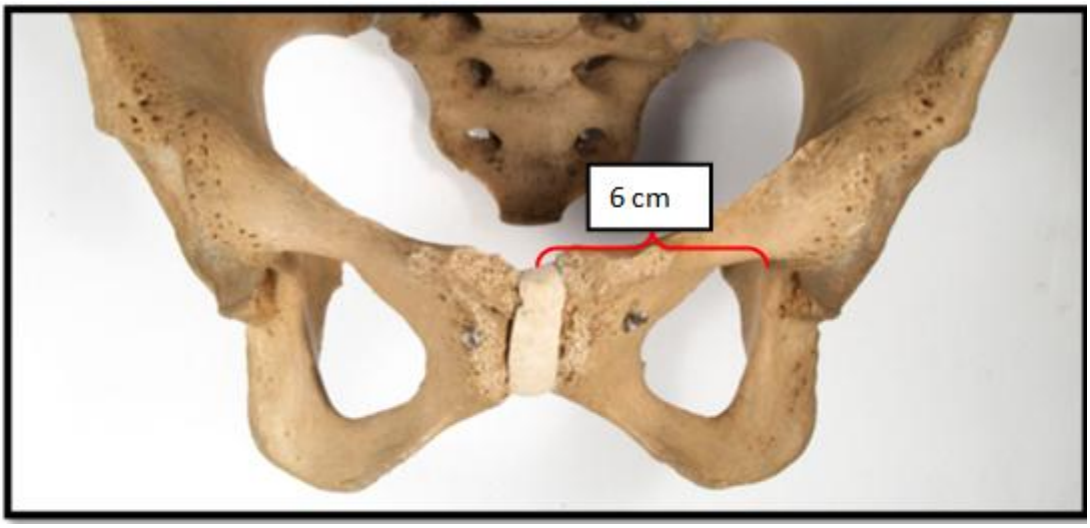


The transobturator sling (inside-out) was passed, and the distances from the devise to the obturator canal were measured (figure 76). It was found that the obturator nerves were nearly 3 cm away from the devise, as it curved around the ischiopubic ramus. This distance is an adequate buffer with placement of the transobturator devise, but not with TVT-O (outside-in), as the needle is considered to be directed more vertically and go through a wider passage.[8] This distance could also be encroached upon in our pelves, as the other distances were smaller and therefore endangering the obturator nerves and branches.[47]

A study performed by Pathi et al., measured the distance from the most superior point on the pubic symphysis to the obturator canal, in fifteen female cadavers from the University of Texas. They found a mean distance of 60 mm (range of 56.0 mm to 82.0 mm).[114] (Figure 77)

This measurement in our study group, demonstrated significant differences between blacks and whites. It was also stature dependent in white females. The mean values of more than 6cm were the largest in taller white females. Values of almost 9 cm were measured in some taller white females, which will make this procedure safer than anticipated by Pathi et al., as the obturator canal is situated more than 3 cm further. Alternatively, some black females presented with distances just more than 5 cm which will predispose these individuals to obturator nerve injuries if not taken into consideration.

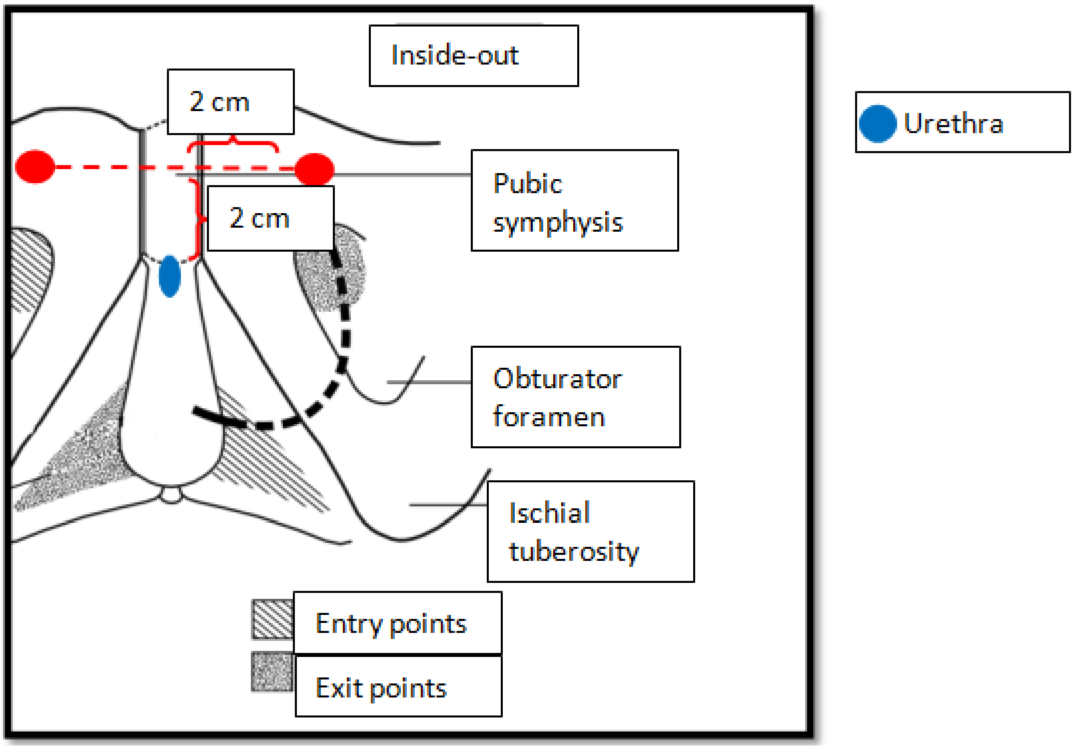
Figure 77. Representation of anticipated location of obturator canal as adapted from Pathi et al.



The TOT inside approach described by the GYNECARE TVT Obturator system[48], describes the exit points of the needle, by tracing a horizontal line at the level of the urethral meatus, and a second line parallel and 2 cm above the first line. The exit points are located 2 cm lateral to the fold of the thigh. This is illustrated in figure 78. The tape passes through the obturator foramen on the upper third of the inferior pubic ramus.[24]

Although the width of the inferior pubic ramus could influence the distance of the exit point as it is statistically smaller in black individuals, the difference between the maximum values were only about 5mm and therefore will not have a great impact on this distance.

Figure 78. Indication of the entry and exit points in the TOT inside out technique



Studies performed by Lee et al., compared the inside-out (using the Gynecare kit) and outside-in transobturator tape procedures (using the TOT ® (transobturator) kit) in female patients presenting in Korea.[17, 63]

Although Lee et al., found no significant differences in the surgery- related complications between the two procedures, Zahn found that the outside in technique was farther away from the obturator canal than the inside out procedure and therefore safer.[9, 17]

The outside-in procedure may therefore, be a more suitable approach for the black female South African population, taking into account their significantly smaller inferior pubic ramus and shorter distance from the most medial point of the obturator foramen to the obturator canal (measurement B_L-C_L of 23.53 mm). This approach may ensure a safe distance between the pathway of the needles and the obturator neurovascular bundle as there is seemingly more control over the entrance point than the exit point. According to the researched techniques, for inserting the transobturator tape, only the entrance of the passer is performed under direct vision and the rest of the procedure is done blindly.[45]

If the inside- out procedure is performed in black females, it may require alteration of the angle used in the swing of the introducers. A lesser swing may be necessary to ensure that the introducer does not encroach the obturator nerves.

On the other hand, when the outside –in procedure is performed on white females who have significantly broader inferior pubic rami and longer distances between their most medial point of the obturator foramen and the obturator canal, care should be taken not to injure the dorsal nerve of the clitoris under the ramus. White females may therefore, be better candidates for the inside- out approach as the needles are also less likely to encroach onto the obturator neurovascular bundle.

5.2.1.3. TOT in males, bulbo-urethal sling and rectal prolapse procedures

As this procedure was initially described on white females, certain adaptations need to be made when performed on males and on South African blacks [5, 8, 17, 37-39, 41, 47]

Two relevant dissimilarities that need to be considered when adapting this sling route in males: firstly, the inferior pubic rami are thicker and secondly, the subpubic angle may be less open in males than females.[13, 24, 59] The results of this study, confirm these impressions as the mean broadness of the ischiopubic ramus was greater and the subpubic angle were statistically significantly smaller.

As the size of the subpubic angle will give a reflection of the available space for the mesh[10] a mesh tape with a fixed distance as described by the package insert of the Gynecare TVT Obturator System[48] of 1.1 x 45cm may result in discrepancy in the tension of the tape around the urethra due to the differences in the distance of the course of the mesh. As folding might be an important contributing factor in mesh exposure, the available space between the ischiopubic rami in the various groups is of importance and was measured.[37]

As the ease of placing the bulbo-urethral sling, as well as performance of rectal prolapse procedures in both males and females, may be enhanced by a wider dissection plane; white males may be at an advantage. This plane is smaller in black males, as a result of a significantly smaller subpubic angle and intertuberous diameter. The length of the pubic symphysis was also found to be significantly larger in white males.

Increased care should be taken when placing this sling in black males, as a result of this smaller dissection plane to ensure that the trajectory of the passer encroaching onto the perineal nerves.[36] A dissection performed at a more shallow level may be necessary to avoid this problem.

Individuals that have a smaller subpubic angle and shorter, distance between the ischial tuberosities and interobturator foramina distance, as in the case with black males may result in the mesh tape having a slightly decreased route to exit at the expected point. If not anticipated this might lead to mesh folding and mesh exposure in black males.

5.2.1.4. Four-arm or Quadratic male sling

Although white males presented with a sufficiently longer mean interobturator foramina distance (measurement C_R-C_L) and pubic symphysis lengths (measurement F-G), than required by the Coloplast Virtue Male Sling System[50], as both measurements approximated 5 cm; increased care should be taken when placing this sling in certain black males. Although the mean values for both these measurements were longer than the recommended 2 cm in black males, the interobturator foramina distance might be less than

4 cm and the pubic symphysis length may be as small as just more than 3 cm in some black individuals.

As the length of the pubic symphysis differs significantly between populations, the pre-pubic arm of the sling will need to pass further in white males than in black males. These dimensions may impact the proper positioning pre-pubic arms during surgery. This may lead to diversion of the introducers.

5.2.1.5. Sacrospinous colpopexy

Various authors describe the correct placement of the suture onto the sacrospinous ligament by palpating two finger breadths medial to the ischial spine. Various other authors impose the same technique.[115-118] Sagsoz et al., reported a safe zone along the sacrospinous ligament 2.5 cm medial to and away from the ischial spine, where no major vessels can be found[119], while Maher et al., as well as other authors reports 2 cm medial to the ischial spine.[66, 115, 120] El Tohamy reports a 2-3 cm approximation.[117]

Goldberg describes a lateral suspension suture is placed through the ligament roughly a finger-breadth medial to the ischial spine, safe guarding against injury to the pudendal vessels. He highlights that care is taken to place sutures through the superficial portion of the ligament, rather than deep into or around it.[116]

A correlation was found between the obstetric conjugate and the sacrospinous ligament. The larger the obstetric conjugate, the longer the sacrospinous ligament and the distance from the ischial spine to the sciatic nerve.[66]

Our results showed although the obstetric conjugate (measurement F-H) was significantly different between the populations, the distance from the ischial spine to the medial border of the sacrum (measurement J_L-L_L) coinciding to the length of the sacrospinous ligament was not.

It will therefore not be useful to determine the obstetric conjugate to predict the length of the sacrospinous ligament and therefore the position of the suture placement.

5.2.2. Pelvic procedures

Various authors support the possibility that performing RRP, as well as the surgical procedures for rectal cancer may be easier in a wider and shallower pelvis as opposed to patients presenting with a narrower and deeper pelvis.[70, 71, 73]

Our results support that because of an anatomically narrower pelvis found in blacks and in males in general, this may lead to a technically more challenging operation. With shape analysis it was found that ischial tuberosities were inwardly directed in black males.

Prominent sacral promontory, an acute curved sacrum or a pelvis narrow in the transverse plane could considerably represent anatomical bottlenecks, impeding vision, access and space in which instruments can be manipulated.[72] There were no outstanding shape differences in the prominence of the sacral promontory when comparing males or females. Black males however, had a more inwardly directed coccyx as demonstrated by geometric morphometric shape analysis.

5.3. Parturition

The two aspects that need to be considered when CPD is expected: the size and shape of the pelvic canal and the size of the fetus, and more specifically the fetal skull.[2, 4, 11, 13, 59, 121] Many previous studies suggest that the shape of the pelvic inlet and outlet may reflect shape of the skull passing through the birth canal.[2, 4, 11, 13, 59, 74] Considerable variation has been demonstrated in the pelves of various populations of blacks and whites.[4, 121]

Statistical analysis of shape variation of the pelvic inlet and outlet between females were not significant. However, when comparing the shape of the pelvic canal between females, the p - value for inter-population variation; a significant value of 0.0395 was determined. These significant differences were thought to be influenced by significantly smaller pelvic inlets and interspinous diameters in black females as compared to white females, whilst the outlet diameters did not differ significantly. In addition, the pubic symphysis length was shorter and straighter in black females causing the space available in the anterior part of the pelvis to be smaller in black females.

Leong found a correlation between skeletal frame size and the distance between the ischial spines in females. [13] This was confirmed in the present study, as the interspinous distance (measurement J_R-J_L) was found to be significantly different between the populations as well as stature dependant in black females. The overall stature of females was also found to be statistically significant different between populations.

Population and sex both have effects on birth weight. Female neonates were found to be on average 95 g lighter, 0.6 cm shorter and had a head circumference that was 0.6 cm smaller than male neonates. Black neonates were smaller than Hispanic and white neonates according to a study by Thomas et al.[87]

The birth weights of children have been consistently used to reflect the well being of communities for two reasons. Firstly, birth weights are strongly conditioned by the health and nutritional status of the mother; in the sense that maternal under-nutrition, ill-health, and other deprivations are the most commonly cited causes of retarded fetal growth and/or prematurity. Secondly, birth weight is universally the single most important determinant of the chances of the newborn surviving to experience healthy growth and development.

It has been suggests that smaller women, however, tend to have smaller babies, some of whom will show signs of intrauterine growth restriction, raising the possibility that this biological relationship may protect shorter women from suffering an excess of delivery complications.[15]

A study conducted on the Ghanaian population, found that male babies were observed to have a higher mean birth weight of 3.206 kg than the female babies who had a mean birth weight of 2.97 6kg.[46] A study conducted on the South African population found that the mean birth weights of females were 3.028 kg and males were 3.119 kg. This was less than that standards derived for American babies who were weighed 3.410 kg for females and

3.570 kg for males.[16] The fact that South African black babies are smaller might counteract CPD.

CPD might be less prevalent than expected, when the health and nutritional status of the mother negatively affected her pelvic shape and size as well as the size of the fetus. The scenario of a mother deprived of good nutrition in her youth, with associated small stature and contracted pelvis, experience good nutrition and care during pregnancy delivering a heavier baby and experiencing CPD should also be considered. This might be a problem challenging clinicians in South Africa with changing socio-economic statuses.[16, 83, 122]

The sex and population differences noted between the pelvic inlet, outlet and canal, although not implicated in obstetrics, might have forensic anthropological importance. It is of note that that the pelvic brim index (PBI) ratio according to Turner's classification[77] did not differ between sex groups. Shape analysis however showed that significant differences in the pelvic inlet were seen in white individuals and not in black individuals.

Pelvic outlet shape and pelvic canal shape was significantly different between the sexes in both populations. These results fits in with those of Patriquin, who found that there were more statistically significant differences in the ratios of metric pelvic measurements between white males and females as opposed to black males and females.[11] Tobias postulated that the lack of sexual differentiation seen in black individuals could be ascribed to lower socio-economic status and conditions of poor nutrition.[83]

Due to the later maturation of the pubis in females than males, it is that the period of growth is prolonged, thereby contributing to sexual dimorphism in pubic length, linea terminalis length and pelvic inlet circumference. It is during this accelerated growth period in adolescence, that individuals are vulnerable to poor socio-economic conditions and food deprivation so that sexual differential growth is limited.[13]

6. Conclusion

The purpose of this study was to assess the possible variations of the dimensions of the pelvis and perineum in order to predict the adaptations necessary to surgical procedures or during parturition according to sex, population group and stature.

6.1. Perineal procedures

The expected size of the dissection plane in males in general, and more specifically black males, was smaller as a result of a significantly smaller subpubic angle and intertuberous diameter. The smaller dissection plane may influence the ease of the performance of these procedures.

During transobturator procedures, those with a smaller subpubic angle, intertuberous distance and distance between obturator foramina as in black males; a mesh tape with fixed dimensions may be associated with folding and prolonged healing of the wound.

The tension-free vaginal tape and the bulbo-urethral sling involves a sling passing retropubically, taking care to exit as medially under the pubic arch as possible. Some black females presented with interobturator distances of less than 4 cm. This might lead to placement of the needles too far laterally, which might endanger branches of the pudendal nerve or even the obturator or iliac vessels, or toward the bowel in a posterior route.

An over-estimation of the pubic symphysis length which may occur in black and shorter females, may possibly lead to the placement of the needles too far superior to the upper border of the pubic symphysis during the retropubic or prepubic procedures. This may cause the diversion of the needles in the retropubic space, which could potentially injure large blood vessels and nerves in the pelvis as well as perforate the bladder. On the other hand, under-estimation may cause difficulty in the performance of the procedure.

In transobturator sling placement in females, it should be noted that even though the distance between the most medial point on the obturator foramen to the obturator canal (measurement B_L-C_L) does not differ significantly amongst groups, or with stature, the obturator canal is brought closer to the midline in blacks as opposed to whites. This is because of the narrower ischiopubic ramus and the more posteriorly directed obturator foramen in blacks. The obturator neurovascular bundle contained within the obturator canal is therefore more likely to be endangered.

The anteroposterior dimensions of the peri-obturator area were relatively much shorter in relationship with the side-to-side diameter in black females and shorter white females. In these individuals, it needs to be considered that as soon as the needle is directed superiorly from the subpubic region, that the available distance to the obturator canal is diminished and the obturator neurovascular bundle might be so endangered during the inside-out procedure.

The obturator canal is also brought closer to the midline in black males as opposed to white males, because of a thinner ischiopubic ramus and because of a smaller subpubic angle. The ischiopubic ramus width was further also stature dependent in blacks.

It will therefore, be important to consider modifications to the introducers, or/and the technique when performing transobturator procedures. The introducer should be guided along a smaller more curved route during the inside-out procedure in blacks, females and shorter individuals as compared to whites, males or taller individuals as to not injure intra-pelvic structures or the obturator neurovascular bundle. An introducer with a smaller open circular segment than 3 cm radius, might facilitate the procedure in blacks or shorter individuals.

In males in general, and more specific white males, it may be considered to use a wider circular introducer as the ischiopubic ramus is broader. The introducer should be guided along a wider route in, especially white males. Care should be taken not to injure the pudendal nerve branches in close relationship with the ischiopubic ramus during the outside-in approach because of a restrictive curve of the introducer relative to the dimensions of the route.

In males, as opposed to females, the inferior pubic rami were wider and the subpubic angle smaller affording a more difficult procedure because of a smaller dissection plane and a wider curved route around the inferior pubic ramus.

For these reasons, it might be more beneficial to perform the outside-in technique in blacks, females and shorter individuals and the inside out technique in males, especially whites.

6.2. Parturition

Variations in pelvic dimensions and shape were noted between population groups and with stature.

The pelvic inlet transverse diameter and the pelvic inlet AP diameter were significantly smaller in black females. Black females also showed a correlation to stature with these two measurements. Although differences in data collection techniques, such as; measurements during physical examination, intra-operative measurements and radiographic measurements, as opposed to direct measurements on intact cadaver pelves could contribute to discrepancies found, it is still noteworthy that both population groups presented with smaller pelvic inlet transverse diameter than frequently reported.

As both the AP dimension and transverse dimension were significantly smaller in blacks, the relationship between the AP distance and the transverse inlet diameters as implicated in Turner's[77] classification were similar. The pelvic inlet shape as determined by geometric morphometric shape analyses also did not vary amongst black and white females.

As the transverse diameter was smaller than expected, the most common pelvic inlet shape in all female groups was anthropoid (dolichopellic) according to the PBI. By means of geometric morphometric shape analyses, the relative position of the pelvic inlet transverse diameter as opposed to the pelvic inlet A-P diameter could be noted, and as expected for gynaecoid shaped pelves was situated more anteriorly.

The significant pelvic shape differences noted amongst the females may be related to the significantly smaller pelvic inlet and interspinous diameters in black females as compared to white females, whilst the outlet diameters did not differ significantly. In addition, the total length of the pubic symphysis was significantly shorter in black females. This rotated the pelvic outlet down more in line with the pelvic inlet, and diminishing the space available in the anterior part of the pelvis.

During parturition, even though the pelvic inlet shape did not differ amongst groups, white women and taller black women may present with larger inlet dimensions which may facilitate the passage of the fetus. White women further also presented with a more spacious pelvis anteriorly.

Black women shorter than 163cm, poses a risk for CPD according to established recommendations. This did not seem to be applicable to white females as these dimensions were not stature dependent in this group.

6.3. Intrapelvic procedures

As a small pelvic canal may impede vision, access and space for surgical excision, consideration of pelvic dimensions are important when planning intrapelvic procedures. Our results indicate that an anatomically narrower pelvis was found in blacks and in men in general, which may lead to technical difficulties.

Apart from the distance between the pubic symphysis and the ischial tuberosity, all dimensions across the pelvic inlet and outlet were larger in whites and black females than black males. This was especially so in the transverse diameters (interspinous and intertuberous), creating a wider pelvic outlet shape in whites and in black females.

Surgeons need to take note of these differences between sexes and populations before embarking on the procedures considered.

All predicted adaptations to procedures or during parturition based on pelvic variations should be verified by further studies in the clinical setting.

6.4. Physical anthropology

The sex differences noted between the pelvic inlet, outlet and canal amongst population groups, although not implicated in obstetrics, might have forensic anthropological importance.

It is of note that that the pelvic brim index (PBI) ratio according to Turner's classification, did not differ between sex groups in both populations. Significant differences between the sexes in the shape analysis of the pelvic inlet were seen in white individuals and not in black individuals. Sex identification by means of pelvic inlet shape might not be possible in all black South Africans. This finding fits in with what has been found by other researchers regarding sexual differences in the skeleton of black SA individuals.[1, 2, 11, 83]

The subpubic angle, on the other hand, was significantly greater in females of both populations, and significant difference existed between black and white males, white males being larger. In general the subpubic angle was smaller than reported and this should be taken into consideration when identifying unknown South African remains.[10, 14, 80, 93]

It will be desirable to expand the sample sizes of intact cadaver pelves in all groups to confirm these findings on the pelvic inlet, canal and outlet and specifically also the subpubic area.

7. References

1. Patriquin M, Steyn M, Loth S. Metric assessment of race from the pelvis in South Africans. Forensic science international. 2002;127(1):104-13.

2. Patriquin M, Steyn M, Loth S. Metric analysis of sex differences in South African black and white pelves. Forensic science international. 2005;147(2):119-27.

3. Loth SR, Henneberg M. Mandibular ramus flexure: a new morphologic indicator of sexual dimorphism in the human skeleton. American journal of physical anthropology. 1996;99(3):473-85.

4. Patriquin M, Loth S, Steyn M. Sexually dimorphic pelvic morphology in South African whites and blacks. HOMO-Journal of Comparative Human Biology. 2003;53(3):255-62.

5. Hinoul P, Vanormelingen L, Roovers JP, de Jonge E, Smajda S. Anatomical variability in the trajectory of the inside-out transobturator vaginal tape technique (TVT-O). International Urogynecology Journal. 2007;18(10):1201-6.

6. CLEMENS JQ, BUSHMAN W, SCHAEFFER AJ. Urodynamic analysis of the bulbourethral sling procedure. The Journal of Urology. 1999;162(6):1977-82.

7. Schaeffer AJ, Clemens JQ, Ferrari M, Stamey TA. The male bulbourethral sling procedure for post-radical prostatectomy incontinence. The Journal of Urology. 1998;159(5):1510-5.

8. De Leval J. Novel surgical technique for thetreatment of female stress urinary incontinence: transobturator vaginal tape inside-out. Eur Urol. 2003;6:724-30.

9. Zahn CM, Siddique S, Hernandez S, Lockrow EG. Anatomic comparison of two transobturator tape procedures. Obstetrics & Gynecology. 2007;109(3):701-6.

10. Ridgeway BM, Arias BE, Barber MD. Variation of the obturator foramen and pubic arch of the female bony pelvis. American Journal of Obstetrics and Gynecology. 2008;198(5):546. e1-. e4.

11. Patriquin ML. A comparative analysis of differences in the pelves of South African blacks and whites: University of Pretoria; 2001.

12. Bauer W, Karik M, Schramek P. The self-anchoring transobturator male sling to treat stress urinary incontinence in men: a new sling, a surgical approach and anatomical findings in a cadaveric study. BJU international. 2005;95(9):1364-6.

13. Leong A. Sexual dimorphism of the pelvic architecture: A struggling response to destructive and parsimonious forces by natural & mate selection. McGill Journal of Medicine: MJM. 2006;9(1):61.

14. Hoyte L, Thomas J, Foster RT, Shott S, Jakab M, Weidner AC. Racial differences in pelvic morphology among asymptomatic nulliparous women as seen on three-dimensional magnetic resonance images. American Journal of Obstetrics and Gynecology. 2005;193(6):2035-40.

15. Merchant KM, Villar J, Kestler E. Maternal height and newborn size relative to risk of intrapartum caesarean delivery and perinatal distress. BJOG: An International Journal of Obstetrics & Gynaecology. 2001;108(7):689-96.

16. Cameron N, De Wet T, Ellison G, Bogin B. Growth in height and weight of South African urban infants from birth to five years: The Birth to Ten Study. American journal of human biology. 1998;10(4):495-504.

17. Lee KS, Choo MS, Lee YS, Han JY, Kim JY, Jung BJ, et al. Prospective comparison of the 'inside–out'and 'outside–in'transobturator-tape procedures for the treatment of female stress urinary incontinence. International Urogynecology Journal. 2008;19(4):577-82.

18. Winters JC, Scarpero HM, Appell RA. Use of bone anchors in female urology. Urology. 2000;56(6):15-22.

19. Trost L, Elliott DS. Male Stress Urinary Incontinence: A Review of Surgical Treatment Options and Outcomes. Advances in urology. 2012;2012.

20. Okorocha I, Jwarah E, Jackson S. Surgery for urinary incontinence. Reviews in Gynaecological Practice. 2005;5(4):251-8.

21. Moore RD. Mini-sling â New Minimally Invasive One-incision Sling for Treatment of Female Stress Urinary Incontinence. 2008.

22. Handa VL, Pannu HK, Siddique S, Gutman R, VanRooyen J, Cundiff G. Architectural differences in the bony pelvis of women with and without pelvic floor disorders. Obstetrics & Gynecology. 2003;102(6):1283-90.

23. Stav K, Alcalay M, Peleg S, Lindner A, Gayer G, Hershkovitz I. Pelvis architecture and urinary incontinence in women. European Urology. 2007;52(1):239-44.

24. De Leval J, Waltregny D. The inside-out trans-obturator sling: a novel surgical technique for the treatment of male urinary incontinence. European Urology. 2008;54(5):1051-65.

25. Christine B, Knoll LD. Treatment of recurrent urinary incontinence after artificial urinary sphincter placement using the AdVance male sling. Urology. 2010;76(6):1321.

26. Schaeffer AJ. Prostatectomy incontinence. The Journal of Urology. 2002;167(2 Pt 1):602.

27. Grise P, Geraud M, Lienhart J, Le Portz B, Bubenheim M, Costa P. Transobturator male sling TOMS™ for the treatment of stress post-prostatectomy incontinence, initial experience and results with one year's experience. International braz j urol. 2009;35(6):706-15.

28. Rehder P, Gozzi C. Transobturator sling suspension for male urinary incontinence including post-radical prostatectomy. European Urology. 2007;52(3):860-7.

29. Magon N, Kalra B, Malik S, Chauhan M. Stress urinary incontinence: What, when, why, and then what? Journal of Mid-life Health. 2011;2(2):57.

30. Goldberg RP, Tchetgen MB, Sand PK, Koduri S, Rackley R, Appell R, et al. Incidence of pubic osteomyelitis after bladder neck suspension using bone anchors. Urology. 2004;63(4):704-8.

31. Madjar S, Beyar M, Nativ O. Transvaginal bone anchored sling. Urology. 2000;55(3):422-6.

32. Madjar S, Jacoby K, Giberti C, Wald M, Halachmi S, Issaq E, et al. Bone anchored sling for the treatment of post-prostatectomy incontinence. The Journal of Urology. 2001;165(1):72.

33. Frederick RW, Carey JM, Leach GE. Osseous complications after transvaginal bone anchor fixation in female pelvic reconstructive surgery: report from single largest prospective series and literature review. Urology. 2004;64(4):669.

34. Riveros S, Lavernia C, Tunuguntla HSGR, Gousse AE. Intractable chronic pelvic pain relieved after bone anchor removal. Journal of Urology. 2004;171:1242-3.

35. Rajpurkar AD, Onur R, Singla A. Patient satisfaction and clinical efficacy of the new perineal bone-anchored male sling. European Urology. 2005;47(2):237.

36. Grise P. Four-arm Transobturator Male Sling for Post-prostatectomy Urinary Incontinence. 2009.

37. Whiteside JL, Walters MD. Anatomy of the obturator region: relations to a trans-obturator sling. International Urogynecology Journal. 2004;15(4):223-6.

38. Reisenauer C, Kirschniak A, Drews U, Wallwiener D. Transobturator vaginal tape inside-out: a minimally invasive treatment of stress urinary incontinence: surgical procedure and anatomical conditions. European Journal of Obstetrics & Gynecology and Reproductive Biology. 2006;127(1):123-9.

39. Boyles SH, Edwards R, Gregory W, Clark A. Complications associated with transobturator sling procedures. International Urogynecology Journal. 2007;18(1):19-22.

40. Achtari C, Mckenzie BJ, Hiscock R, Rosamilia A, Schierlitz L, Briggs CA, et al. Anatomical study of the obturator foramen and dorsal nerve of the clitoris and their relationship to minimally invasive slings. International Urogynecology Journal. 2006;17(4):330-4.

41. Delorme E, Droupy S, de Tayrac R, Delmas V. Transobturator Tape (Uratape< sup>®</sup>): A New Minimally-Invasive Procedure to Treat Female Urinary Incontinence. European Urology. 2004;45(2):203-7.

42. Fernandez P, Raiffort C, Delaney S, Salomon L, Carbonne B, Delmas V, et al. MRI anatomical study of the outside-in transobturator suburethral tape procedure. Acta Obstetricia et Gynecologica Scandinavica. 2008;87(4):457-63.

43. Hazewinkel MH, Schilthuis MS, Roovers JP. Stress urinary incontinence in patients treated for cervical cancer: is TVT-Secur a valuable treatment option? International Urogynecology Journal. 2009;20(3):357-9.

44. Houwert RM, Venema PL, Aquarius AE, Bruinse HW, Roovers JPWR, Vervest HAM. Risk factors for failure of retropubic and transobturator midurethral slings. American Journal of Obstetrics and Gynecology. 2009;201(2):202. e1-. e8.

45. Rapp DE, Reynolds WS, Lucioni A, Bales GT. Surgical technique using AdVance™ Sling placement in the treatment of post-prostatectomy urinary incontinence. International braz j urol. 2007;33(2):231-7.

46. Adadevoh S, Hobbs C, Elkins TE. The relation of the true conjugate to maternal height and obstetric performance in Ghanaians. International Journal of Gynecology & Obstetrics. 1989;28(3):243-51.

47. Bonnet P, Waltregny D, Reul O, De Leval J. Transobturator vaginal tape inside out for the surgical treatment of female stress urinary incontinence: anatomical considerations. The Journal of Urology. 2005;173(4):1223-8.

48. Gynecare TVT Obturator System. In: Worldwide G, editor.

49. Shah HN, Badlani GH. Mesh complications in female pelvic floor reconstructive surgery and their management: A systematic review. Indian Journal of Urology: IJU: Journal of the Urological Society of India. 2012;28(2):129.

50. Virtue Male Sling System. In: Coloplast V, editor.

51. Moore R, Mitchell G, Miklos J. Single-center retrospective study of the technique, safety, and 12-month efficacy of the MiniArc single-incision sling: a new minimally invasive procedure for treatment of female SUI. Surg Technol Int. 2009;18:175-81.

52. Oliveira R, Botelho F, Silva P, Resende A, Silva C, Dinis P, et al. Exploratory study assessing efficacy and complications of TVT-O, TVT-Secur, and Mini-Arc: results at 12-month follow-up. European Urology. 2011;59(6):940-4.

53. Moore KL, Dalley AF. Clinically oriented anatomy: Lippincott Williams & Wilkins; 1999.

54. Harmanli OH, Khilnani R, Dandolu V, Chatwani AJ. Narrow pubic arch and increased risk of failure for vaginal hysterectomy. Obstetrics & Gynecology. 2004;104(4):697-700.

55. Young M, Ince JGH. A radiographic comparison of the male and female pelvis. Journal of Anatomy. 1940;74(Pt 3):374.

56. Bilfeld MF, Dedouit F, Rousseau H, Sans N, Braga J, Rougé D, et al. Human Coxal Bone Sexual Dimorphism and Multislice Computed Tomography: Geometric Morphometric Analysis of 65 Adults. Journal of Forensic Sciences. 2012.

57. Frudinger A, Halligan S, Spencer JAD, Bartram CI, Kamm MA, Winter R. Influence of the subpubic arch angle on anal sphincter trauma and anal incontinence following childbirth. BJOG: An International Journal of Obstetrics & Gynaecology. 2002;109(11):1207-12.

58. Phenice TW. A newly developed visual method of sexing the os pubis. American journal of physical anthropology. 2005;30(2):297-301.

59. Oladipo G, Okoh P, Hart J. Comparative Study of the Sub-Pubic Angles of Adult Ikwerres and Kalabaris. Asian Journal of Medical Sciences. 2010;2(3):107-10.

60. Warwick R, Williams PL. Gray's anatomy. 1973.

61. Standring S, Ellis H, Healy J, Johnson D, Williams A, Collins P, et al. Gray's anatomy: the anatomical basis of clinical practice. American Journal of Neuroradiology. 2005;26(10):2703.

62. Delmas V. Anatomical risks of transobturator suburethral tape in the treatment of female stress urinary incontinence. European Urology. 2005;48(5):793-8.

63. Ottem D, Stothers L. Transobturator tape: variation in the vascular anatomy of the obturator foramen. The Canadian journal of urology. 2007;14(5):3678.

64. Igbigbi PS, Nanono-Igbigbi AM. Determination of sex and race from the subpubic angle in Ugandan subjects. The American journal of forensic medicine and pathology. 2003;24(2):168-72.

65. Gutman RE, Pannu HK, Cundiff GW, Melick CF, Siddique SA, Handa VL. Anatomic relationship between the vaginal apex and the bony architecture of the pelvis: a magnetic

resonance imaging evaluation. American Journal of Obstetrics and Gynecology. 2005;192(5):1544-8.

66. Verdeja AM, Elkins TE, Odoi A, Gasser R, Lamoutte C. Transvaginal sacrospinous colpopexy: anatomic landmarks to be aware of to minimize complications. American Journal of Obstetrics and Gynecology. 1995;173(5):1468-9.

67. Nigro ND. A sling operation for rectal prolapse. Proceedings of the Royal Society of Medicine. 1970;63(Suppl 1):106.

68. Madsen MA. Perineal Approaches to Rectal Prolapse. Clinics in colon and rectal surgery. 2008;21(2):100.

69. Greene FL. Repair of rectal prolapse using a puborectal sling procedure. Archives of Surgery. 1983;118(4):398.

70. Hong SK, Chang IH, Han BK, Yu JH, Han JH, Jeong SJ, et al. Impact of variations in bony pelvic dimensions on performing radical retropubic prostatectomy. Urology. 2007;69(5):907-11.

71. von Bodman C, Matikainen MP, Yunis LH, Laudone V, Scardino PT, Akin O, et al. Ethnic variation in pelvimetric measures and its impact on positive surgical margins at radical prostatectomy. Urology. 2010;76(5):1092-6.

72. Killeen T, Banerjee S, Vijay V, Al-Dabbagh Z, Francis D, Warren S. Magnetic resonance (MR) pelvimetry as a predictor of difficulty in laparoscopic operations for rectal cancer. Surgical endoscopy. 2010;24(12):2974-9.

73. Salerno G, Daniels I, Brown G, Norman A, Moran B, Heald R. Variations in pelvic dimensions do not predict the risk of circumferential resection margin (CRM) involvement in rectal cancer. World journal of surgery. 2007;31(6):1315-22.

74. Correia H, Balseiro S, De Areia M. Sexual dimorphism in the human pelvis: testing a new hypothesis. HOMO-Journal of Comparative Human Biology. 2005;56(2):153-60.

75. Katanozaka M, Yoshinaga M, Fuchiwaki K, Nagata Y. Measurement of obstetric conjugate by ultrasonic tomography and its significance. American Journal of Obstetrics and Gynecology. 1999;180(1):159-62.

76. Weinberg A. Present status of mid-forceps operations, with the prognosis related to pelvic size and architecture. American journal of surgery. 1952:143-54.

77. Turner W. The index of the pelvic brim as a basis of classification. Journal of Anatomy and Physiology. 1885;20(Pt 1):125.

78. Greulich WW, Thoms H, TWADDLE RC. A study of pelvic type and its relationship to body build in white women. Journal of the American Medical Association. 1939;112(6):485-93.

79. Sonal B, Shalini R, Chandra S, Neerga G. Ultrasonic obstetric conjugate measurement: a practical pelvimetric tool. J Obstet Gynecol India. 2006;56(3):212-15.

80. Inuwa I. A study of the neck-shaft of the femur and the sub-pubic angle in Hausa tribe of Nigeria. West Afr J Anat. 1992;1:64.

81. Nwoha P. The anterior dimensions of the pelvis in sex determination. WestAfr J Anal. 1992;7:59-60.

82. Small C, Brits DM, Hemingway J. Quantification of the subpubic angle in South Africans. Forensic science international. 2012.

83. Tobias PV. The biology of the southern African Negro. The Bantu-speaking peoples of Southern Africa London and Boston: Routledge and Kegan Paul. 1974:3-45.

84. Bernard RM. The shape and size of the female pelvis. Edinburgh medical journal. 1952;59(2):1.

85. Baird D. Social factors in obstetrics. Lancet. 1949;1(6565):1079.

86. Stewart K, Cowan D, Philpott R. Pelvic dimensions and the outcome of trial labour in Shona and Zulu primigravidas. S Afr Med J. 1979;55:847-51.

87. Thomas P, Peabody J, Turnier V, Clark RH. A new look at intrauterine growth and the impact of race, altitude, and gender. Pediatrics. 2000;106(2):e21-e.

88. Yaşar IM, Steyn M. Craniometric determination of population affinity in South Africans. International journal of legal medicine. 1999;112(2):91.

89. Steyn M, İşcan MY. Osteometric variation in the humerus: sexual dimorphism in South Africans. Forensic science international. 1999;106(2):77-85.

90. Steyn M, Patriquin M. Osteometric sex determination from the pelvis—Does population specificity matter? Forensic science international. 2009;191(1):113. e1-. e5.

91. Steyn M, Pretorius E, Hutten L. Geometric morphometric analysis of the greater sciatic notch in South Africans. HOMO-Journal of Comparative Human Biology. 2004;54(3):197-206.

92. Decker SJ, Davy-Jow SL, Ford JM, Hilbelink DR. Virtual Determination of Sex: Metric and Nonmetric Traits of the Adult Pelvis from 3D Computed Tomography Models*,†. Journal of Forensic Sciences. 2011;56(5):1107-14.

93. Bonneau N, Bouhallier J, Simonis C, Baylac M, Gagey O, Tardieu C. Technical note: Shape variability induced by reassembly of human pelvic bones. American journal of physical anthropology. 2012.

94. İşcan MY. Global forensic anthropology in the 21st century. Forensic science international. 2001;117(1):1-6.

95. İşcan MY. Forensic anthropology of sex and body size. Forensic science international. 2005;147(2):107-12.

96. Krishan K. Anthropometry in Forensic Medicine and Forensic Science-'Forensic Anthropometry'. The Internet Journal of Forensic Science. 2007;2(1).

97. Lundy J, Feldesman M. Revised equations for estimating living stature from the long bones of the South African Negro. South African Journal of Science. 1987;83:54-5.

98. Dayal MR, Steyn M, Kuykendall KL. Stature estimation from bones of South African whites. South African Journal of Science. 2008;104(3-4):124-8.
99. Steyn M, Smith J. Interpretation of ante-mortem stature estimates in South Africans. Forensic science international. 2007;171(2):97-102.

100. L'Abbé E, Loots M, Meiring J. The Pretoria bone collection: a modern South African skeletal sample. HOMO-Journal of Comparative Human Biology. 2005;56(2):197-205.

101. Steyn M, İşcan MY. Sex determination from the femur and tibia in South African whites. Forensic science international. 1997;90(1):111-9.

102. Loth SR. Sexual dimorphism in the human mandible: a developmental and evolutionary perspective: University of the Witwatersrand; 1996.

103. Moore-Jansen PH, Jantz RL, Ousley SD, University of Tennessee KFAC, University of Tennessee KDoA. Data collection procedures for forensic skeletal material: Forensic Anthropology Center, Department of Anthropology, University of Tennessee; 1994.

104. Fully G. New method of determination of the height]. Annales de médecine légale, criminologie, police scientifique et toxicologie. 1956;36(5):266.

105. Rosenberg LB, Schena BM, Jackson BG. Method and apparatus for tracking the position and orientation of a stylus and for digitizing a 3-D object. Google Patents; 2000.

106. Nagasaka S, Fujimura T, Segoshi K. Development of a non-radiographic cephalometric system. The European Journal of Orthodontics. 2003;25(1):77-85.

107. Parliament SA. National Health Act No. 61 of 2003. Government Gazette. 2005.

108. Driscoll KRD. Secular Change of the Modern Human Bony
Pelvis: Examining Morphology in the United States

using Metrics and Geometric Morphometry [Dissertation]. Tennessee: The University of Tennessee, Knoxville; 2010.

109. van Dillen J, Meguid T, Petrova V, van Roosmalen J. Caesarean section in a semi-rural hospital in Northern Namibia. BMC Pregnancy and Childbirth. 2007;7(1):2.

110. Heyns O. The Influence of X-ray Measurements on the Pelvic Brim Index. British Journal of Radiology. 1947;20(229):31-3.

111. Thoms H. The Pelvic Survey. The Yale Journal of Biology and Medicine. 1946;19(2):171.

112. VAN Sint JS. Color atlas of skeletal landmark definitions: guidelines for reproducible manual and virtual palpation. 2007.

113. Allen EP. The Subpubic Angle: Radiological Aspects. British Journal of Radiology. 1943;16(189):279-82.

114. Pathi SD, Castellanos ME, Corton MM. Variability of the retropubic space anatomy in female cadavers. American Journal of Obstetrics and Gynecology. 2009;201(5):524. e1-. e5.

115. Stanford E. Transvaginal Sacrospinous Ligament
Fixation with Minimal Dissection of the Pararectal Space Featuring the Capio® Suture Capturing Device. Boston Scientific; 2004.

116. Goldberg RP. Sacrospinous Ligament Suspension Using the Capioâ¢ Suture Capture Technique. 2007.

117. El Tohamy O. Sacrospinous Colpopexy, Instruments & Technique. Ain Shams Journal of Obstetrics and Gynecology Clinics of North America. 2006;3:6.

118. Giberti C. Transvaginal sacrospinous colpopexy by palpation—a new minimally invasive procedure using an anchoring system. Urology. 2001;57(4):666-8.

119. Sagsoz N, Ersoy M, Kamaci M, Tekdemir I. Anatomical landmarks regarding sacrospinous colpopexy operations performed for vaginal vault prolapse. European Journal of Obstetrics & Gynecology and Reproductive Biology. 2002;101(1):74-8.

120. Maher CF, Murray CJ, Carey MP, Dwyer PL, Ugoni AM. Iliococcygeus or sacrospinous fixation for vaginal vault prolapse. Obstetrics & Gynecology. 2001;98(1):40-4.

121. Todd TW, Lindala A. Dimensions of the body: Whites and American Negroes of both sexes. American journal of physical anthropology. 1928;12(1):35-119.

122. Hammond-Tooke WD. The Bantu-speaking peoples of southern Africa: Routledge/Thoemms Press; 1980.