The morphometric description of the thoracic and lumbar vertebral pedicles in European, African and Mixed populations of South Africa

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DECLARATION

I, Hassan Yauri Sani hereby declare that this dissertation is my own work, with the assistance of the acknowledged persons. It is being submitted for the degree of Master of Science in Medicine in the Faculty of Health Sciences in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

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12th day of April 2018

DEDICATION

In memory of my mother

Late Hafsat Sani

1950-2015

CONFERENCE PRESENTATION FROM THIS STUDY

The following poster was presented at the 44th congress of the Anatomical Society of Southern Africa hosted by the University of the Free State at the Bloem Spa hotel and Conference Centre, Bloemfontein, from the 8th- 11th May, 2016

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ABSTRACT

The use of pedicle screws fixation for surgical management of spinal disorders has become increasingly popular worldwide. Segmental pedicle screw fixations are used in spinal canal decompression surgery for various spine disorders such as scoliosis, spondylolisthesis, fractures, tumor and iatrogenic or degenerative instability. The main challenge to the use of pedicle screw can be due to mismatched size of the screw and the pedicle. This may result in cortical perforation of the pedicle or fracture of the pedicle. Understanding of pedicle morphometric values is important in designing pedicle screw systems as well as in accurately placing the screws to avoid or minimize complications. Most of the studies on the morphometry of the vertebral pedicles have been reported in the European populations, with a few reports in Asian populations and none in the African populations. Previous studies have shown significant population and ethnic differences in pedicle morphometry. The current study presents information on the thoracic and lumbar pedicle dimensions at the isthmus in the European, African and Mixed-ancestry populations of South Africa.

The study utilized thoracic and lumbar vertebrae of 60 African, 60 European and 54 Mixed-ancestry adult human populations of South Africa with equal male to female representation. The dry human skeletons used were obtained from the Raymond A. Dart Collection of Human specimens housed in the School of Anatomical Sciences at the University of the Witwatersrand. Pedicles of the vertebrae were assessed and measured. The external measurements on the isthmus of the pedicle were performed using a digital Vernier caliper (accuracy, 0.1 mm) on the right and left pedicles. The angular measurements were performed with a standard goniometer (accuracy of 1°). The measurements taken at the isthmus of the vertebral pedicle included the pedicle width, pedicle height, transverse angle, sagittal angle, chord length and inter-pedicular

distance. For the internal measurement, all the vertebrae were radiograph and the transverse (width) and vertical (height) inner cortical diameters were measured at the isthmus of the pedicle using image processing software (image J®).

In the three populations of South Africa, the mean pedicle width was found to gradually decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine whereas in the lumbar spine, the mean pedicle width gradually increased from vertebral levels L1 to L5. The mean pedicle height gradually increased from T1 to T12 in the thoracic spine and in the lumbar spine it gradually decreased from L1 to L5. The mean transverse angle gradually decreases from vertebral levels T1 to T8 and then increased gradually to vertebral level T12 in the thoracic spine, and in the lumbar spine, it increased gradually from vertebral levels L1 to L5. The mean sagittal angle marginally decreased from vertebral levels T1 to T7 and then increased to vertebral level T12 in the thoracic spine, and in the lumbar spine it slightly increased from vertebral levels L1 to L5. The mean chord length gradually increased from vertebral levels T1 to T12 in the thoracic spine, while in the lumbar spine it gradually increased from vertebral levels L1 to L3 and then slightly decreased from level L4 to L5. The mean inter-pedicular distance was found to gradually decrease from vertebral levels T1 to T6 then gradually increased to vertebral level T12 in the thoracic spine, and in the lumbar spine, the mean inter-pedicular distance gradually increased from vertebral levels L1 to L5. The mean transverse inner cortical diameter gradually decreased from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in thoracic spine, and in the lumbar spine; it gradually increased from vertebral levels L1 to L5. The mean vertical inner cortical diameter gradually increase from vertebral levels T1 to T12 in the thoracic spine whereas in the lumbar spine it gradually decrease from L1 to L5.

Pedicle width, pedicle height, transverse angle, sagittal angle, chord length, inter-pedicular distance, transverse inner cortical and vertical inner cortical diameters showed significant differences with age, sex and among the African, European and Mixed ancestry populations of South Africa.

The European population of South Africa showed significantly larger pedicle dimensions when compared to the African and or Mixed ancestry populations. No significant difference was found between the pedicle dimensions in the African and Mixed ancestry populations. Males had larger dimensions than females. This information is vital in determining the safety margin of transpedicular fixation in South African population. Orthopedic surgeons should therefore be aware of racial disparities on pedicular parameters.

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ABBREVIATIONS

CT	Computed tomography
SD	Standard deviation
T1	First thoracic vertebra
T2	Second thoracic vertebra
T3	Third thoracic vertebra
T4	Fourth thoracic vertebra
T5	Fifth thoracic vertebra
T6	Sixth thoracic vertebra
T7	Seventh thoracic vertebra
T8	Eighth thoracic vertebra
T9	Ninth thoracic vertebra
T10	Tenth thoracic vertebra
T11	Eleventh thoracic vertebra
T12	Twelfth thoracic vertebra
L1	First lumbar vertebra
L2	Second lumbar vertebra

L3	Third lumbar vertebra
L4	Fourth lumbar vertebra
L5	Fifth lumbar vertebra

1 CHAPTER ONE: INTRODUCTION

The use of pedicle screw fixation for surgical management of spinal disorders has become increasingly popular worldwide. Segmental pedicle screw fixations are used in spinal canal decompression surgery for various spinal disorders such as scoliosis, spondylolisthesis, fractures, tumor and iatrogenic or degenerative instability (Chadha *et al.*, 2003). The initial methods of pedicle screw fixation were described by Raymond Roy (Boos and Webb, 1997). Roy-Camille *et al.* (1973) described the use of the posterior plate with screws positioned sagittally through the pedicle and articular processes. The screws were designed following recommendations from anatomical studies of the pedicle by Saillant (1976). The technique was first used to treat fractures of the spine, and later extended to other spinal disorders such as vertebral mal-unions, tumors, spondylolisthesis and low-back pain disorder. Louis (1986) modified Roy-Camille's technique and instrumentation by supplementing osteosynthesis with fusion of the posterior joint. Earlier fixation methods before pedicle screwing typically involved the use of hooks and wires, and both methods were designed to provide immediate stability and rigid immobilization of the spine. However, pedicle screw fixation has the additional advantage of not requiring the presence of intact bone laminae, facet joints or spinous processes (Kabins and Weinstein, 1991). The pedicle screws also enable various devices (plates, rods or wires) to be applied in order to achieve immobilization and fixation (Amonoo-Kuofi, 1995).

The complications of the use of pedicle screw can be due to mismatched size of the screw and the pedicle. This may result in cortical perforation of the pedicle or fracture of the pedicle (Singel *et al.*, 2004). Other complications include dural tears and injury to the nerve roots (Singel *et al.*, 2004). Therefore, an understanding of pedicle morphometric values is important in designing pedicle screw systems as well as in accurately placing the screws to avoid or minimize complications.

The anatomic and biomechanic characteristics of the pedicle favours pedicle screw insertion (Boos and Webb, 1997). The strongest portion of the vertebrae is the pedicle, which transmits all forces from the posterior elements to the vertebral body. The pedicle can withstand stressors of rotation, side bending, and extension of the spine (McLain *et al.*, 2002). It is an ideal structure to lock into and control with posterior instrumentation when spinal fixation is needed (McLain *et al.*, 2002).

The studies of the pedicle have been undertaken based on the direct anatomic and radiologic measurements mostly in the European populations and have dictated many of the decisions in the instrumentation and screw design (Hou *et al.*, 1993). Most of the studies have been reported in European populations (Saillant, 1976; Roy-Camille *et al.*, 1986; Marchesi *et al.*, 1988), with a few reports in Asian and African populations (Hou *et al.*, 1993; Kim *et al.*, 1994; Mitra *et al.*, 2002). Previous studies had shown significant inter-racial and ethnic differences in pedicle morphometry (Kim *et al.*, 1994; Datir *et al.*, 2004; Tan *et al.*, 2004). However, there is no available information on the dimensions of the vertebral pedicles in the South African populations. This information is vital to provide data on surgically relevant parameters of pedicle dimensions and to determine how safe pedicle screwing can be used in the South Africa populations. Hence, the aim of this study is to assess the morphometry of the pedicle dimensions at the isthmus in the European, African and Mixed-ancestry populations in South Africa.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Anatomy of the Human Spine

The human spine or the vertebral column consists of complex structures designed to allow mobility of the trunk and extremities and protect the spinal cord (Middleditch and Oliver, 2005). It is made up of 33 vertebral bones divided into: seven cervical vertebrae (C1 to C7), twelve thoracic vertebrae (T1 to T12), five lumbar vertebrae (L1 to L5), five sacral vertebrae fused together to form sacrum and four fused elemental vertebrae to form the coccyx.

On the lateral view, the vertebral column has four normal curves, which consist of lordosis (anterior convexity) in the cervical and lumbar region and kyphosis (posterior convexity) in the thoracic and sacral regions (Asmussen, 1959). These normal anatomical curves provide the vertebral column with increased flexibility and also augment its shock-absorbing capacity (White and Panjabi, 1990).

2.2 Functional movement of the human spine

The human spine is like a mechanical structure that consists of vertebrae and other related structures such as facets, intervertebral discs, ligaments and muscles. The lever in the mechanics is the vertebrae; the pivots are the facet joints and the intervertebral disc whereas the activators are the muscles and the ligaments (White and Panjabi, 1990). These structures give human spine its three fundamental biomechanical functions: (1) to allow sufficient mobility between head, trunk and pelvis; (2) to transfer weight of the head to the pelvis and (3) to offer protection to the spinal cord.

2.3 Vertebrae

The vertebra is divided into two segments, the vertebral body anteriorly and the posterior elements posteriorly (Moore, 2013). The vertebral body bears the compressive loads due to body weight on the spine and is composed of a porous trabecular bone surrounded by dense and solid cortical shell (Roy-Camille *et al.*, 1986). The posterior elements, which protect the spinal cord, consist of the pedicles, lamina, transverse process and spinous process.

2.4 Intervertebral disc

The intervertebral disc functions to absorb and distribute loads applied to the spine (Boos and Aebi, 2008). They comprise the endplates, peripheral annulus fibrosus and central nucleus pulposus (Scott *et al.*, 1994). The endplates provide attachment to the vertebral bodies and serve as medium for nutrient transfer into the disc (Scott *et al.*, 1994). The annulus fibrosus consists of concentric oblique fibres which are important in limiting rotational movements of the spine (Boos and Aebi, 2008). The nucleus pulposus is a gel-like material consisting mainly of water that easily deforms, but is incompressible (Boos and Aebi, 2008).

2.5 Facet joints

These are the synovial joints of the spine between the superior articular processes and inferior articular processes (Bogduk and Long, 1979). The joints have a fibrous capsule, articular cartilage and synovial lining (Bogduk, 2005). The joints play an important role in axial load-bearing during extension and their orientation differs from one region of the spine to the other. In the cervical region, the joints adopted a coronal orientation and therefore allow for all possible range of movements such as flexion, extension, lateral flexion and rotation (Kowalski *et al.*, 2005). In the lumbar region, the joints lie in sagittal plane which allows flexion but no rotation movements (Gray, 2008). The joints in the thoracic region assumed an intermediate position between coronally oriented cervical and sagittally oriented lumbar regions. This allows for lateral flexion and rotation but no flexion or extension movements (Kowalski *et al.*, 2005).

2.6 Functional spinal unit

A functional spinal unit of the vertebral column consists of two contiguous vertebrae and intervening intervertebral disc, two facet joints and all the adjoining ligaments excluding muscles (Herzog, 2000). Stability of the spine is defined when there is neither abnormal strain nor excessive motion in the functional spinal unit. A single functional spinal unit allows for six degrees of freedom of movement, three rotations in the sagittal, transverse and coronal planes and three translations. The integrity of the spinal unit is examined to evaluate the effects disease, degeneration, implant or other procedures have on the spinal biomechanics (Schultz and Ashton-Miller, 1991).

2.7 Anatomy of the individual vertebrae

A typical vertebra consists of the vertebral body situated anteriorly and the vertebral arch posteriorly. The vertebral arch encircles a foramen, the vertebral foramen, and consists of pairs of pedicles and laminae, four articular processes, and two transverse and one spinous processes (Grey, 2008). However, the vertebrae of each region have special distinguishing characteristics which are unique to that particular region, for example the C7 has the longest spinous process in the cervical region (Drake *et al.*, 2005).

2.7.1 Cervical vertebrae

These are smallest vertebrae and characterised by the presence of a foramen in their transverse processes, the foramen transversarium, which transmit the vertebral artery and veins (Grey, 2008). The atlas is the first cervical vertebra with no vertebral body and spinous process. It consists of two lateral masses which are joined by a short anterior and a long posterior arch (Kramer and Allan, 2005). The axis is the second cervical vertebra and bears an upward projection from its body called the odontoid process. The odontoid process articulates with the anterior arch of the atlas above (Netter, 2014). From the third to the sixth vertebrae, these are typical cervical vertebrae; characterised by the presence of a short, bifid spinous processes and each transverse process bears a foramen transversarium (Kramer and Allan, 2005). The seventh cervical vertebra is atypical and consists of a small foramen transversarium and a very large spinous process which is not bifid.

2.7.2 Thoracic vertebrae

The thoracic vertebrae have a body size between the cervical and lumbar vertebrae, which increase gradually from above downward, and are characterised by the presence of facet for articulation with head of the ribs on the side of the vertebral bodies (Grey, 2008). They also possess another facet for articulation with the tubercles of the ribs on all the transverse processes except the eleventh and twelfth vertebrae (Drake *et al.*, 2005).

In a typical thoracic vertebra, the body is heart-shaped when view from above with two demi-facets on each side at the junction of the body and the pedicle (Grey, 2008). The atypical (first, ninth, tenth, eleventh and twelfth) thoracic vertebrae have other peculiar characteristics. The first vertebra has a whole facet on either of the body for the first rib and a demi-facet for the second rib (Netter, 2014). The ninth vertebra may have only one demi-facet below, but in some individual may have two demi-facets, and when this happens the tenth vertebra could only have one demi-facet above (Grey, 2008). The tenth vertebra has the whole facet on either side of the body, which is usually close to the lateral aspect of the pedicle (Kramer and Allan, 2005). In the eleventh vertebra, the facets are large and mainly on the pedicle, its spinous and transverse processes are short (Kramer and Allan, 2005). The twelfth vertebra closely resembles a lumbar, but may be distinguished from it by the presence of the laterally convex inferior articular surface (Grey, 2008).

2.7.3 Lumbar vertebra

The largest vertebra in the human spine are the lumbar vertebra, which are characterised by the absence of the foramina in the transverse processes and the facet for the ribs (Bogduk, 2005). Their vertebral body is larger, wider and thicker than the thoracic vertebra (Grey, 2008). They have very strong pedicles that projected backward from the upper part of the body (Drake *et al.*, 2005). The triangular vertebral foramen is smaller than in the cervical, but larger than in the thoracic region with broad, short and strong laminae and quadrilateral spinous process (Drake *et al.*, 2005).

2.7.4 Sacrum

This is triangular-shaped bone in lower part of the spine. It consists of five fused sacral vertebrae (S1-S5) (Moore, 2013). The superior part is the base which articulates with the body of the last lumbar vertebrae and its inferior part, the apex, articulates with the coccyx (Grey, 2008). Its anterior surface is the posterior wall of the pelvic cavity, whereas the posterior surface is essentially subcutaneous. The two irregular lateral surfaces articulate with the hip bones (Netter, 2014).

The superior surface of the body of the first sacral bone which forms the base of the sacrum has a prominent anterior lip called the sacral promontory, which serves as an important obstetric landmark (Bogduk, 2005). The lateral, wing-like parts of the base form the alae of the sacrum. Each ala consists anteriorly of the costal element, and posteriorly of the transverse process

(Kramer and Allan, 2005). Both components are fused to the side of S1 body and its pedicle forming the lateral boundary of the sacral canal (Moore, 2013)

The anterior or pelvic surface of the sacrum is relatively smooth. Its central portion has four transverse ridges which indicate the regions of fusion between the bodies of the five sacral vertebrae (Grey, 2008). Lateral to these ridges are anterior sacral foramina through which the anterior rami of S1 to S4 spinal nerves enter the pelvis on each side (Drake *et al.*, 2005).

The posterior surface is slightly convex and very irregular. There are five prominent longitudinal ridges on this surface (Bogduk, 2005). The lateral surface is rough and triangular in shape. It articulates with the ilium forming the sacro-iliac joint (Moore, 2013).

2.7.5 Coccyx

This is a small triangular bone, formed by the fusion of four coccygeal vertebrae (Kramer and Allan, 2005). Their number is variable and may be one less or more in some people. They are concave anteriorly, thus continuing the curve of the sacrum. There are traces of a vertebral arch and processes but the vertebral bodies are absent and there is no vertebral canal (Moore, 2013). The most obvious features of these vertebrae are the tubercles which represent remnants of the transverse or articular processes (Kramer and Allan, 2005).

2.8 Surgical Anatomy of Pedicle

The pedicles are two short and tubular bones that connect the lamina to the vertebral body. The pedicle is the strongest part of the vertebrae, even in osteoporosis (Gertzbein and Robbins, 1990). As such, about 80 percent of the hold of pedicular screw is contributed by the pedicle (John, 2008). It consists of an outer cortical shell and inner cancellous part. The dimensions and shape vary between the levels of vertebrae. Anatomically, the pedicle forms the lateral border of the vertebral foramen and also the upper and lower margin of the intervertebral foramen (Hirano *et al.*, 1997). Medial to the pedicle is the dural sac and the nerve roots pass directly inferior to it as they exit through their respective intervertebral foramen (Weinstein *et al.*, 1992). Because of these anatomical relationships, the spinal cord or nerve root can be injured by damage of the medial or inferior pedicular cortex during pedicle screw placement (Misenhimer *et al.*, 1989).

2.9 Morphometry of pedicles

The pedicle has been the subject of many morphometric studies in different populations around the world to determine their true dimensions. There are reports regarding pedicle dimensions in Americans (Olsewski *et al.*, 1990), Koreans (Kim *et al.*, 1994), Greeks (Christodoulou *et al.*, 2005), Japanese (Nojiri *et al.*, 2005) and Egyptian (Maaly *et al.*, 2010) populations. Many authors have studied the pedicles of the vertebrae using different methods such as direct measurement on cadavers (Chaynes *et al.*, 2001; Mitra *et al.*, 2002; Christodoulou *et al.*, 2005; Charles *et al.*, 2014), the measurement of dry vertebrae (Berry *et al.*, 1987; Scoles *et al.*, 1988; Moran *et al.*, 1989; Nojiri *et al.*, 2005), computed tomography (CT) scans (Zindrick *et al.*, 1987; Krag *et al.*, 1988) plain radiograph (Olsewski *et al.*, 1990; Kang *et al.*, 2011), and quantitative 3-dimension anatomic technique (Panjabi *et al.*, 1991; Tan *et al.*, 2004). These studies demonstrated that significant differences exist between different populations, sex, age groups, and vertebral levels. Other factors that also contribute to the wide disparity in the reported results are the differences in sample size, methods of the studies.

2.9.1 Pedicular width

The pedicle width is the minimum value between the medial and lateral surfaces of the pedicle. It is the most important parameter because it determines the size of the pedicle screw to be use during surgery (Weinstein *et al.*, 1992). Significant variations were found in its values from previous studies. Pedicle width measured by Scoles *et al.* (1988) were smaller than those measured by Zindrick *et al.* (1987), Berry *et al.* (1987) and Panjabi *et al.* (1991). Both Berry *et al.* (1987) and Scoles *et al.* (1988) measured the pedicle dimensions from the dry human skeletons in the same collections of bone, although they took the measurement at separate vertebral levels and on different specimens. The differences in values of pedicle width between these two studies are likely due to variation in the sample size (50 adult vertebral column for Scoles *et al*. (1988) and 30 vertebral column for Berry *et al* (1987)). The pedicle width of the lumbar spine increased gradually from L1 to L4 and increased sharply at L5 (Lien *et al.*, 2007). The largest pedicle width was seen at the L5. Moran *et al.* (1989) showed an almost similar trend in which the pedicular width increased slowly and irregularly from L1 to L5. The minimum diameter measured at vertebral level L1 by all authors ranged from 7 to 9mm. The range of maximum diameter at vertebral level L5 was 18-21mm.

2.9.2 Pedicular height

Pedicle height is the minimum value which separates the superior and inferior margins the of pedicle (Maillot and Wolfram-Gabel, 1993). Pedicle height carries lesser importance in deciding pedicle screw diameter, because its value is much higher than pedicular width. This dimension was not part of Krag *et al.* (1988) study. However, it still remains of interest due to the clearance it gives to the surgeon at the time of the pedicular aiming.

Generally, pedicle height increases gradually from vertebral level T1 to L5, with the increase being mostly at the extremities of the thoracic spine. Caudally, in the lumbar spine the dimension was found to decrease with a minimum at L3, then increase up to L5 (Charles *et al.*, 2014). The work of several authors showed comparable values and close to 15mm in the lumbar region (Saillant, 1976; Moran *et al.*, 1989; Olsewski *et al.*, 1990). On the contrary, Berry *et al.* (1987) and Zindrick *et al.*

(1987) found that the pedicular height decreased at L4 and L5, whereas Scoles *et al.* (1988) and Panjabi *et al.* (1991) found large increases towards the lower lumbar levels. For Berry *et al.* (1987) the decrease was more obvious at L4 vertebra. Olsewski *et al.* (1990) showed a clear increase of this value at the vertebral level L5.

2.9.3 Pedicle angle

The angle between the vertebral body and pedicle varies considerably throughout the spine. In the transverse plane, the pedicle angles from posterolateral to anteromedial at most levels, the exception being in the region of the thoracolumbar junction. At this point the pedicle angle may be neutral (parallel to the midline) or even reversed from the angulation in other regions of the spine (Zindrick and Hodges, 1996). In the sagittal plane, the pedicle angle is neutrally oriented in the lumbar spine while in the thoracic spine the pedicle angle is orientated downwards to meet the vertebral body.

The transverse angle is an important parameter in obtaining correct screw insertion without damaging neurologic structures such as nerve roots. Roy-Camille *et al.* (1986) and Louis (1986) suggested that a pedicle screw must be inserted in the straight direction. In contrast, Krag *et al.* (1988) and Zindrick *et al.* (1987) reported that insertion of the pedicle screw along the medial trajectory is a safer technique. If the screw's medial-lateral trajectory differs from that of the pedicle by even a relatively small amount, medial or lateral breach may result.

Measurements of pedicle angles varied significantly in previous studies (Zindrick *et al.*, 1987; Krag *et al.*, 1988; Scoles *et al.*, 1988). This may be due to the different techniques employed to measure the angle. Zindrick *et al.* (1987) measured angles from CT and radiographic data whereas Krag *et al.* (1988) and Scoles *et al.* (1988) used direct measurement from the dry vertebrae. Panjabi *et al.* (1991) used computer software and measured the angles from a pedicle midline to each of the sagittal and transverse planes. Although the values found by these studies are different they all concurred that the transverse angle decreases steadily as one continues down the thoracic spine until in the lower thoracic vertebrae, where it shows a sharp increase; it then increases steeply across the lumbar level such that the L5 pedicle has transverse angle of 25 to 30 degrees (Zindrick *et al.*, 1987; Krag *et al.*, 1988; Scoles *et al.*, 1988).

2.9.4 Chord length

Chord length (Screw path length) is the distance from the junction of the superior facet and transverse process to the anterior cortex of the vertebral body along the pedicle axis. Chord length determines the safest length of any screw that can be used for pedicular fixation. It is an important parameter that prevents perforation of the anterior cortex and the consequent injury to major blood vessels which lie anterior to the vertebral body (Patil and Bhuiyan, 2014). It varies with the size of the vertebral body and is approximately 40-45mm in the thoracic spine and 50mm in the lumbar spine (Weinstein *et al.*, 1992).

2.10 Demographic factors and pedicle dimensions

There are conflicting reports about the relationship between the demographic factors (age, sex, and population) and pedicle dimensions. Kim *et al.* (1994) and Tan *et al.* (2004) reported that pedicle dimensions in Koreans and Chinese Singaporeans respectively are smaller than in people of European descent. On the other hand, Chadha *et al.* (2003) and Acharya *et al.* (2010) demonstrated that white had significantly larger pedicle size than Indian populations. Olsewski *et al.* (1990) and Hou *et al.* (1993) showed that males had significantly larger pedicle dimensions than females. In addition, Charles *et al.* (2014) concluded that pedicle dimensions generally increase with age. However, McLain *et al.* (2002) found no correlation between pedicle size and sex or race

2.11 History of the pedicle screw fixation

The use of bone screws to obtain internal spinal fixation at the time of fusion was first described by Toumey (1943) and King (1948). Their techniques involved passing a screw from medial to lateral across the facet joint. The screws were short and designed only to cross the facet joint but the method was faulty and it led to higher rates of pseudo arthrosis. Boucher (1959) modified the technique by using a longer (one and a half to two inches) stainless steel screws placed through the inferior facets into the pedicle and vertebral body below. This led to the reduction of pseudo arthrosis rates to approximately 14% to 17% (Andrea *et al.*, 2005). Magerl (1984) introduced another form of facet screws in which a screw was passed from one side of the spinous process into the opposite lamina across the facet joint to the base of the transverse process. The disadvantage of this technique was that it required intact lamina.

Harrington (1988) initially used facet screws to correct scoliosis in patients with poliomyelitis without success. Later on, a much improved *Harrington instrumentation* was developed which had screws inserted into the pedicle of fifth lumbar vertebra and attached distraction rods by heavy stainless steel wires for reduction and stabilization of spondylolisthesis. The first to use pedicle screws and connect it to a dorsal plate was by Roy-Camille *et al.* (1973). Beginning in 1963, Roy-Camille used pedicle screw fixation in the spines for correction of fractures, instability after the resection of vertebral tumours, and in lumbosacral fusion.

Cotrel *et al.* (1988) introduced a new method that used both pedicle screw and hook connecting them with dorsal rods and plate, which is now called the universal spinal instrumentation for treatment of scoliosis through application of multiple corrective force at different point on the rods. This method allowed for the correction of some of the features of scoliosis that were not treatable by Harrington rods, such as rib hump.

Panjabi *et al.* (1991) analysed and compared the facet fixation and pedicle screw fixation methods and found that the stability of the spine was relatively low during flexion/extension and lateral bending with facet screw fixation compared to pedicle screw fixation system. The pedicle screw was then recommended as the method which supports and maintains the biomechanics of the vertebral column.

2.12 Screw design

A pedicle screw consists of a head, neck and body (Fig. 2.1). It has a major (outer) and minor (inner) diameter (Cho *et al.*, 2010). The outside diameter of the screw ranges from 4.5 to 7mm. Screw length ranges from 30 to 55mm and is measured from the tip to the base of the screw head (Andrea *et al.*, 2005). The main function of the screw head is to provide the anchoring site to a rod or plate which connects the other screws along the screw-rod construct (Parham, 2013). The inner diameter of the screw is the determining factor for resistance of screw to bending or fracture. The strength of the screws increases exponentially as the inner diameter is increased (Petersilge *et al.*, 1996).

The thread depth, pitch and type are three most important design element of the screw. Thread depth is the difference between the outer and inner diameters (Parham, 2013). Larger thread depth result in better bone securing and stronger screw pull-out in soft cancellous bone but reduces fracture strength of the screw (Parham, 2013). Thread pitch is the distance between two adjacent threads or may be defined as the number of threads per inch (Parham, 2013). Thread type refer to the shape of the thread, of which there are many options, the design utilized most often in surgical implants include "V" shaped threads, buttress shaped thread and square shaped threads (Parham, 2013)

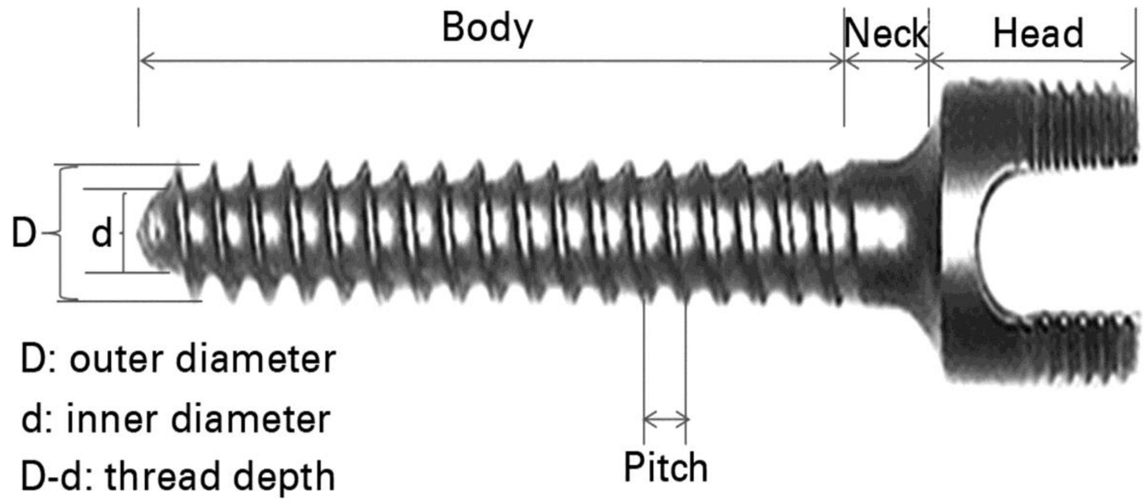

Figure 2.1. Image showing different parts of pedicle screw. Adopted from Cho et al. (2010)

Two types of screws are generally used in surgery depending on the type of bone that is being instrumented (Cortical bone or Cancellous bone) (Parham, 2013). Cortical screws are more like machine screws, meaning that they have a low thread depth and low thread pitch, an ideal combination for gaining screw purchase in a hard material. On the other hand, cancellous screws are more like wood screws in that they have a high thread pitch and large thread depth (Parham, 2013). This combination allows for screw purchase in relatively weak material such as cancellous bone because it allows for a large amount of bone to be present between each thread thus increasing its strength (Parham, 2013). Since pedicle screw fixation is mostly within cancellous bone, most pedicle screws are designed like wood screws (Parham, 2013)

2.13 Techniques for screw insertion

There are different methods for detecting the pedicle and inserting the pedicle screw, but basic steps include: (1) clearing of the soft tissue after skin incision, (2) identifying the intersection at the base of the facet between a vertical line passing through the middle articular facets and the horizontal line through middle of the transverse process, (3) removing the cortex at this point to expose cancellous part of the pedicle, (4) proving the pedicle, (5) locating the four walls of the pedicle by probing or radiographic confirmation, (6) tapping the pedicle, and (7) placing the screw (John, 2008).

The entry point is decorticated using a burr to create a posterior cortical breach, approximately 5mm in depth (Roy-Camille *et al.*, 1986). Using a bur or awl the dorsal cortex of the pedicle is penetrated. Then a straight pedicle probe is used to create a path for the screw through the pedicle into the vertebral body. The progression of the probe should be smooth and steady. After cannulation, a sounding probe is placed into the pedicle that is then palpated from within to make sure there is no medial, lateral, cranial or caudal disruption in the cortex of the pedicle (Pennal *et al.*, 1964). After the pedicle has been probed and sounded, Steinman pins or K-wires are placed into the pedicle to confirm the trajectory and entry site, and then the pedicle screw path is tapped when non self-tapping screws are used (Weinstein *et al.*, 1992). After tapping the pedicles, the permanent screws with largest diameters that will not break the pedicle are placed. The screw length can be determined by measuring the length of the Steinman pin from the pedicle entry site to the depth of 50% of the vertebral body (Xu *et al.*, 1998). Once the pedicle screws are in place, the lateral aspect of the facet joints and transverse process are decorticated and then the screws are connected to the longitudinal rods or plates (Andrea et al., 2005).

2.14 Entry point

Anatomical landmarks, and confirmatory radiography are commonly used for pedicle screw insertion (Steinmann *et al.*, 1993). In the lumbar spine, the entry point is at the intersection between a vertical line passing through the middle of the inferior facet and the transverse line passing through the middle of the transverse process (Roy-Camille *et al.*, 1986). In the thoracic spine, the anatomical landmark for the entry point defers depending on the vertebral level (Xu *et al.*, 1998). The starting point in the lower thoracic spine at vertebral levels T10-T12 is at the junction of a vertical line which passes along the lateral boundary of the space between the inferior and superior articular processes of the facet joint, and a transverse line dividing the transverse process in its half (Kim *et al.*, 2004). In the mid-thoracic level, the starting point shifts medially so that at vertebral levels T7-T9 the entry point is along a vertical line just lateral to the midpoint of the superior articular process, and a transverse line along the superior border of the transverse process (Cinotti *et al.*, 1999). At vertebral levels T1-T2 the entry point is located at the intersection of a vertical line along the lateral border of the space between the inferior and superior articular processes of the facet joint, and a transverse line bisecting the transverse process (Kim *et al.*, 2004).

2.15 Complications

There are many controversies and complications regarding the use of pedicle screws to stabilise the injured spine. Brown *et al.* (1998) reported a complication rate of 2.2% in paediatric patients using thoracolumbar and lumbar pedicle screws. In a study of pedicle screws fusion for non-traumatic disorders, Lonstein *et al.* (1999) reported complications rate of 24% that were directly related to pedicle screws. Pihlajamäki *et al.* (1997) reported complications in approximately 50% of patients.

The complications reported are due to misplaced screw or coupling failure, nerve root injuries, fracture of the screw and non-union or screw loosening. The rate of screw misplacement ranges from 0-25% (Barr *et al.*, 1997; Liljenqvist *et al.*, 1997) in patients with scoliosis and about 4.2% in patients with degenerative diseases (Blumenthal and Gill, 1993). Coupling failures of the device occur due to inadequate nut tightening, resulting in disengagement of the screw from the clamp elements of the rod (Pihlajamäki *et al.*, 1997). Nerve-root and/or cauda equine injuries are associated with pain and sensory deficit. Screws that are placed medially and inferiorly are the ones that place the nerve at the risk of injury.

Pihlajamäki *et al.* (1997) showed that 36% screws had fatigue failure. In other studies, the frequency of screw breakage ranged from 0.5-11.2% of the inserted screws. Lonstein *et al.* (1999) associated screw breakage to three factors: design of the screw, presence of pseudo arthrosis and their use in burst fracture. Loosening of the pedicle screw has been commonly seen in patients with low bone mineral density (BMD) and osteoporosis and it indicates micro movement at the region of the screw and rod (Pihlajamäki *et al.*, 1997). Loosening of the pedicle screws was most commonly seen in patients with multilevel instrumentation and in patients with screw fixation in the sacral vertebra (Pihlajamäki *et al.*, 1997). Other complications include bending of screws, infection and injury to the blood vessels.

2.16 Use of pedicle screws in spinal disorders

The use of pedicle screw fixation has brought about clinical improvement in surgical care of spinal disorders (Boos and Webb, 1997). The indications for the application of a pedicle screw system differ from one spinal pathology to another (Boos and Webb, 1997).

2.16.1 Scoliosis

Pedicle screw fixation has been a standard for the surgical treatment of scoliosis since its first introduction by Harrington (1988). Harrington's correction method was based on insertion of screws with distraction rods along the concavity of the curve whereas Cotrel *et al.*'s (1988) correction was by the rod-rotation manoeuvre. Both methods provide excellent deformity correction (Boos and Webb, 1997).

2.16.2 Spinal fracture

Treatment of spinal fractures includes fracture reduction and spinal canal decompression so as to provide stability of the spine and allow early mobility (Boos and Webb, 1997). Pedicle screw fixation allows reduction of displaced fractured vertebrae and stabilisation of the anterior column of the vertebrae even if the posterior elements are damaged (Boos and Webb, 1997). The method has the ability to decompress the spinal canal and therefore relieve cord compression (Boos and Webb, 1997)

2.16.3 Tumours

The use of pedicle screws has allowed the short-segment treatment of the primary and metastatic tumours of the spine (Gaines, 2000). The use of the pedicle screw has provided the opportunity to perform safe radical resection of primary spinal tumours (Gaines, 2000).

2.16.4 Spondylolisthesis

Pedicle screws have enhanced the rate of fusion and improve the ability to fix and maintain reduction of high grade spondylolisthesis (Boos and Webb, 1997). The previous single-stage posterior technique used in the treatment of spondylosis is associated with complications such as implant failure and loss of reduction. However, the use of pedicular fixation with anterior fusion provides high success rate (Boos and Webb, 1997).

2.17 AIMS AND OBJECTIVES OF THE STUDY

The aim of this study is to morphometrically assess the thoracic and lumbar pedicle dimensions at the level of isthmus in the European, African and Mixed-ancestry populations of South African.

2.17.1 OBJECTIVES

1. To determine the transverse (width) and vertical (height) diameters of the pedicle at the level of isthmus
2. To determine the sagittal and transverse angles of the pedicle
3. To determine the screw path length (chord length)
4. To determine the transverse inner cortical width at the narrowest point of the pedicle isthmus on radiographic specimens
5. To determine the distance between the pedicles of the same vertebra (inter-pedicular distance)
6. To Compare the pedicular dimensions in three South African populations.

3 CHAPTER THREE: MATERIALS AND METHODS

3.1 The sample and study design

The study utilized thoracic and lumbar vertebrae of 60 African, 60 European and 54 Mixed-ancestry adult human populations of South Africa. The dry skeletons used were obtained from the Raymond A. Dart Collection of Human specimens housed in the School of Anatomical Sciences at the University of the Witwatersrand. The age, race and sex of the study sample were known.

The specimens were stratified according to age into early adult group (age range, 20-50 years) and late adult group (age range, 51-65 years) with 30 individuals in each sample (15 males and 15 females) from each age group in the European and African populations. In the mixed-ancestry population 15 males and 9 females were selected due to limited number of samples in the late adult group. The age, race and sex distribution of the study sample are shown in the Table 3.1.

Table 3.1: Age, Sex and Race distribution of the sample specimens

RACE	SEX	AGE RANGE		TOTAL
		20-50 years	51-65 years	
EUROPEAN	MALE	15	15	60
	FEMALE	15	15	
MIXED-ANCESTRY	MALE	15	15	54
	FEMALE	15	9	
AFRICAN	MALE	15	15	60
	FEMALE	15	15	

3.2 Inclusion/exclusion criteria

Only specimens with a complete number of thoracic and lumbar vertebrae and age ranging between 20 to 65 years were included in the study. The specimens were classified as African, European and Mixed-ancestry population groups according to their ancestry as recorded in the Raymond A Dart collection of Human skeletons. In the case of the African group, different ethnic groups were considered homogeneous and the sample therefore included Zulu, Xhosa, Pedi, Sotho, Tswana, Tsonga and Venda individuals (Dayal *et al.*, 2009). Skeletons showing gross deformities or other bone distortions that could affect measurements were excluded from the sample.

3.3 External measurements

Pedicles of thoracic and lumbar vertebrae were assessed and measured. The external linear measurements on the isthmus of the pedicle were performed using a digital caliper (accuracy, 0.1 mm) on both the right and left pedicles. The angular measurements were performed with a standard goniometer (accuracy of 1°). The following parameters were measured on both sides: pedicular width, pedicular height, transverse angle, sagittal angle, chord length and inter-pedicular distances

3.3.1 Pedicular width

Using a superior approach in the transverse plane, the distance between medial and lateral surfaces of the pedicle at isthmus were measured at the right angle to the long axis of the pedicle (Fig. 3.1A). As proposed by Zindrick *et al.* (1987), the pedicle axis was defined as a line perpendicular to and bisecting the narrowest diameter of the pedicle.

3.3.2 Pedicular height

The vertical distance between superior and inferior border of the pedicle at its isthmus was measured from the lateral aspect (Fig. 3.1B). This is the maximum diameter of the pedicle

3.3.3 Transverse pedicle angle

The transverse angle was defined as the angle between the mid-sagittal plane of vertebral body and the plane bisecting the pedicle (Berry *et al.*, 1987) (Fig. 3.1C).

3.3.4 Sagittal angle

The sagittal angle was defined as the angle between a line passing through the pedicle axis and superior vertebral border in the sagittal plane (Fig. 3.1D).

3.3.5 Chord length

It is the distance from the most posterior aspect of the lamina cortex to the anterior cortex of the vertebral body along the pedicle axis as described or reported by Olsewski *et al.* (1990) (Fig. 3.1E).

3.3.6 Inter-pedicular distance

The maximum distance between the medial surfaces of the right and left isthmuses of the pedicles of the vertebra was measured and also recorded as the transverse diameter of the vertebral canal (Fig. 3.1F).

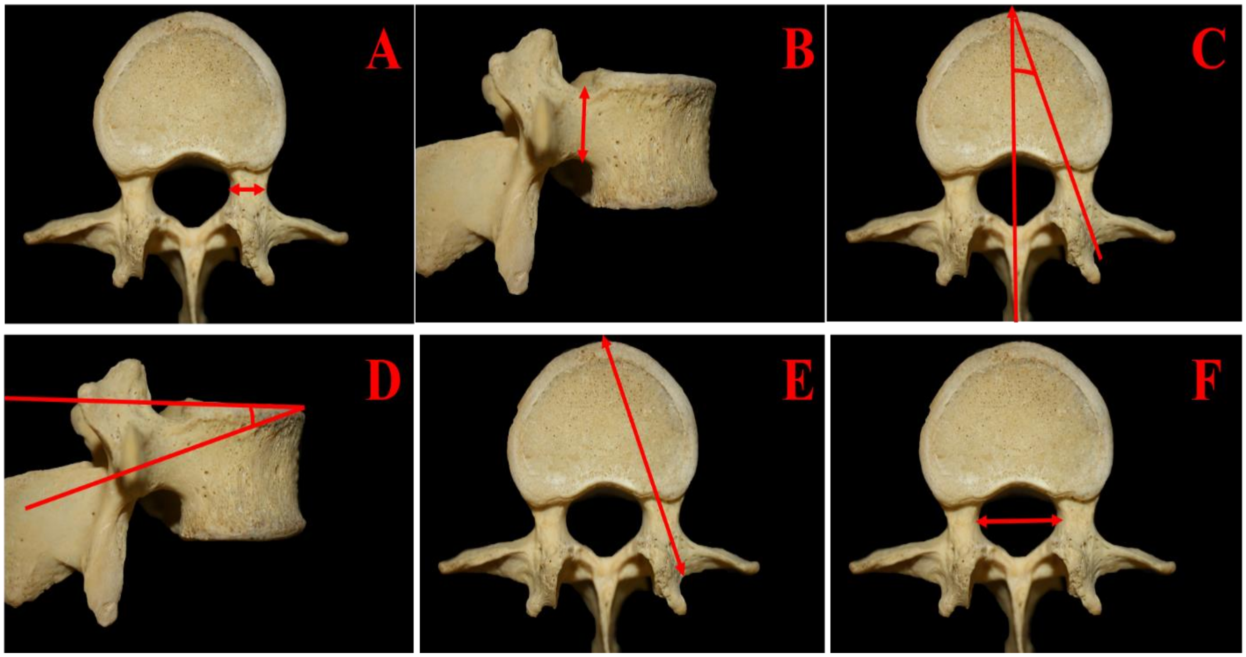

Figure 3.1. Superior and Lateral view of vertebrae showing measurement of **A**. Pedicle width, **B**. Pedicle height, **C**. Transverse angle, **D**. Sagittal angle, **E**. Chord length and **F**. Inter-pedicular distance as indicated by red arrows.

3.4 Internal measurements

Using radiographs, the transverse (width) and vertical (height) inner cortical diameters were measured (Figs. 3.2A and B). A standardized technique was used to radiograph all the vertebrae. Before the radiography, the isthmus of the pedicles of each vertebra was identified, and a fine malleable wire was applied to this region. The wire was drawn tightly on the pedicle isthmus so that direct contact existed between the wire and the cortical bone at all points. The individual vertebrae were then arranged and stuck together with Prestik Tn adhesive putty placed between each vertebra. The vertebrae were radiographed using a Shimadzu mobile X- ray machine (model- mux 200, serial no. 0162590104, Kyoto Japan) in an anterior-posterior direction. The size of the film cassette used was 24×30cm for the thoracic vertebrae and 18×24 cm for the lumbar vertebrae. The X-ray beam was centered on the 6th thoracic vertebra and 3rd lumbar vertebra for thoracic and lumbar vertebrae respectively and directed at 90º to the film. The anode-film distance of 100 cm and the exposure factors of 50 kilovoltage as well as 1.5 milliamperage were maintained for all the radiographs. The magnification resulting from this technique was negligible.

A South African 10-cent coin was also X-rayed together on the same film with the vertebrae (Fig 3.2A and B). The value of the diameter of the coin was used to set the scale. In this way the diameter of the coin represented a standardized distance when measuring the transverse and vertical inner cortical diameter. The measurements of the transverse and vertical inner cortical diameters were done using the image processing software, image J®.

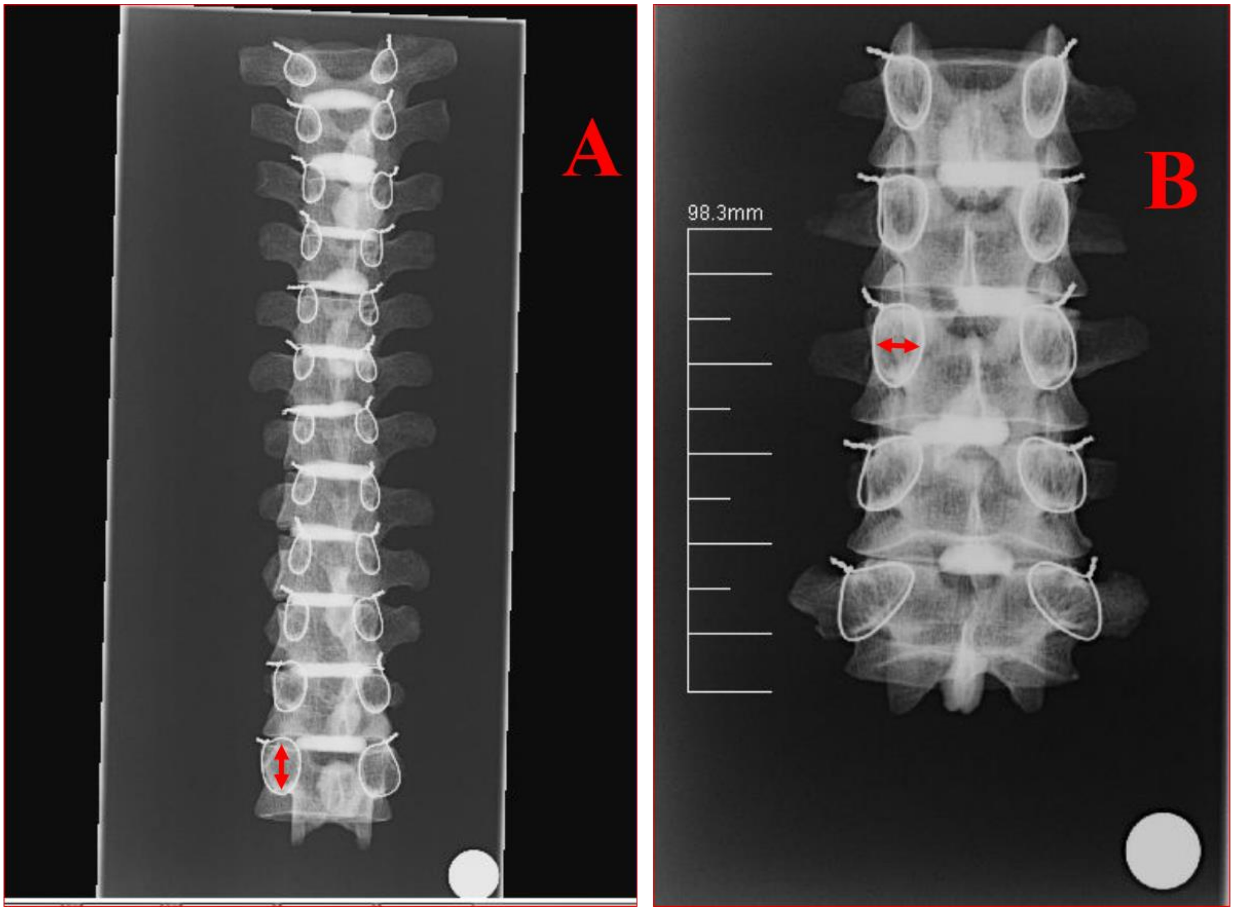

Figure 3.2. Anterior radiographs of thoracic (**A**) and lumbar (**B**) vertebrae showing measurements of transverse inner cortical diameter (red arrow in **B**) and vertical inner cortical diameter (red arrow in **A**)

3.5 Test of repeatability

To measure the intra observer error, the first, second and eighth thoracic vertebrae as well as second and fifth lumbar vertebrae of 10 specimens (5 females and 5 males) were measured, and were repeated on different occasions. The Lin's concordance correlation coefficient of repeatability was used to assess the intra observer error and the value obtained is shown in table 3.2 below.

Table 3.2: Lin's concordance correlation coefficient (Pc) values for each parameter measured.

Parameters	Pedicle width	Pedicle height	Transverse angle	Sagittal angle	Chord length	Inter-pedicular distance	Transverse inner cortical diameter	Vertical inner cortical diameter
Pc values	0.98370	0.99675	0.88735	0.99915	0.99794	0.99364	0.97256	0.96658

Pc values range from 0 to 1 and a value close to 1 indicate a high degree of repeatability. Except for transverse angle, all *Pc* values obtained were greater than 0.9, which shows that the correlation between repeated measurements was high and thus, the intra observer error was minimal.

3.6 Statistical analysis

The data was entered into Microsoft Excel spreadsheet, (2007) and data validation and cleaning was conducted. Afterwards the data was exported to Stata version 13.0 (Stata Corp) statistical software for analysis. For descriptive analysis, the categorical variables such as race, sex, age and side of the pedicle (left or right) were described as frequencies and percentages.

The continuous variables were tested for normality by drawing histogram (with normal distribution curve) and by using Skewness-Kurtosis (sktest) test command in Stata. A variable is assumed to be normally distributed when the P-value from the sktest is greater than 0.05. All the continuous variables in the study were normally distributed and therefore their means and standard deviations were determined and reported. Furthermore, appropriate bar chart (error bars) and line graphs were also drawn. Bar charts were used to compare attributes of the three population groups.

Student’s t-test was used to compare the means of pedicle width, height, transverse angle, sagittal angle, chord length and the inter-pedicular distance between: (i) males and females (ii) early adult and late adult groups and (iii) right and left sides. Differences in means with p-value <0.05 were considered statistically significant.

Analysis of variance (ANOVA) was used to compare the means of pedicle width, height, transverse angle, sagittal angle, chord length and the inter-pedicular distance among the three population groups (African, European, Mixed-ancestry). Bonferroni *post hoc* test was further conducted when the p-value of ANOVA test was less than 0.05.

4 CHAPTER FOUR: RESULTS

4.1 EXTERNAL MEASUREMENTS IN AFRICAN POPULATION

4.1.1 Pedicle width

In the thoracic spine, the mean pedicle width was found to sharply decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 (Fig. 4.1A). The largest mean thoracic pedicle width was seen at vertebral level T1 in both males (7.9 mm ±0.94) and females (7.32 mm ±1.02) and the least was at vertebral level T5 in both males (3.54 mm ±0.6) and females (3.25 mm ±0.8) (Table 4.7). In the Lumbar spine, the mean pedicle width gradually increased from vertebral levels L1 to L4 and then abruptly increased at vertebral level L5 (Fig. 4.1A). The largest mean lumbar pedicle width was seen at vertebral level L5 in both males (16.01 mm ±2.24) and females (15.22 mm ±1.67) and the least was at vertebral level L1 in both males (8.15 mm ±1.61) and females (6.6 mm ±1.19) (Table 4.7).

In almost all the vertebral levels, the mean pedicle width was larger in males than in females and the difference was statistically significant ($p \leq 0.05$) except at vertebral levels T11 and T12 (Table 4.7). Similarly, the mean pedicle width in the older age group (51 to 65 years) was larger than the mean pedicle width in the younger age group (20 to 50 years) with statistically significant differences ($p \leq 0.05$) being observed from vertebral levels T1 to T9 (Table 4.1). No statistically significant differences were found between right and left in all the vertebral levels ($p \geq 0.05$).

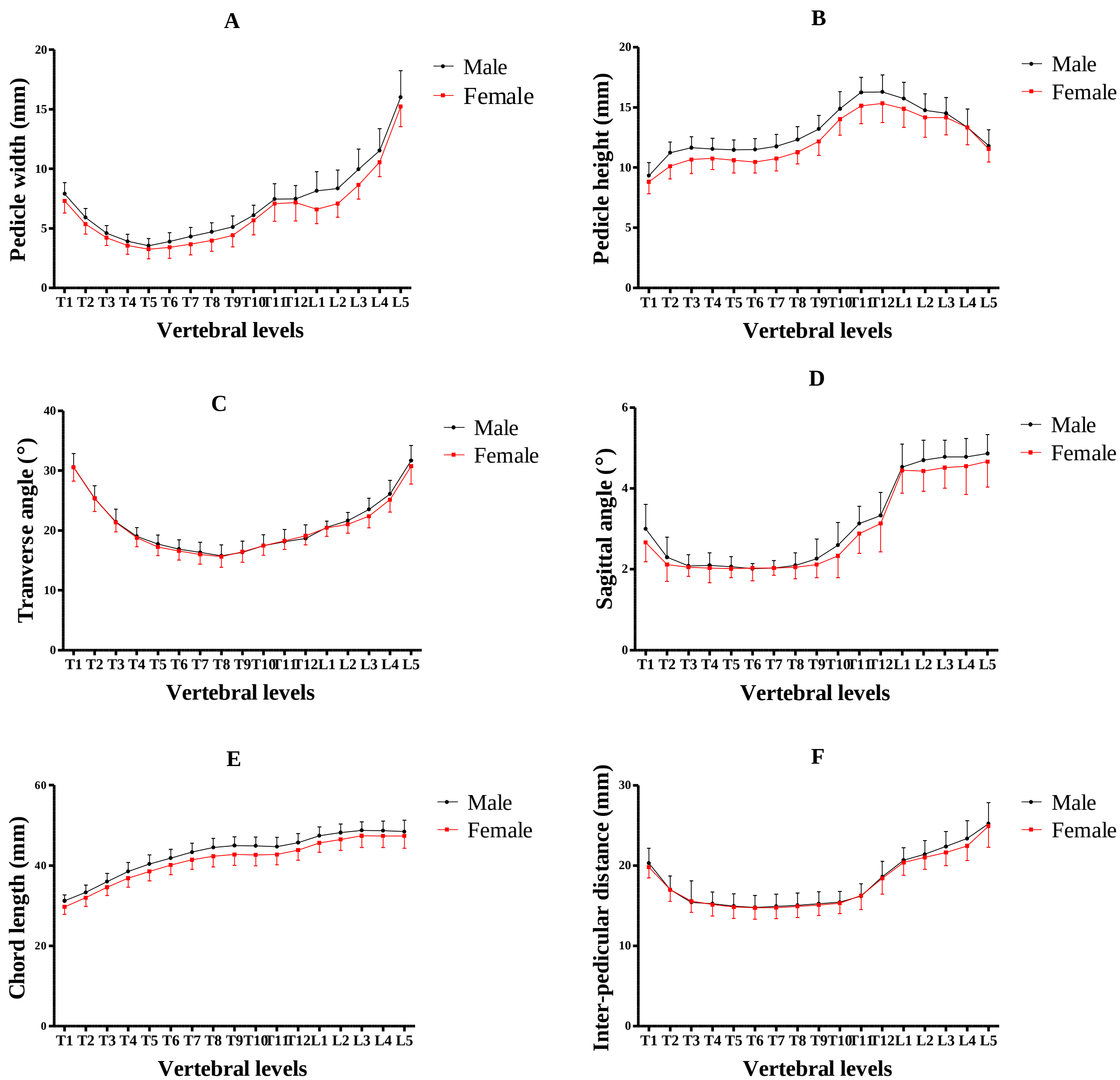

Figure 4.1. Graphs showing the relationship between pedicle width (**A**), pedicle height (**B**), transverse angle (**C**), sagittal angle (**D**), chord length (**E**) and inter-pedicular distance (**F**) and the vertebral levels in both males and females of the African population.

Table 4.1: Comparison of pedicle width between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the African population

Vertebral Levels	20-50 yrs. Mean ±SD (mm)	51-65 yrs. Mean ±SD (mm)	P-value
T1	7.41 ± 1.1	7.8 ± 0.9	0.0357
T2	5.4 ± 0.84	5.87 ± 0.79	0.0021
T3	4.19 ± 0.65	4.62 ± 0.64	0.0004
T4	3.55 ± 0.71	3.91 ± 0.62	0.0039
T5	3.2 ± 0.72	3.59 ± 0.66	0.0025
T6	3.43 ± 0.89	3.88 ± 0.79	0.004
T7	3.68 ± 0.81	4.3 ± 0.84	0.0001
T8	4.07 ± 0.93	4.61 ± 0.83	0.001
T9	4.48 ± 0.93	5.06 ± 1	0.0014
T10	5.81 ± 1.15	5.96 ± 0.96	0.4508
T11	7.28 ± 1.48	7.26 ± 1.33	0.9382
T12	7.31 ± 1.44	7.33 ± 1.25	0.9584
L1	7.32 ± 1.7	7.42 ± 1.53	0.7388
L2	7.61 ± 1.62	7.84 ± 1.35	0.3941
L3	9.32 ± 1.71	9.3 ± 1.49	0.9408
L4	11.06 ± 1.68	11.04 ± 1.57	0.9571
L5	15.73 ± 2.42	15.5 ± 1.5	0.5235

4.1.2 Pedicle height

The mean pedicle height was found to gradually increase from vertebral levels T1 to T12 in the thoracic spine (Fig. 4.1B). The largest mean pedicle height was observed at vertebral level T12 in both males (16.28 mm ±1.41) and females (15.34 mm ±1.59) and the least was at vertebral level T1 in both males (9.33 mm ±1.08) and females (8.81 mm ±0.98) (Table 4.7). The mean pedicle height of the lumbar spine gradually decreased from vertebral levels L1 to L5 (Fig. 4.1B). The largest mean pedicle height was seen at vertebral level L1 in both males (15.73 mm ±1.34) and females (14.88 mm ±1.54) and the least was at vertebral level L5 in both males (11.8 mm ±1.34) and females (11.54 mm ±1.09) (Table 4.7).

From T1 to L2 vertebral levels, the mean pedicle height in males was larger than in females and the difference was statistically significant ($p \leq 0.05$) (Table 4.7). But, the mean pedicle height showed no statistically significant differences between the older (20 to 50 years) and younger (51 to 65 years) age groups (Table 4.2) and between right and left side in all the vertebral levels ($p \geq 0.05$).

Table 4.2: Comparison of pedicle height between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the African population.

Vertebral Levels	20-50 yrs. Mean ±SD (mm)	51-65 yrs. Mean ±SD (mm)	P-value
T1	9.18 ± 0.97	8.97 ± 1.15	0.2873
T2	10.62 ± 1.11	10.73 ± 1.14	0.6112
T3	11.01 ± 1.08	11.3 ± 1.2	0.1807
T4	11.11 ± 1.02	11.2 ± 0.95	0.6283
T5	10.97 ± 1.06	11.12 ± 1.02	0.4344
T6	10.94 ± 1.07	11.01 ± 1.03	0.7023
T7	11.21 ± 1.08	11.3 ± 1.17	0.6491
T8	11.82 ± 1.17	11.78 ± 1.14	0.846
T9	12.68 ± 1.18	12.69 ± 1.33	0.9589
T10	14.55 ± 1.38	14.35 ± 1.5	0.4551
T11	15.69 ± 1.52	15.69 ± 1.46	0.982
T12	15.79 ± 1.63	15.83 ± 1.53	0.9027
L1	15.31 ± 1.33	15.3 ± 1.67	0.9528
L2	14.47 ± 1.38	14.45 ± 1.69	0.9407
L3	14.17 ± 1.22	14.49 ± 1.51	0.2023
L4	13.23 ± 1.32	13.43 ± 1.63	0.4611
L5	11.61 ± 1.23	11.73 ± 1.22	0.5765

4.1.3 Transverse angle

The mean of transverse angles was found to rapidly decrease from vertebral levels T1 to T8 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.1C). The largest mean angle was seen at vertebral T1 in both males (30.55º ±2.32) and females (30.58º ±2.32) and the least was at vertebral level T8 in both males (15.77º ±1.84) and females (15.63º ±1.79) (Table 7). In the lumbar spine, the mean of transverse angle gradually increased from vertebral levels L1 to L5 (Fig. 4.1C). The largest mean angle was seen at vertebral level L5 in both males (31.68º ±2.54) and females (30.73º ±2.97) and the least was at vertebral level L1 in both males (20.52º ±1.02) and females (20.43º ±1.43) (Table 4.7)

The mean transverse angles at vertebral levels L2 to L4 was larger in males than in females and the difference was statistically significant ($p \leq 0.05$) (Table 4.7). The mean angle in the older age group (51 to 65 years) was greater than in the younger age group (20 to 50 years) with significant difference ($p \leq 0.05$) seen from vertebral levels T10 to T12 and at L5 (Table 4.3). However, no significant difference was seen between the mean of right and left side at all the vertebral levels ($p \geq 0.05$).

Table 4.3: Comparison of transverse angle between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the African population.

Vertebral Levels	20-50yrs Mean ±SD (deg)	51-65yrs Mean ±SD (deg)	P-value
T1	30.23 ± 1.99	30.9 ± 2.57	0.1145
T2	25.33 ± 1.92	25.38 ± 2.47	0.9017
T3	21.17 ± 1.43	21.58 ± 2.21	0.2227
T4	18.88 ± 1.71	18.92 ± 1.23	0.9025
T5	17.37 ± 1.68	17.63 ± 1.34	0.3379
T6	16.48 ± 1.43	16.97 ± 1.6	0.0843
T7	15.97 ± 1.63	16.37 ± 1.7	0.1899
T8	15.63 ± 1.9	15.77 ± 1.73	0.6881
T9	16.08 ± 2.04	16.72 ± 1.49	0.0546
T10	17.03 ± 1.88	17.88 ± 1.4	0.0058
T11	17.82 ± 2.07	18.6 ± 1.25	0.0135
T12	18.35 ± 2.29	19.45 ± 1.28	0.0015
L1	20.33 ± 1.19	20.62 ± 1.28	0.2108
L2	21.23 ± 1.42	21.45 ± 1.51	0.4198
L3	22.95 ± 1.98	22.97 ± 2.01	0.9635
L4	25.72 ± 2.44	25.53 ± 1.98	0.6523
L5	30.68 ± 2.74	31.73 ± 2.77	0.0391

4.1.4 Sagittal angle

The mean sagittal angle was found to marginally decrease from vertebral levels T1 to T7 and then gradually increased to vertebral level T12 in thoracic spine (Fig. 4.1D). The largest mean sagittal angle was seen at vertebral level T12 in both males (3.33º ±0.57) and females (3.13º ±0.7) and the least was at vertebral level T7 in both males (2.03º ±0.18) and females (2.03º ±0.18) (Table 4.8). In the lumbar spine, the mean sagittal angle slightly increased from vertebral levels L1 to L5 (Fig. 4.1D). The largest mean sagittal angle was seen at vertebral level L5 in both males (4.87º ±0.47) and females (4.67º ±0.63) while the least was at vertebral level L1 in both males (4.53º ±0.57) and females (4.45º ±0.57) (Table 4.8).

The mean sagittal angle in males was larger than in females and this difference was statistically significantly different ($p \leq 0.05$), particularly at vertebral levels T1, T2, T10, T11 and L1 to L3 vertebral levels (Table 4.8). At vertebral level T4 the mean sagittal angle was significantly greater in older age group (51 to 65 years) than in the younger age group (20 to 50 years) ($p \leq 0.05$), but at vertebral levels T11, T12 L4 and L5 the mean sagittal angle was significantly larger ($p \leq 0.05$) in the younger age than in the older age group (Table 4.4). There was no significant difference seen between the mean sagittal angle of right and left side ($p \geq 0.05$).

Table 4.4: Comparison of sagittal angle between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the African population.

Vertebral Levels	20-50yrs Mean ±SD (deg)	51-65yrs Mean ±SD (deg)	P-value
T1	2.78 ± 0.49	2.88 ± 0.64	0.3387
T2	2.18 ± 0.39	2.23 ± 0.53	0.5586
T3	2.03 ± 0.18	2.1 ± 0.3	0.1457
T4	1.97 ± 0.18	2.17 ± 0.42	0.0009
T5	2 ± 0.18	2.08 ± 0.28	0.0557
T6	1.98 ± 0.13	2.07 ± 0.31	0.0582
T7	2.02 ± 0.13	2.05 ± 0.22	0.3132
T8	2.07 ± 0.25	2.08 ± 0.33	0.7581
T9	2.15 ± 0.36	2.23 ± 0.46	0.2744
T10	2.45 ± 0.57	2.48 ± 0.57	0.7477
T11	3.1 ± 0.4	2.92 ± 0.53	0.0344
T12	3.37 ± 0.64	3.1 ± 0.63	0.0228
L1	4.43 ± 0.53	4.55 ± 0.59	0.2598
L2	4.6 ± 0.49	4.53 ± 0.54	0.48
L3	4.73 ± 0.45	4.57 ± 0.5	0.0563
L4	4.78 ± 0.49	4.55 ± 0.67	0.0322
L5	4.88 ± 0.52	4.65 ± 0.58	0.0221

4.1.5 Chord length

The mean chord length in the thoracic spine was found to gradually increase from vertebral levels T1to T12 (Fig. 4.1E). The largest mean chord length was seen at vertebral T12 in both males (45.72 mm ±2.25) and females (43.85 mm ±2.52) and the least was at vertebral level T1 in both males (31.21 mm ±1.51) and females (29.72 mm ±1.84) (Table 4.8). In the lumbar spine, the mean chord length gradually increased from vertebral levels L1 to L3 and then marginally decreased at vertebral levels L4 to L5 (Fig. 4.1E). The largest mean chord length was seen at vertebral level L3 in both males (48.77 mm ±2.11) and females (47.42 mm ±2.91) and the least was at vertebral level L1 in both males (47.45 mm ±2.17) and females (45.66 mm ±2.37) (Table 4.8).

The mean chord length in males was larger than in females and the difference was statistically significant at all the vertebral level ($p \leq 0.05$) (Table 4.8) and similarly, from vertebral levels T4 to T11 in the thoracic spine and from vertebral levels L1 to L3 in the lumbar spine, the mean chord length in the older age group was significantly larger than in the younger age group ($p \leq 0.05$) (Table 4.5). However, no statistically significant difference was observed between the right and left side ($p \geq 0.05$).

Table 4.5: Comparison of chord length between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the African population.

Vertebral Levels	20-50 yrs. Mean ±SD (mm)	51-65 yrs. Mean ±SD (mm)	P-value
T1	30.18 ± 1.77	30.74 ± 1.87	0.0946
T2	32.38 ± 2.06	32.94 ± 2.13	0.15
T3	34.94 ± 2.07	35.69 ± 2.2	0.0582
T4	37.01 ± 2.37	38.4 ± 2.23	0.0013
T5	38.89 ± 2.38	40.09 ± 2.45	0.0077
T6	40.35 ± 2.37	41.61 ± 2.41	0.0045
T7	41.92 ± 2.48	42.88 ± 2.38	0.0333
T8	42.92 ± 2.48	43.92 ± 2.79	0.0404
T9	43.38 ± 2.4	44.39 ± 2.88	0.0388
T10	43.2 ± 2.44	44.45 ± 2.85	0.0116
T11	43.26 ± 2.37	44.23 ± 2.79	0.0411
T12	44.38 ± 2.42	45.2 ± 2.64	0.0792
L1	46.11 ± 2.24	46.99 ± 2.55	0.047
L2	46.8 ± 2.1	47.94 ± 2.89	0.0149
L3	47.56 ± 2.1	48.62 ± 2.98	0.0267
L4	47.66 ± 2.42	48.43 ± 2.89	0.1186
L5	47.49 ± 2.94	48.39 ± 2.95	0.0979

4.1.6 Inter-pedicular distance

The mean inter-pedicular distance was found to gradually decrease from vertebral levels T1 to T6 and then increased from vertebral levels T7 to T12 in the thoracic spine (Fig. 4.1F). The largest distance was seen at vertebral level T1 in both males (20.31 mm ±1.85) and females (19.8 mm ±1.31) and the least was at vertebral level T6 in both males (14.78 mm ±1.48) and females (14.75 mm ±1.4) (Table 4.8). In the lumbar spine the mean inter-pedicular distance gradually increased from vertebral levels L1 to L5 (Fig. 4.1F). The largest distance was seen at vertebral level L5 in both males (25.21 mm ±2.64) and females (24.92 mm ±2.62) and the least was at vertebral level L1 in both males (20.66 mm ±1.57) and females (20.38 mm ±1.58) (Table 4.8).

No statistical significant differences ($p \geq 0.05$) were found between the mean inter-pedicular distance of the males (Table 4.8) and females and between the older (51 to 65 years) and younger age (20 to 50 years) groups at all the vertebral levels (Table 4.6).

Table 4.6: Comparison of inter-pedicular distance between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the African population.

Vertebral levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	20.18 ± 1.61	19.93 ± 1.62	0.5648
T2	17.13 ± 1.52	16.87 ± 1.6	0.5247
T3	15.85 ± 1.49	15.13 ± 2.57	0.1874
T4	15.43 ± 1.45	14.97 ± 1.39	0.2086
T5	15.17 ± 1.45	14.65 ± 1.42	0.1646
T6	14.95 ± 1.44	14.58 ± 1.43	0.3293
T7	15.04 ± 1.37	14.65 ± 1.48	0.2977
T8	15.15 ± 1.34	14.84 ± 1.56	0.4172
T9	15.32 ± 1.25	15.05 ± 1.54	0.4705
T10	15.57 ± 1.29	15.21 ± 1.33	0.2879
T11	16.38 ± 1.56	16.1 ± 1.7	0.5127
T12	18.6 ± 1.99	18.4 ± 1.89	0.6921
L1	20.54 ± 1.54	20.5 ± 1.62	0.9095
L2	21.16 ± 1.57	21.29 ± 1.64	0.7557
L3	22.01 ± 1.78	22 ± 1.8	0.9897
L4	22.82 ± 2.01	22.99 ± 2.17	0.7532
L5	25.23 ± 2.61	24.91 ± 2.66	0.641

Table 4.7: Comparison of mean pedicle width, pedicle height and transverse angle between male and female in the African Population.

	Pedicle Width (mm)		Pedicle Height (mm)		Transverse angle (deg)	
Vertebral levels	**M**	**F**	**M**	**F**	**M**	**F**
T1	7.9 ± 0.94	7.32 ± 1.02**	9.33 ± 1.08	8.81 ± 0.98*	30.55 ± 2.32	30.58 ± 2.32
T2	5.9 ± 0.77	5.36 ± 0.84***	11.24 ± 0.88	10.12 ± 1.06***	25.32 ± 2.2	25.4 ± 2.23
T3	4.6 ± 0.64	4.22 ± 0.67**	11.64 ± 0.9	10.67 ± 1.17***	21.42 ± 2.13	21.33 ± 1.57
T4	3.91 ± 0.59	3.55 ± 0.73**	11.54 ± 0.88	10.76 ± 0.93***	19.02 ± 1.47	18.78 ± 1.5
T5	3.54 ± 0.6	3.25 ± 0.8*	11.47 ± 0.83	10.61 ± 1.05***	17.73 ± 1.54	17.27 ± 1.47
T6	3.9 ± 0.73	3.42 ± 0.93**	11.49 ± 0.92	10.45 ± 0.9***	16.88 ± 1.54	16.57 ± 1.52
T7	4.32 ± 0.76	3.66 ± 0.87***	11.76 ± 0.99	10.75 ± 1.01***	16.33 ± 1.71	16 ± 1.62
T8	4.7 ± 0.77	3.97 ± 0.92***	12.33 ± 1.07	11.27 ± 0.98***	15.77 ± 1.84	15.63 ± 1.79
T9	5.12 ± 0.93	4.41 ± 0.96**	13.2 ± 1.13	12.17 ± 1.16***	16.35 ± 1.88	16.45 ± 1.75
T10	6.1 ± 0.83	5.67 ± 1.22*	14.88 ± 1.42	14.02 ± 1.33**	17.45 ± 1.84	17.47 ± 1.58
T11	7.46 ± 1.3	7.09 ± 1.49	16.25 ± 1.25	15.13 ± 1.5***	18.13 ± 2.03	18.28 ± 1.43
T12	7.48 ± 1.11	7.16 ± 1.53	16.28 ± 1.41	15.34 ± 1.59**	18.68 ± 2.27	19.12 ± 1.51
L1	8.15 ± 1.61	6.6 ± 1.19***	15.73 ± 1.34	14.88 ± 1.54**	20.52 ± 1.02	20.43 ± 1.43
L2	8.36 ± 1.53	7.09 ± 1.15***	14.76 ± 1.38	14.15 ± 1.64*	21.65 ± 1.39	21.03 ± 1.48*
L3	9.96 ± 1.7	8.65 ± 1.18***	14.51 ± 1.3	14.15 ± 1.43	23.52 ± 1.89	22.4 ± 1.93**
L4	11.54 ± 1.82	10.56 ± 1.21**	13.34 ± 1.52	13.33 ± 1.45	26.1 ± 2.25	25.15 ± 2.09*
L5	16.01 ± 2.24	15.22 ± 1.67*	11.8 ± 1.34	11.54 ± 1.09	31.68 ± 2.54	30.73 ± 2.97

*P<0.05; **P<0.005; ***P<0.0005

Table 4.8: Comparison of sagittal angle, chord length and inter-pedicular distance between males and females in the African Population.

	Sagittal angle (deg)		Chord length (mm)		Interpeduncular distance (mm)	
Vertebral Levels	**M**	**F**	**M**	**F**	**M**	**F**
T1	3 ± 0.61	2.67 ± 0.48**	31.21 ± 1.51	29.72 ± 1.84***	20.31 ± 1.85	19.8 ± 1.31
T2	2.3 ± 0.5	2.12 ± 0.42*	33.31 ± 1.87	32.01 ± 2.14**	17 ± 1.68	16.99 ± 1.44
T3	2.08 ± 0.28	2.05 ± 0.22	36.04 ± 2.03	34.59 ± 2.06***	15.42 ± 2.69	15.57 ± 1.36
T4	2.1 ± 0.3	2.03 ± 0.37	38.54 ± 2.23	36.86 ± 2.27***	15.25 ± 1.46	15.14 ± 1.41
T5	2.07 ± 0.25	2.02 ± 0.22	40.41 ± 2.22	38.57 ± 2.39***	14.97 ± 1.5	14.85 ± 1.41
T6	2.02 ± 0.13	2.03 ± 0.32	41.85 ± 2.23	40.12 ± 2.39***	14.78 ± 1.48	14.75 ± 1.4
T7	2.03 ± 0.18	2.03 ± 0.18	43.37 ± 2.17	41.44 ± 2.37***	14.93 ± 1.51	14.77 ± 1.37
T8	2.1 ± 0.3	2.05 ± 0.29	44.54 ± 2.24	42.31 ± 2.63***	15.05 ± 1.54	14.93 ± 1.38
T9	2.27 ± 0.48	2.12 ± 0.32	44.99 ± 2.2	42.78 ± 2.7***	15.26 ± 1.49	15.11 ± 1.32
T10	2.6 ± 0.56	2.33 ± 0.54*	44.95 ± 2.13	42.7 ± 2.78***	15.45 ± 1.32	15.33 ± 1.32
T11	3.13 ± 0.43	2.88 ± 0.49**	44.71 ± 2.28	42.77 ± 2.6***	16.21 ± 1.54	16.26 ± 1.73
T12	3.33 ± 0.57	3.13 ± 0.7	45.72 ± 2.25	43.85 ± 2.52***	18.59 ± 1.94	18.41 ± 1.94
L1	4.53 ± 0.57	4.45 ± 0.57	47.45 ± 2.17	45.66 ± 2.37***	20.66 ± 1.57	20.38 ± 1.58
L2	4.7 ± 0.5	4.43 ± 0.5**	48.2 ± 2.16	46.53 ± 2.7***	21.43 ± 1.7	21.02 ± 1.48
L3	4.78 ± 0.42	4.52 ± 0.5**	48.77 ± 2.11	47.42 ± 2.91**	22.37 ± 1.88	21.63 ± 1.62
L4	4.78 ± 0.45	4.55 ± 0.7*	48.71 ± 2.36	47.38 ± 2.84*	23.37 ± 2.23	22.45 ± 1.83
L5	4.87 ± 0.47	4.67 ± 0.63	48.49 ± 2.77	47.39 ± 3.08*	25.21 ± 2.64	24.92 ± 2.62

*P<0.05; **P<0.005; ***P<0.0005

4.2 EXTERNAL MEASUREMENTS IN EUROPEAN POPULATION

4.2.1 Pedicle width

The mean pedicle width was found to sharply decrease from vertebral level T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.2A). The largest mean pedicle width was seen at vertebral level T1 in both males (8.73 mm ±1.19) and females (7.53 mm ±1.16) and the least was at vertebral level T5 in both males (4.26 mm ±1.05) and females (3.63 mm ±0.85) (Table 4.15). In the lumbar spine the mean pedicle width increased gradually from vertebral levels L1 to L4 followed by a sharp increase at L5 (Fig. 4.2A). The largest mean width was seen at vertebral level L5 in both males (16.52 mm ±1.93) and females (14.38 mm ±2.4) and the least was at vertebral level L1 in both males (7.47 mm ±1.52) and females (6.23 mm ±1.63) (Table 4.15).

In all the vertebral levels the mean pedicle width in males was larger than in females and the difference was statistically different ($p \leq 0.05$) (Table 4.15). But no statistically significant difference was found between the mean pedicle width in older (51 to 65 years) and younger (20 to 50 years) age groups (Table 4.9), and between the right and left sides ($p \geq 0.05$).

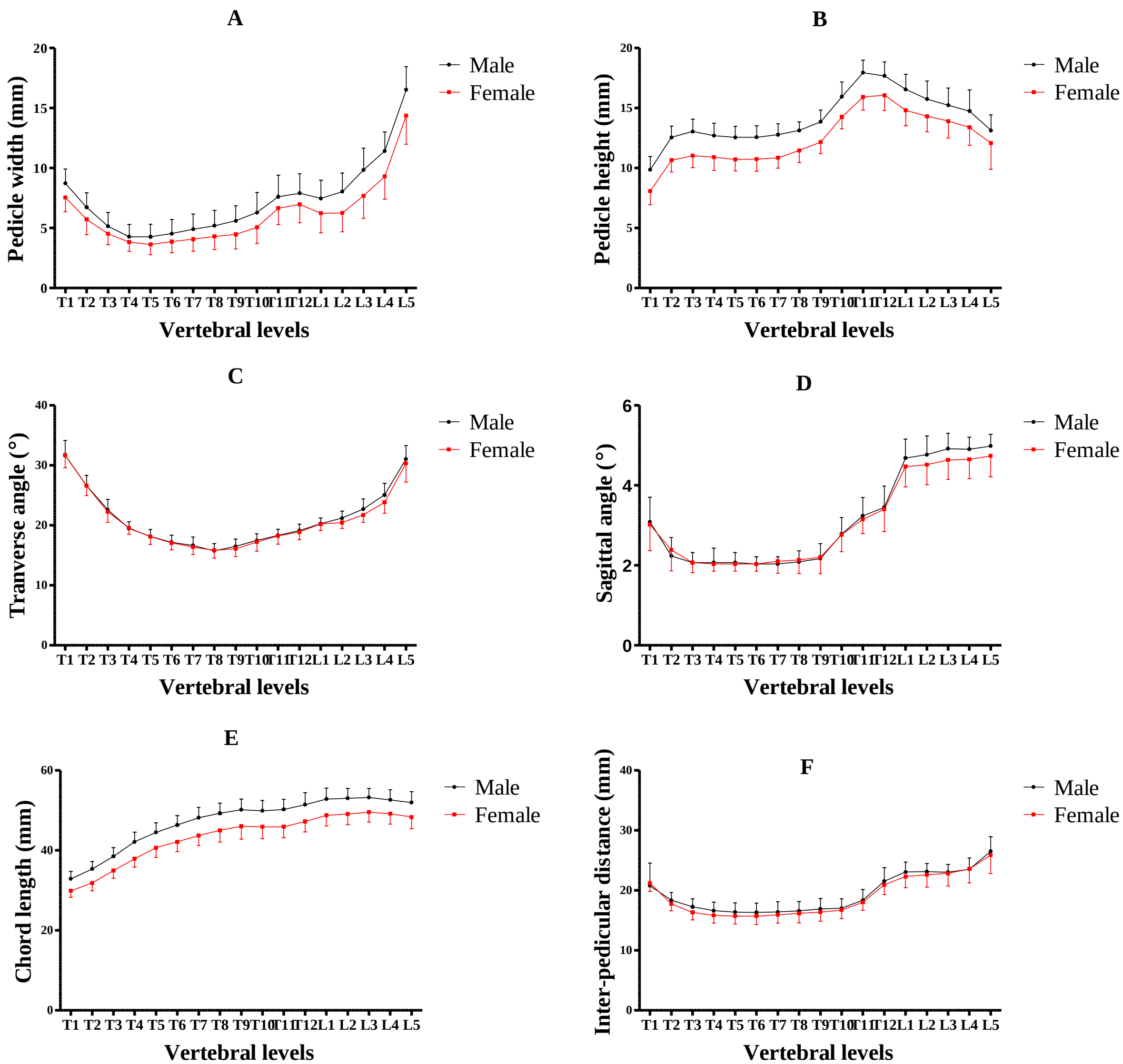

Figure 4.2. Graphs showing the relationship between the pedicle width (**A**), pedicle height (**B**), transverse angle (**C**) and sagittal angle (**D**), chord length (**E**) and inter-pedicular (**F**) and the vertebral levels in both males and females of the European population.

Table 4.9: Comparison of pedicle width between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the European population.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	8.15 ± 1.28	8.11± 1.36	0.8544
T2	6.21 ± 1.36	6.23 ± 1.33	0.9228
T3	4.76 ± 1	4.89 ± 1.16	0.5284
T4	4.04 ± 0.94	4.07 ± 0.93	0.8748
T5	3.99 ± 1.06	3.9 ± 0.95	0.6326
T6	4.21 ± 1.13	4.18 ± 1.1	0.8816
T7	4.54 ± 1.27	4.43 ± 1.14	0.6169
T8	4.75 ± 1.22	4.74 ± 1.32	0.9486
T9	4.96 ± 1.37	5.1 ± 1.34	0.5717
T10	5.68 ± 1.65	5.66 ± 1.64	0.9434
T11	7.23 ± 1.79	7.02 ± 1.55	0.4788
T12	7.61 ± 1.59	7.25 ± 1.68	0.2253
L1	6.93 ± 1.72	6.77 ± 1.66	0.62
L2	7.15 ± 1.82	7.15 ± 1.79	0.9851
L3	8.92 ± 1.9	8.61 ± 2.35	0.4293
L4	10.36 ± 1.94	10.35 ± 2.16	0.978
L5	15.18 ± 2.28	15.73 ± 2.55	0.2195

4.2.2 Pedicle height

The mean pedicle height was found to gradually increase from vertebral levels T1 to T12 in the thoracic spine (Fig. 4.2B). The largest mean pedicle height was seen at vertebral level T12 in both males (17.94 mm ±1.03) and females (16.05 mm ±1.25) and the least was at vertebral T1 in both males (9.86 mm ±1.1) and females (8.07 mm ±1.14) (Table 4.15). In the lumbar spine, the mean pedicle height gradually decreased from vertebral levels L1 to L5 (Fig. 4.2B). The largest mean height was seen at vertebral level L1 in both males (16.55 mm ±1.27) and females (14.81 mm ±1.29) and the least was at vertebral level L5 in both males (13.13 mm ±1.29) and females (12.07 mm ±2.19) (Table 4.15).

At all the vertebral levels, the mean pedicle height in males was larger than in females and the difference was statistically significant ($p \leq 0.05$) (Table 4.15). Similarly, the mean pedicle height in older age (51 to 65 years) group was larger than in the younger age (20 to 50 years) group with a statistical difference ($p \leq 0.05$) being observed at vertebral level T2 (Table 4.10). But no significant differences were seen between the right and left sides ($p \geq 0.05$).

Table 4.10: Comparison of pedicle height between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the European population.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	8.81 ± 1.46	9.12 ± 1.4	0.24
T2	11.35 ± 1.36	11.85 ± 1.3	0.0407
T3	11.91 ± 1.64	12.16 ± 1.2	0.3318
T4	11.68 ± 1.56	11.92 ± 1.23	0.3689
T5	11.48 ± 1.43	11.79 ± 1.17	0.1961
T6	11.6 ± 1.41	11.71 ± 1.27	0.6479
T7	11.79 ± 1.43	11.84 ± 1.2	0.8413
T8	12.2 ± 1.32	12.38 ± 1.09	0.409
T9	12.84 ± 1.38	13.18 ± 1.16	0.15
T10	15.08 ± 1.5	15.1 ± 1.3	0.9529
T11	16.9 ± 1.5	16.95 ± 1.45	0.8617
T12	17.03 ± 1.57	16.69 ± 1.32	0.1937
L1	15.86 ± 1.64	15.5 ± 1.44	0.2011
L2	15.19 ± 1.68	14.86 ± 1.43	0.2481
L3	14.71 ± 1.65	14.42 ± 1.5	0.3254
L4	14.06 ± 1.95	14.08 ± 1.59	0.9437
L5	12.52 ± 1.89	12.68 ± 1.86	0.6574

4.2.3 Transverse angle

The mean transverse angle was found to rapidly decrease from vertebral levels T1 to T8 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.2C). The largest mean angle was seen at vertebral level T1 in both males (31.65º ±2.5) and females (31.7º ±2.12) and the least was at vertebral level T8 in both males (15.75º ±1.19) and females (15.82º ±1.28) (Table 4.15). In the lumbar spine, the mean transverse gradually increased from vertebral level L1 to L4 and then abruptly at vertebra level L5 (Fig. 4.2C). The largest mean transverse angle was seen at vertebral level L5 in both males (31.05º ±2.26) and females (30.32º ±3.12) and the least was at vertebral level L1 in both males (20.27º ±0.94) and females (20.22º ±1.11) (Table 4.15).

The mean transverse angle from vertebral levels L2 to L4 was larger in males than in females and the difference was statistically significant ($p \leq 0.05$) (Table 4.15). No significant difference was seen between the mean transverse angle in the older age (51 to 65 years) group and younger age (20 to 50 years) group (Table 4.11), and between the right and left sides ($p \geq 0.05$).

Table 4.11: Comparison of transverse angle between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the European population.

Vertebral Levels	20-50yrs Mean ±SD (deg)	51-65yrs Mean ±SD (deg)	P-value
T1	31.7 ± 1.98	31.65 ± 2.61	0.906
T2	26.78 ± 1.71	26.37 ± 1.64	0.175
T3	22.43 ± 1.62	22.38 ± 1.87	0.8758
T4	19.55 ± 1.06	19.48 ± 1.11	0.7379
T5	18.12 ± 1.28	18.13 ± 1.2	0.9414
T6	17.05 ± 1.24	17.18 ± 1.07	0.529
T7	16.67 ± 1.4	16.32 ± 1.23	0.1478
T8	15.68 ± 1.26	15.88 ± 1.21	0.3758
T9	16.12 ± 1.32	16.47 ± 1.2	0.1306
T10	17.15 ± 1.39	17.5 ± 1.26	0.1501
T11	18.08 ± 1.38	18.45 ± 0.98	0.0964
T12	18.82 ± 1.32	19.17 ± 0.99	0.1038
L1	20.07 ± 0.94	20.42 ± 1.08	0.0601
L2	20.65 ± 1.07	20.98 ± 1.2	0.1111
L3	21.98 ± 1.49	22.42 ± 1.64	0.1324
L4	24.18 ± 1.81	24.7 ± 2.09	0.1498
L5	30.67 ± 2.86	30.7 ± 2.63	0.9472

4.2.4 Sagittal angle

The mean sagittal angle was found to marginally decrease from vertebral levels T1 to T6 and then increased gradually to vertebral level T12 in the thoracic spine (Fig. 4.2D). The largest mean angle was seen at vertebral level T12 in both males (3.45º ±0.53) and females (3.4º ±0.56) and the least was at vertebral levels T6 and T7 in males (2.03º ±0.18) and from vertebral levels T5 to T7 in females (2.03º ±0.18) (Table 4.16). In the lumbar spine, the mean sagittal angle slightly increased from vertebral levels L1 to L5 (Fig. 4.2D). The largest mean angle was seen at vertebral level L5 in both males (4.98º ±0.29) and females (4.73º ±0.52) and the least was at vertebral level L1 in both males (4.68º ±0.47) and females (4.47º ±0.5) (Table 4.16).

From vertebral levels L1 to L5, the mean sagittal angle in males was larger than in females and the differences were statistically significant ($p \leq 0.05$) (Table 4.16), At vertebral levels T1, T2, T11 and T12 in the thoracic spine and at vertebral levels L1 and L2 in the lumbar spine the mean angle in the older age (51 to 65 years) group was significantly larger than in the younger age (20 to 50 years) group ($p \leq 0.05$) (Table 4.12). No significant differences were seen between right and left sides ($p \geq 0.05$).

Table 4.12: Comparison of sagittal angle between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the European population

Vertebral Levels	20-50yrs Mean ±SD (deg)	51-65yrs Mean ±SD (deg)	P-value
T1	2.85 ± 0.58	3.25 ± 0.63	0.0004
T2	2.18 ± 0.39	2.43 ± 0.56	0.0055
T3	2.05 ± 0.22	2.08 ± 0.28	0.4684
T4	2 ± 0	2.1 ± 0.4	0.0547
T5	2.05 ± 0.22	2.05 ± 0.22	1
T6	2.02 ± 0.13	2.05 ± 0.22	0.3132
T7	2.08 ± 0.28	2.05 ± 0.22	0.4684
T8	2.15 ± 0.36	2.07 ± 0.25	0.1443
T9	2.18 ± 0.39	2.18 ± 0.39	1
T10	2.73 ± 0.45	2.82 ± 0.39	0.2782
T11	3.1 ± 0.3	3.28 ± 0.49	0.0151
T12	3.32 ± 0.5	3.53 ± 0.57	0.0288
L1	4.48 ± 0.5	4.67 ± 0.48	0.0426
L2	4.53 ± 0.5	4.75 ± 0.47	0.0167
L3	4.78 ± 0.45	4.77 ± 0.46	0.8429
L4	4.75 ± 0.44	4.8 ± 0.4	0.516
L5	4.88 ± 0.37	4.83 ± 0.49	0.5319

4.2.5 Chord length

The mean chord length was found to gradually increase from vertebral levels T1 to T12 in thoracic spine (Fig. 4.2E). The largest mean length was seen at vertebral level T12 in both males (51.41 mm ±3.01) and females (47.18 mm ±2.59) and the least was at vertebral level T1 in both males (32.87 mm ±1.84) and females (29.92 mm ±1.65) (Table 4.16). In the lumbar spine, the mean chord length slightly increased from vertebral levels L1 to L3 and then marginally decreased from vertebral levels L4 to L5 (Fig. 4.2E). The largest mean length was seen at vertebral level L3 in both males (53.2 mm ±2.31) and females (49.56 mm ±2.47) and the least was at vertebral level L5 in both males (51.92 mm ±2.76) and females (48.35 mm ±2.97) (Table 4.16).

In all the vertebra levels the mean chord length in males was larger than in females and these differences were statistically significant ($p \leq 0.05$) (Table 4.16). Similarly, the mean chord length in the older (51 to 65 years) age group was slightly larger than in the younger age (20 to 50 years) group with statistically significant differences being observed at vertebral levels T2 and T6 ($p \leq 0.05$) (Table 4.13). No significant differences were seen between the right and left sides ($p \geq 0.05$)

Table 4.13: Comparison of chord length between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the European population.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	31.19 ± 1.96	31.59 ± 2.57	0.3362
T2	33.14 ± 2.54	34.06 ± 2.61	0.0512
T3	36.33 ± 2.65	37.11 ± 2.77	0.1178
T4	39.73 ± 3.06	40.33 ± 3.15	0.2914
T5	42.21 ± 2.87	42.94 ± 3.26	0.1927
T6	43.64 ± 3.12	44.84 ± 3.18	0.0389
T7	45.4 ± 3.25	46.49 ± 3.46	0.0785
T8	46.57 ± 3.43	47.66 ± 3.47	0.0881
T9	47.49 ± 3.53	48.67 ± 3.57	0.0724
T10	47.55 ± 3.44	48.24 ± 3.44	0.2747
T11	47.83 ± 3.36	48.3 ± 3.48	0.4561
T12	49.31 ± 3.4	49.28 ± 3.65	0.9582
L1	50.77 ± 3.37	50.82 ± 3.39	0.9354
L2	51.1 ± 3.18	51.01 ± 3.32	0.8723
L3	51.1 ± 2.85	51.66 ± 3.14	0.3135
L4	50.8 ± 2.6	50.97 ± 3.53	0.7682
L5	50.38 ± 2.97	49.89 ± 3.74	0.426

4.2.6 Inter-pedicular distance

The mean inter-pedicular distance was found to gradually decrease from vertebral levels T1 to T6 and then gradually increased from vertebral levels T7 to T12 in the thoracic spine (Fig. 4.2F). The largest mean distance was seen at vertebral level T1 in both males (20.79 mm ±3.76) and females (21.21 mm ±1.36) and the least was at vertebral level T6 in both males (16.33 mm ±1.58) and females (15.69 mm ±1.35) (Table 4.16). In the lumbar spine, the mean inter-pedicular distance gradually increased from vertebral levels L1 to L5 (Fig. 4.2F). The largest mean distance was seen at vertebral level L5 in both males (26.49 mm ±2.45) and females (25.91 mm ±3.1) and the least was at vertebral level L1 in both males (23.07 mm ±1.65) and females (22.33 mm ±1.86) (Table 4.16).

At vertebral level T4, the mean inter-pedicular distance was larger in males than in females and the differences were statistically significant ($p \leq 0.05$) (Table 4.16). No statistically significant difference between the mean inter-pedicular distance in the older and younger age groups was observed ($p \geq 0.05$) (Table 4.14).

Table 4.14: Comparison of inter-pedicular distance between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the European population.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	21.61 ± 1.29	20.39 ± 3.69	0.0925
T2	18.15 ± 1.28	17.98 ± 1.29	0.6255
T3	16.71 ± 1.37	16.92 ± 1.37	0.5623
T4	16.08 ± 1.33	16.41 ± 1.49	0.3834
T5	15.81 ± 1.32	16.26 ± 1.55	0.2354
T6	15.71 ± 1.44	16.31 ± 1.51	0.1222
T7	15.85 ± 1.45	16.47 ± 1.61	0.1193
T8	16.06 ± 1.3	16.68 ± 1.77	0.1244
T9	16.33 ± 1.54	16.95 ± 1.71	0.1456
T10	16.59 ± 1.38	17.16 ± 1.55	0.1415
T11	17.93 ± 1.42	18.48 ± 1.71	0.1797
T12	20.89 ± 1.91	21.61 ± 1.99	0.1621
L1	22.44 ± 1.76	22.96 ± 1.8	0.2688
L2	22.64 ± 1.67	23.1 ± 1.79	0.3095
L3	22.63 ± 1.45	23.26 ± 1.98	0.1653
L4	23.4 ± 1.91	23.73 ± 2.24	0.5432
L5	26.55 ± 2.42	25.85 ± 3.11	0.3288

Table 4.15: Comparison of pedicle width, pedicle height and transverse angle between males and females in the European Population.

Vertebral Levels	Pedicle Width (mm)		Pedicle Height (mm)		Transverse angle (deg)	
	M	F	M	F	M	F
T1	8.73 ± 1.19	7.53 ± 1.16***	9.86 ± 1.1	8.07 ± 1.14***	31.65 ± 2.5	31.7 ± 2.12
T2	6.72 ± 1.22	5.72 ± 1.27***	12.55 ± 0.94	10.65 ± 0.98***	26.58 ± 1.74	26.57 ± 1.63
T3	5.14 ± 1.16	4.52 ± 0.9**	13.04 ± 1.04	11.03 ± 1.01***	22.57 ± 1.75	22.25 ± 1.73
T4	4.28 ± 1.02	3.83 ± 0.78*	12.7 ± 1.05	10.9 ± 1.11***	19.47 ± 1.1	19.57 ± 1.08
T5	4.26 ± 1.05	3.63 ± 0.85***	12.56 ± 0.91	10.72 ± 0.96***	18.13 ± 1.17	18.12 ± 1.3
T6	4.53 ± 1.19	3.86 ± 0.93**	12.56 ± 0.96	10.75 ± 1.02***	17.18 ± 1.17	17.05 ± 1.14
T7	4.89 ± 1.26	4.07 ± 0.99***	12.78 ± 0.92	10.85 ± 0.86***	16.63 ± 1.39	16.35 ± 1.25
T8	5.19 ± 1.28	4.31 ± 1.09***	13.12 ± 0.72	11.46 ± 1.02***	15.75 ± 1.19	15.82 ± 1.28
T9	5.59 ± 1.25	4.47 ± 1.22***	13.86 ± 0.98	12.16 ± 0.95***	16.48 ± 1.21	16.1 ± 1.3
T10	6.28 ± 1.68	5.06 ± 1.35***	15.93 ± 1.25	14.25 ± 0.97***	17.45 ± 1.13	17.2 ± 1.5
T11	7.6 ± 1.8	6.65 ± 1.39**	17.67 ± 1.17	15.91 ± 1.09***	18.3 ± 1.03	18.23 ± 1.37
T12	7.9 ± 1.62	6.97 ± 1.53**	17.94 ± 1.03	16.05 ± 1.25***	19.1 ± 1.07	18.88 ± 1.28
L1	7.47 ± 1.52	6.23 ± 1.63***	16.55 ± 1.27	14.81 ± 1.29***	20.27 ± 0.94	20.22 ± 1.11
L2	8.04 ± 1.54	6.25 ± 1.58***	15.75 ± 1.49	14.31 ± 1.28***	21.18 ± 1.17	20.45 ± 1***
L3	9.85 ± 1.82	7.69 ± 1.88***	15.23 ± 1.44	13.91 ± 1.42***	22.68 ± 1.73	21.72 ± 1.24**
L4	11.42 ± 1.59	9.29 ± 1.89***	14.75 ± 1.77	13.39 ± 1.51***	25.05 ± 1.93	23.83 ± 1.81**
L5	16.52 ± 1.93	14.38 ± 2.4***	13.13 ± 1.29	12.07 ± 2.19**	31.05 ± 2.26	30.32 ± 3.12

*P<0.05; **P<0.005; ***P<0.0005

Table 4.16: Comparison of sagittal angle, chord length and inter-pedicular distance between males and females in the European Population.

	Sagittal angle (deg)		Chord length (mm)		Inter-pedicular distance (mm)	
Vertebral Levels	**M**	**F**	**M**	**F**	**M**	**F**
T1	3.08 ± 0.62	3.02 ± 0.65	32.87 ± 1.84	29.92 ± 1.65***	20.79 ± 3.76	21.21 ± 1.36
T2	2.23 ± 0.46	2.38 ± 0.52	35.34 ± 1.9	31.86 ± 1.98***	18.37 ± 1.31	17.76 ± 1.19
T3	2.07 ± 0.25	2.1 ± 0.3	38.47 ± 2.2	34.96 ± 1.98***	17.27 ± 1.31	16.36 ± 1.28
T4	2.07 ± 0.36	2.07 ± 0.25	42.14 ± 2.44	37.92 ± 2.1***	16.63 ± 1.45	15.86 ± 1.29*
T5	2.07 ± 0.25	2.03 ± 0.18	44.5 ± 2.39	40.65 ± 2.42***	16.37 ± 1.55	15.71 ± 1.28
T6	2.03 ± 0.18	2.03 ± 0.18	46.35 ± 2.34	42.12 ± 2.45***	16.33 ± 1.58	15.69 ± 1.35
T7	2.03 ± 0.18	2.03 ± 0.18	48.18 ± 2.57	43.72 ± 2.54***	16.4 ± 1.7	15.92 ± 1.38
T8	2.08 ± 0.28	2.13 ± 0.34	49.26 ± 2.54	44.97 ± 2.93***	16.58 ± 1.57	16.17 ± 1.57
T9	2.17 ± 0.38	2.2 ± 0.4	50.17 ± 2.63	45.99 ± 3.19***	16.91 ± 1.76	16.37 ± 1.5
T10	2.78 ± 0.42	2.77 ± 0.43	49.9 ± 2.6	45.89 ± 2.99***	17.02 ± 1.56	16.73 ± 1.41
T11	3.23 ± 0.46	3.15 ± 0.36	50.23 ± 2.53	45.9 ± 2.76***	18.36 ± 1.79	18.04 ± 1.36
T12	3.45 ± 0.53	3.4 ± 0.56	51.41 ± 3.01	47.18 ± 2.59***	21.55 ± 2.24	20.95 ± 1.64
L1	4.68 ± 0.47	4.47 ± 0.5*	52.8 ± 2.75	48.78 ± 2.67***	23.07 ± 1.65	22.33 ± 1.86
L2	4.77 ± 0.46	4.52 ± 0.5*	53.03 ± 2.45	49.07 ± 2.68***	23.13 ± 1.34	22.62 ± 2.05
L3	4.92 ± 0.38	4.63 ± 0.49***	53.2 ± 2.31	49.56 ± 2.47***	23.05 ± 1.3	22.84 ± 2.13
L4	4.9 ± 0.3	4.65 ± 0.48**	52.61 ± 2.5	49.17 ± 2.63***	23.55 ± 1.85	23.57 ± 2.3
L5	4.98 ± 0.29	4.73 ± 0.52**	51.92 ± 2.76	48.35 ± 2.97***	26.49 ± 2.45	25.91 ± 3.1

*P<0.05; **P<0.005; ***P<0.0005

4.3 EXTERNAL MEASUREMENTS IN MIXED ANCESTRY POPULATION

4.3.1 Pedicle width

The mean pedicle width was found to sharply decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.3A). The largest mean width was seen at vertebral level T1 in both males (8.27 mm ±1.11) and females (7.3 mm ±0.99) and the least was at vertebral level T5 in both males (3.74 mm ±0.88) and females (3.17 mm ±0.82) (Table 4.23). In the lumbar spine, pedicle width gradually increased from vertebral level L1 to L4 and then abruptly at vertebral level L5 (Fig. 4.3A). The largest mean width was seen at vertebral level L5 in both males (15.71 mm ±1.9) and females (14.85 mm ±1.81) and the least was at vertebral level L1 in both males (7.9 mm ±1.65) and females (7.02 mm ±1.33) (Table 4.23).

In almost all the vertebral levels, the mean pedicle width in males was larger than in females and the difference was statistically significant ($p \leq 0.05$) except at vertebral levels T6, T10 and T12 (Table 4.23). Similarly, the mean pedicle widths in the older age (51 to 65 years) group were larger than in the younger (20 to 50 years) age group with statistically significant differences ($p \leq 0.05$) being observed from vertebral levels T2 to L5 (Table 4.17). No statistically significant differences were seen between the right and left sides in all the vertebral levels ($p \geq 0.05$).

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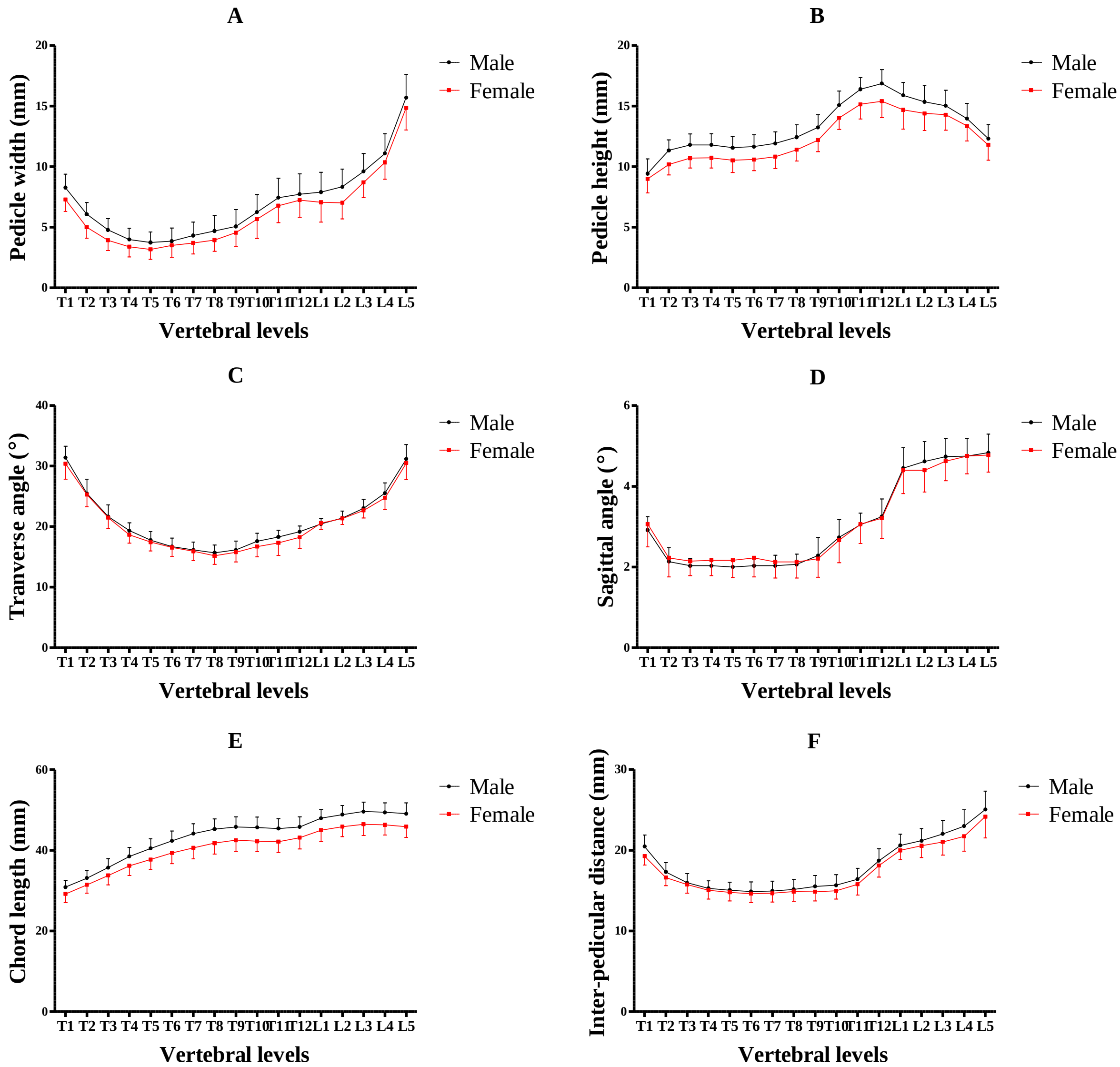


Figure 4.3. Graphs showing the relationship between pedicle width (**A**), pedicle height (**B**), transverse angle (**C**) and sagittal angle (**D**), chord length (**E**) and inter-pedicular distance (**F**) and the vertebral levels in both males and females of the Mixed ancestry.

Table 4.17: Comparison of pedicle width between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the Mixed ancestry.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	7.7 ± 1.12	8.02 ± 1.2	0.1548
T2	5.35 ± 1.12	5.92 ± 0.95	0.0059
T3	4.19 ± 0.97	4.68 ± 0.94	0.0092
T4	3.45 ± 0.79	4.08 ± 1	0.0005
T5	3.27 ± 0.87	3.76 ± 0.86	0.0039
T6	3.4 ± 0.92	4.07 ± 1.07	0.0007
T7	3.7 ± 0.86	4.47 ± 1.15	0.0001
T8	3.97 ± 0.98	4.84 ± 1.26	0.0001
T9	4.46 ± 1.19	5.31 ± 1.27	0.0005
T10	5.42 ± 1.36	6.7 ± 1.47	<0.0001
T11	6.61 ± 1.34	7.84 ± 1.53	<0.0001
T12	7.08 ± 1.34	8.08 ± 1.69	0.0008
L1	7.08 ± 1.61	8.08 ± 1.62	0.0019
L2	7.42 ± 1.54	8.17 ± 1.49	0.013
L3	8.84 ± 1.37	9.67 ± 1.43	0.0028
L4	10.49 ± 1.51	11.11 ± 1.57	0.0394
L5	14.75 ± 1.88	16.04 ± 1.69	0.0003

4.3.2 Pedicle height

The mean pedicle height was found to gradually increase from vertebral levels T1 to T12 in the thoracic spine (Fig. 4.3B). The largest mean pedicle height was seen at vertebral level T12 in both males (16.88 mm ±1.15) and females (15.41 mm ±1.35) and the least was at vertebral level T1 in both males (9.43 mm ±1.22) and females (8.99 mm ±1.14) (Table 23). In the lumbar spine, the mean pedicle heights gradually decreased from vertebral levels L1 to L5 (Fig. 4.3B). The largest mean height was seen at vertebral level L1 in both males (15.89 mm ±1.05) and females (14.7 mm ±1.59) and the least was at vertebral level L5 in both males (12.32 mm ±1.15) and females (11.81 mm ±1.26) (Table 4.23).

In almost all the vertebral levels, the mean height in males was larger than in females and the differences were statistically significant ($p \leq 0.05$) except at vertebral level T1 (Table 4.23). Similarly, the mean pedicle height in the older (51 to 65 years) age group was larger than in the younger (20 to 50 years) age group with statistically significant differences ($p \leq 0.05$) being observed at vertebral levels T1, T2, T3, T4, T8, T10 and L1 (Table 4.18). There were no significant differences between the right and left sides in all the vertebral levels ($p \leq 0.05$).

Table 4.18: Comparison of pedicle height between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the Mixed ancestry.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	8.92 ± 1.06	9.63 ± 1.26	0.002
T2	10.58 ± 1.01	11.14 ± 1.01	0.005
T3	11.08 ± 0.95	11.61 ± 1.03	0.0066
T4	11.11 ± 0.86	11.59 ± 1.18	0.0185
T5	10.97 ± 1.03	11.29 ± 1.15	0.1317
T6	10.93 ± 0.96	11.52 ± 1.16	0.0047
T7	11.3 ± 0.98	11.61 ± 1.24	0.1524
T8	11.79 ± 0.98	12.22 ± 1.21	0.0444
T9	12.62 ± 1.2	12.98 ± 1.01	0.1062
T10	14.4 ± 1.19	14.89 ± 1.15	0.032
T11	15.71 ± 1.25	16.01 ± 1.22	0.2124
T12	16.12 ± 1.39	16.35 ± 1.5	0.4022
L1	15.08 ± 1.28	15.71 ± 1.57	0.0223
L2	14.73 ± 1.2	15.18 ± 1.72	0.1114
L3	14.53 ± 1.28	14.91 ± 1.36	0.1333
L4	13.56 ± 1.31	13.89 ± 1.2	0.1851
L5	12 ± 1.11	12.21 ± 1.36	0.3752

4.3.3 Transverse angle

The mean transverse angle was found to rapidly decrease from vertebral levels T1 to T8 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.3C). The largest mean transverse angle was seen at vertebral level T1 in both males (31.38º ±1.92) and females (30.4º ±2.53) and the least was at vertebral level T8 in both males (15.68º ±1.31) and females (15.17º ±1.36) (Table 23). In the lumbar spine, the mean transverse angle increased gradually from vertebral levels L1 to L5 (Fig. 4.3C). The largest mean angle was seen at vertebral level L5 in both males (31.17º ±2.41) and females (30.52º ±2.75) and the least was at vertebral level L1 in both males (20.43º ±0.91) and females (20.63º ±1.08) (Table 4.23).

The mean transverse angle at vertebral levels T1, T4, T8, T10, T11 and L4 in males was larger than in females and the differences were statistically significant ($p \leq 0.05$) (Table 4.23). There were no significant differences between the mean transverse angle in the younger (20 to 50 years) and older age (51 to 65 years) groups (Table 4.19), and between right and left sides at all the vertebral levels ($p \geq 0.05$).

Table 4.19: Comparison of transverse angle between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the Mixed ancestry.

Vertebral Levels	**20-50yrs Mean ±SD (deg)**	**51-65yrs Mean ±SD (deg)**	**P-value**
T1	31.27 ± 2.18	30.54 ± 2.32	0.0975
T2	25.3 ± 2.34	25.5 ± 2.05	0.6421
T3	21.65 ± 1.83	21.5 ± 1.92	0.6799
T4	19 ± 1.38	19.08 ± 1.38	0.7557
T5	17.65 ± 1.4	17.56 ± 1.46	0.7519
T6	16.73 ± 1.34	16.5 ± 1.52	0.398
T7	16.1 ± 1.32	15.98 ± 1.48	0.6557
T8	15.48 ± 1.42	15.42 ± 1.27	0.7999
T9	16.1 ± 1.51	15.83 ± 1.55	0.3701
T10	17.05 ± 1.57	17.38 ± 1.54	0.2827
T11	17.83 ± 1.68	17.92 ± 1.67	0.7979
T12	18.73 ± 1.55	18.79 ± 1.41	0.8403
L1	20.32 ± 0.85	20.77 ± 1.1	0.0172
L2	21.38 ± 1.12	21.44 ± 1.07	0.7996
L3	22.8 ± 1.44	22.96 ± 1.34	0.5583
L4	24.95 ± 2	25.46 ± 1.6	0.1543
L5	30.35 ± 2.86	31.54 ± 2.01	0.0161

4.3.4 Sagittal angle

The mean sagittal angle was found to marginally increase from vertebral levels T1 to T7 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.3D). The largest mean angle was seen at vertebral level T12 in both males (3.25º ±0.44) and females (3.21º ±0.5) and the least was at vertebral level T7 in both males (2.03º ±0.26) and females (2.13º ±0.39) (Table 4.24). In the lumbar spine, the mean sagittal angles gradually increased from vertebral levels L1 to L5 (Fig. 4.3D). The largest mean sagittal angle was seen at L5 in both males (4.83º ±0.46) and females (4.77º ±0.42) and the least was at L1 in both males (4.45º ±0.5) and females (4.4º ±0.57) (Table 4.24).

At vertebral levels T3, T4, T5, T6 and L2, the mean sagittal angle in males was larger than in females and the differences were statistically significant ($p \leq 0.05$) (Table 4.24). But no significant difference was seen between the mean sagittal angle in the older age (51 to 65 years) group and younger age (20 to 50 years) group (Table 4.20) and between the right and left sides in all the vertebral levels ($p \geq 0.05$).

Table 4.20: Comparison of sagittal angle between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the Mixed ancestry.

Vertebral Levels	20-50yrs Mean ±SD (deg)	51-65yrs Mean ±SD (deg)	P-value
T1	2.97 ± 0.49	3 ± 0.41	0.7059
T2	2.22 ± 0.45	2.13 ± 0.33	0.2457
T3	2.03 ± 0.18	2.15 ± 0.36	0.0358
T4	2.07 ± 0.25	2.13 ± 0.33	0.3031
T5	2.03 ± 0.26	2.13 ± 0.33	0.1108
T6	2.13 ± 0.39	2.1 ± 0.31	0.6728
T7	2.05 ± 0.34	2.1 ± 0.31	0.3941
T8	2.07 ± 0.31	2.13 ± 0.33	0.3515
T9	2.22 ± 0.45	2.29 ± 0.46	0.3982
T10	2.62 ± 0.49	2.81 ± 0.49	0.0417
T11	3.02 ± 0.34	3.1 ± 0.42	0.2394
T12	3.18 ± 0.39	3.29 ± 0.54	0.2314
L1	4.35 ± 0.48	4.52 ± 0.58	0.0981
L2	4.47 ± 0.54	4.58 ± 0.5	0.2487
L3	4.7 ± 0.46	4.67 ± 0.48	0.714
L4	4.77 ± 0.43	4.73 ± 0.45	0.6583
L5	4.87 ± 0.43	4.73 ± 0.45	0.1086

4.3.5 Chord length

The mean chord length was found to gradually increase from vertebral levels T1 to T12 in thoracic spine (Fig. 4.3E). The largest mean length was seen at vertebral level T12 in both males (45.82 mm ±2.5) and females (43.14 mm ±2.8) and the least was at vertebral level T1 in both males (30.9 mm ±1.64) and females (29.2 mm ±2.11) (Table 4.24). In the lumbar spine, the mean chord length gradually increased from vertebral levels L1 to L3 and then marginally decreased from vertebral levels L4 to L5 (Fig. 4.3E). The largest length was seen at vertebral level L3 in both males (49.6 mm ±2.37) and females (46.44 mm ±2.77), the least was at vertebral level L1 in both males (47.96 mm ±2.15) and females (45 mm ±2.83) (Table 4.24).

The mean chord length in males was larger than in females and the difference was statistically significant at all the vertebral levels ($p \leq 0.05$) (Table 4.24). Similarly, the mean length in the older age (51 to 65 years) group was larger than in the younger age (20 to 50 years) group with significant differences being observed in all the vertebral levels ($p \leq 0.05$) (Table 4.21). However, no significant differences were seen between the right and left sides ($p \geq 0.05$).

Table 4.21: Comparison of chord length between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the Mixed ancestry.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	29.8 ± 1.91	30.58 ± 2.14	0.0474
T2	31.99 ± 2.17	32.86 ± 2.03	0.0347
T3	34.15 ± 2.41	35.78 ± 2.27	0.0005
T4	36.83 ± 2.65	38.18 ± 2.34	0.0068
T5	38.6 ± 2.84	40.06 ± 2.44	0.0058
T6	40.18 ± 2.79	42.06 ± 2.77	0.0007
T7	41.9 ± 3.08	43.43 ± 2.97	0.0106
T8	43.06 ± 3.01	44.58 ± 3.06	0.011
T9	43.69 ± 2.98	45.14 ± 3.05	0.0145
T10	43.54 ± 3.04	44.88 ± 3.03	0.024
T11	43.37 ± 3.07	44.69 ± 2.85	0.0238
T12	43.8 ± 2.89	45.66 ± 2.67	0.0008
L1	46.01 ± 2.76	47.45 ± 2.83	0.009
L2	46.79 ± 2.67	48.39 ± 2.68	0.0026
L3	47.59 ± 2.91	48.96 ± 2.96	0.0174
L4	47.38 ± 2.67	48.85 ± 2.91	0.0076
L5	46.85 ± 2.93	48.7 ± 3.13	0.0021

4.3.6 Inter-pedicular distance

The mean inter-pedicular distance was found to gradually decrease from vertebral levels T1 to T6 and then gradually increased from vertebral levels T7 to T12 in the thoracic spine (Fig. 4.3F). The largest mean distance was seen at vertebral level T1 in both males (20.47 mm ±1.4) and females (19.28 mm ±1.12) and the least was at vertebral level T6 in both males (14.88 mm ±1.19) and females (14.61 mm ±1.1) (Table 4.24). In the lumbar spine, the mean inter-pedicular distance gradually increased from vertebral levels L1 to L5 (Fig. 4.3F). The largest mean inter-pedicular distance was seen at vertebral level L5 in both males (25.04 mm ±2.27) and females (24.16 mm ±2.62) and the least was at vertebral level L1 in both males (20.6 mm ±1.4) and females (19.98 mm ±1.15) (Table 4.24).

At vertebral levels T1 and T2, the mean distance in males was larger than in females and the differences were statistically significant ($p \leq 0.05$) (Table 4.24). Similarly, the mean distance in the older age (51 to 65 years) group was larger than in the younger age (20 to 50 years) group with statistically significant differences being observed from vertebral levels T10 to T12 ($p \leq 0.05$) (Table 4.22).

Table 4.22: Comparison of inter-pedicular distance between older (51-65 yrs.) and younger (20-50 yrs.) age groups in the Mixed ancestry.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	19.95 ± 1.22	19.93 ± 1.66	0.9721
T2	17.01 ± 1.18	17.02 ± 1.09	0.9951
T3	15.85 ± 1.16	15.9 ± 1.08	0.8707
T4	15.08 ± 1.13	15.3 ± 0.85	0.4315
T5	14.83 ± 1.07	15.07 ± 0.97	0.3989
T6	14.62 ± 1.11	14.95 ± 1.19	0.3012
T7	14.66 ± 1.09	15.03 ± 1.24	0.2526
T8	14.77 ± 1.01	15.38 ± 1.38	0.0637
T9	14.94 ± 0.98	15.58 ± 1.55	0.0707
T10	15.04 ± 0.97	15.75 ± 1.41	0.0341
T11	15.81 ± 1.11	16.55 ± 1.55	0.0486
T12	18.06 ± 1.35	18.92 ± 1.54	0.0334
L1	20.09 ± 0.98	20.63 ± 1.63	0.1383
L2	20.66 ± 1.34	21.19 ± 1.66	0.1987
L3	21.22 ± 1.47	22.04 ± 1.89	0.0801
L4	22.07 ± 1.9	22.89 ± 2.1	0.1394
L5	24.26 ± 2.48	25.14 ± 2.37	0.194

Table 4.23: Comparison of mean pedicle width, pedicle height and transverse angle between males and females in the Mixed ancestry.

	Pedicle Width (mm)		**Pedicle Height (mm)**		**Transverse angle (deg)**	
Vertebral Levels	**M**	**F**	**M**	**F**	**M**	**F**
T1	8.27 ± 1.11	7.3 ± 0.99***	9.43 ± 1.22	8.99 ± 1.14	31.38 ± 1.92	30.4 ± 2.53*
T2	6.09 ± 0.97	5.01 ± 0.9***	11.34 ± 0.87	10.2 ± 0.88***	25.47 ± 2.36	25.29 ± 2.02
T3	4.78 ± 0.93	3.93 ± 0.85***	11.8 ± 0.9	10.71 ± 0.81***	21.67 ± 1.95	21.48 ± 1.77
T4	3.99 ± 0.93	3.41 ± 0.85**	11.79 ± 0.94	10.74 ± 0.85***	19.33 ± 1.31	18.67 ± 1.37*
T5	3.74 ± 0.88	3.17 ± 0.82**	11.57 ± 0.94	10.54 ± 1.01***	17.75 ± 1.41	17.44 ± 1.43
T6	3.85 ± 1.08	3.5 ± 0.98	11.66 ± 0.98	10.6 ± 0.92***	16.7 ± 1.43	16.54 ± 1.41
T7	4.31 ± 1.12	3.71 ± 0.91**	11.93 ± 0.96	10.83 ± 0.99***	16.15 ± 1.27	15.92 ± 1.53
T8	4.7 ± 1.28	3.94 ± 0.91***	12.44 ± 1.02	11.41 ± 0.93***	15.68 ± 1.31	15.17 ± 1.36*
T9	5.06 ± 1.39	4.56 ± 1.12*	13.25 ± 1.04	12.2 ± 0.94***	16.15 ± 1.47	15.77 ± 1.59
T10	6.24 ± 1.47	5.67 ± 1.59	15.09 ± 1.15	14.04 ± 0.96***	17.58 ± 1.33	16.71 ± 1.69**
T11	7.45 ± 1.61	6.78 ± 1.4*	16.4 ± 0.96	15.16 ± 1.21***	18.3 ± 1.08	17.33 ± 2.09**
T12	7.74 ± 1.66	7.25 ± 1.44	16.88 ± 1.15	15.41 ± 1.35***	19.17 ± 0.92	18.25 ± 1.86
L1	7.9 ± 1.65	7.02 ± 1.33**	15.89 ± 1.05	14.7 ± 1.59***	20.43 ± 0.91	20.63 ± 1.08
L2	8.34 ± 1.48	7.06 ± 1.63***	15.35 ± 1.38	14.41 ± 1.41**	21.43 ± 1.17	21.38 ± 1
L3	9.62 ± 1.48	8.7 ± 1.25**	15.03 ± 1.29	14.29 ± 1.27**	23.03 ± 1.48	22.67 ± 1.24
L4	11.1 ± 1.62	10.36 ± 1.38*	13.98 ± 1.24	13.36 ± 1.22*	25.52 ± 1.7	24.75 ± 1.93*
L5	15.71 ± 1.9	14.85 ± 1.81*	12.32 ± 1.15	11.81 ± 1.26*	31.17 ± 2.41	30.52 ± 2.75

*P<0.05; **P<0.005; ***P<0.0005

Table 4.24: Comparison of mean sagittal angle, chord length and inter-pedicular distance between males and females in the Mixed ancestry.

	Sagittal angle (deg)		Chord length (mm)		Interpeduncular distance (mm)	
Vertebral Levels	**M**	**F**	**M**	**F**	**M**	**F**
T1	2.92 ± 0.33	3.06 ± 0.56	30.9 ± 1.64	29.2 ± 2.11***	20.47 ± 1.42	19.28 ± 1.12**
T2	2.13 ± 0.34	2.23 ± 0.47	33.1 ± 1.92	31.47 ± 2.08***	17.32 ± 1.15	16.63 ± 1*
T3	2.03 ± 0.18	2.15 ± 0.36	35.74 ± 2.22	33.79 ± 2.35***	15.97 ± 1.15	15.76 ± 1.09
T4	2.03 ± 0.18	2.17 ± 0.38	38.46 ± 2.27	36.14 ± 2.41***	15.28 ± 0.94	15.06 ± 1.11
T5	2.07 ± 0.25	2.17 ± 0.43	40.46 ± 2.37	37.74 ± 2.45***	15.06 ± 1	14.78 ± 1.06
T6	2.03 ± 0.18	2.23 ± 0.47	42.35 ± 2.41	39.34 ± 2.65***	14.88 ± 1.19	14.61 ± 1.1
T7	2.03 ± 0.26	2.13 ± 0.39	44.14 ± 2.48	40.63 ± 2.72***	14.95 ± 1.23	14.67 ± 1.08
T8	2.07 ± 0.25	2.13 ± 0.39	45.28 ± 2.5	41.79 ± 2.7***	15.17 ± 1.24	14.88 ± 1.19
T9	2.28 ± 0.45	2.21 ± 0.46	45.81 ± 2.47	42.49 ± 2.73***	15.51 ± 1.35	14.87 ± 1.15
T10	2.73 ± 0.45	2.67 ± 0.56	45.65 ± 2.6	42.24 ± 2.6***	15.67 ± 1.3	14.96 ± 1.01
T11	3.05 ± 0.29	3.06 ± 0.48	45.38 ± 2.49	42.17 ± 2.71***	16.42 ± 1.36	15.79 ± 1.32*
T12	3.25 ± 0.44	3.21 ± 0.5	45.82 ± 2.5	43.14 ± 2.8***	18.71 ± 1.5	18.11 ± 1.44
L1	4.45 ± 0.5	4.4 ± 0.57	47.96 ± 2.15	45 ± 2.83***	20.6 ± 1.4	19.98 ± 1.15
L2	4.62 ± 0.49	4.4 ± 0.54	48.84 ± 2.25	45.84 ± 2.48***	21.17 ± 1.51	20.55 ± 1.44*
L3	4.73 ± 0.45	4.63 ± 0.49	49.6 ± 2.37	46.44 ± 2.77***	22.03 ± 1.64	21.03 ± 1.64*
L4	4.75 ± 0.44	4.75 ± 0.44	49.42 ± 2.35	46.3 ± 2.48***	23 ± 2.01	21.73 ± 1.83
L5	4.83 ± 0.46	4.77 ± 0.42	49.09 ± 2.71	45.9 ± 2.74***	25.04 ± 2.27	24.16 ± 2.62

*P<0.05; **P<0.005; ***P<0.0005

4.4 COMPARISON OF EXTERNAL PEDICULAR MEASUREMENTS IN AFRICAN, EUROPEAN AND MIXED ANCESTRY POPULATION OF SOUTH AFRICAN

4.4.1 Pedicle width

In all the populations, the mean pedicle width was found to gradually decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.4A). In the lumbar spine, the mean pedicle width gradually increased from vertebral levels L1 to L5 (Fig. 4.4A). There was a statistically significant difference in the mean pedicle width between the African, European and mixed ancestry populations from levels T1 to T8 ($p \leq 0.05$) in the thoracic spine and from vertebral levels L1 to L4 in the lumbar spine after conducting analysis of variance tests (Table 4.25). Bonferroni-corrected pairwise analysis revealed that the mean pedicle widths from vertebral levels T1 to T8 were significantly larger in European population than in the African and or Mixed ancestry populations in the thoracic spine ($p \leq 0.05$). In the lumbar vertebrae, the mean pedicle widths from vertebral levels L1 to L4 were significantly larger in African population than in the European population, and at vertebral levels L1 and L2 the mean pedicle width was significantly larger in Mixed ancestry population than in the European population ($p \leq 0.05$) (Table 4.26). In all the vertebral levels, no statistically significant differences were found between the mean pedicle width in the African and the Mixed ancestry population ($p \geq 0.05$)

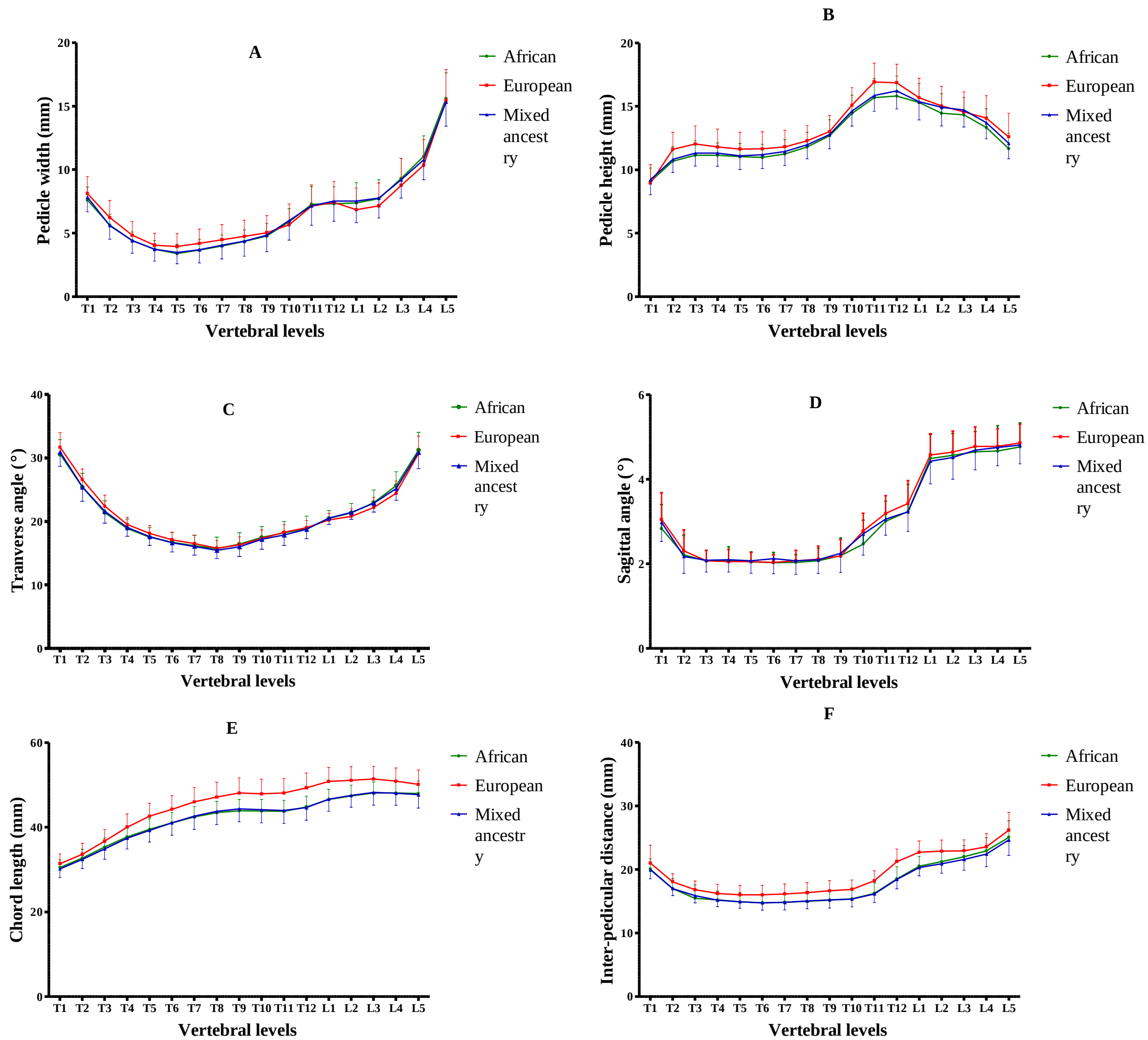


Figure 4.4. Graphs showing the relationship between pedicle width (**A**), pedicle height (**B**), transverse angle (**C**) and sagittal angle (**D**), chord length (**E**) and inter-pedicular distance (**F**) and vertebral levels in the three populations.

Table 4.25: The ANOVA table showing comparison of the mean pedicle width in the three population of South African.

Vertebral Levels	African Mean ±SD (mm)	European Mean ±SD (mm)	Mixed ancestry Mean ±SD (mm)	P-Value
T1	7.61 ± 1.02	8.13 ± 1.31	7.84 ± 1.16	0.0028
T2	5.63 ± 0.85	6.22 ± 1.34	5.61 ± 1.08	<0.0001
T3	4.41 ± 0.68	4.83 ± 1.08	4.41 ± 0.99	0.0004
T4	3.73 ± 0.69	4.06 ± 0.93	3.73 ± 0.94	0.004
T5	3.4 ± 0.72	3.95 ± 1	3.49 ± 0.9	<0.0001
T6	3.66 ± 0.87	4.2 ± 1.11	3.7 ± 1.04	<0.0001
T7	3.99 ± 0.88	4.48 ± 1.2	4.04 ± 1.07	0.0005
T8	4.34 ± 0.92	4.75 ± 1.27	4.36 ± 1.19	0.0083
T9	4.77 ± 1	5.03 ± 1.35	4.84 ± 1.3	0.234
T10	5.89 ± 1.06	5.67 ± 1.64	5.99 ± 1.54	0.2283
T11	7.27 ± 1.4	7.13 ± 1.67	7.16 ± 1.55	0.7355
T12	7.32 ± 1.34	7.43 ± 1.64	7.52 ± 1.58	0.603
L1	7.37 ± 1.61	6.85 ± 1.69	7.52 ± 1.68	0.0053
L2	7.72 ± 1.49	7.15 ± 1.8	7.75 ± 1.55	0.006
L3	9.31± 1.6	8.77 ± 2.14	9.21 ± 1.45	0.0429
L4	11.05 ± 1.62	10.35 ± 2.04	10.77 ± 1.56	0.0096
L5	15.61 ± 2.01	15.45± 2.42	15.33 ± 1.9	0.5945

Table 4.26: Pair wise (post hoc Bonferroni) comparison of the mean pedicle width among populations groups of South African.

Vertebral Levels	**European Vs African**	**European Vs Mixed ancestry**	**African Vs Mixed ancestry**
T1	0.002*	0.180	0.429
T2	<0.0001*	<0.0001*	1.000
T3	0.002*	0.002*	1.000
T4	0.012*	0.013*	1.000
T5	<0.0001*	<0.0001*	1.000
T6	<0.0001*	0.001*	1.000
T7	0.001*	0.006*	1.000
T8	0.017*	0.031*	1.000
T9	0.298	0.718	1.000
T10	0.741	0.283	1.000
T11	1.000	1.000	1.000
T12	1.000	1.000	0.951
L1	0.044*	0.007*	1.000
L2	0.019*	0.016*	1.000
L3	0.054*	0.178	1.000
L4	0.007*	0.228	0.703
L5	1.000	1.000	0.932

*Statistically significant values

4.4.2 Pedicle height

In all the three populations, the mean pedicle height was found to gradually increase from T1 to T12 in the thoracic spine whereas in the lumbar spine it gradually decreased from L1 to L5 (Fig. 4.4B). In almost all the vertebral levels, the mean pedicle height showed statistically significant differences ($p \leq 0.05$) between African, European and Mixed ancestry populations except at T1 and T9 in the thoracic spine and at L1 and L3 in the lumbar spine after conducting analysis of variance (Table 4.27). Bonferroni-corrected pairwise analysis showed that the mean pedicle height at vertebral levels T2 to T8 and T10 to T12 in the thoracic spine was significantly larger in European population than in African and or Mixed populations ($p \leq 0.05$). Similarly, in the lumbar spine, the mean pedicle height at vertebral levels L1, L4 and L5 was significantly larger in the European population than in African and or Mixed ancestry populations ($p \leq 0.05$) (Table 4.28). No significant differences were found between the mean pedicle height in the African and Mixed ancestry populations in all the vertebral levels.

Table 4.27: The ANOVA table showing comparison of the mean pedicle height in the three population of South African.

	African	**European**	**Mixed ancestry**	
Vertebral Level	**Mean ±SD (mm)**	**Mean ±SD (mm)**	**Mean ±SD (mm)**	**P-value**
T1	9.07 ± 1.06	8.96 ± 1.43	9.23 ± 1.2	0.2631
T2	10.68 ± 1.12	11.6 ± 1.35	10.83 ± 1.04	<0.0001
T3	11.16 ± 1.15	12.03 ± 1.44	11.31 ± 1.02	<0.0001
T4	11.15 ± 0.98	11.8 ± 1.4	11.32 ± 1.04	0.0001
T5	11.04 ± 1.04	11.64 ± 1.31	11.11 ± 1.09	0.0001
T6	10.97 ± 1.05	11.65 ± 1.34	11.19 ± 1.09	<0.0001
T7	11.25 ± 1.12	11.81 ± 1.31	11.44 ± 1.11	0.0012
T8	11.8 ± 1.15	12.29 ± 1.21	11.98 ± 1.1	0.0043
T9	12.69 ± 1.25	13.01 ± 1.28	12.78 ± 1.13	0.1168
T10	14.4 ± 1.44	15.09 ± 1.4	14.62 ± 1.19	0.0009
T11	15.69 ± 1.48	16.93 ± 1.47	15.85 ± 1.24	<0.0001
T12	15.81 ± 1.57	16.86 ± 1.45	16.22 ± 1.44	<0.0001
L1	15.31± 1.5	15.68 ± 1.55	15.36 ± 1.44	0.1191
L2	14.46 ± 1.54	15.03 ± 1.56	14.93 ± 1.46	0.0086
L3	14.33 ± 1.37	14.57 ± 1.57	14.7 ± 1.33	0.1425
L4	13.33 ± 1.48	14.07 ± 1.77	13.71 ± 1.26	0.001
L5	11.67 ± 1.22	12.6 ± 1.87	12.09 ± 1.22	<0.0001

Table 4.28: Pair wise (post hoc Bonferroni) comparison of the mean pedicle height among populations groups of South African.

Vertebral Levels	**European Vs African**	**European Vs Mixed ancestry**	**African Vs Mixed ancestry**
T1	1.000	0.311	0.985
T2	<0.0001*	<0.0001*	0.973
T3	<0.0001*	<0.0001*	0.980
T4	<0.0001*	0.007*	0.790
T5	<0.0001*	0.002*	1.000
T6	<0.0001*	0.009*	0.489
T7	0.001*	0.056	0.708
T8	0.003*	0.127	0.734
T9	0.131	0.487	1.000
T10	0.001*	0.028*	1.000
T11	<0.0001*	<0.0001*	1.000
T12	<0.0001*	0.004*	0.114
L1	0.164	0.337	1.000
L2	0.012*	1.000	0.056
L3	0.610	1.000	0.158
L4	0.001 *	0.217	0.199
L5	<0.0001*	0.030*	0.094

*Statistically significant values

4.4.3 Transverse angle

The mean transverse angle in all the populations was found to gradually decrease from vertebral levels T1 to T8 and then increased gradually to vertebral level T12 in the thoracic spine (Fig. 4.4C). In the lumbar spine, the mean transverse angle increased gradually from vertebral levels L1 to L5 (Fig. 4.4C). There were statistically significant differences ($p \leq 0.05$) in the mean transverse angle between African, European and Mixed ancestry populations from vertebral levels T1 to T6 in the thoracic spine and from vertebral levels L2 to L4 in the lumbar spine after conducting analysis of variance (Table 4.29). Bonferroni-corrected pairwise analysis showed that the mean transverse angle from vertebral levels T1 to T6 in the thoracic spine and vertebral levels L1 to L4 in the lumbar spine was significantly ($p \leq 0.05$) larger in European population than in African and or Mixed ancestry population (Table 4.30). No significant differences were found between the mean transverse angle in the African and Mixed ancestry populations in all the vertebral levels.

Table 4.29: The ANOVA table showing comparison of the mean transverse angle in the three population of South African.

Vertebral Level	African Mean ±SD (deg)	European Mean ±SD (deg)	Mixed Mean ±SD (deg)	P-Value
T1	30.57 ± 2.31	31.68 ± 2.31	30.94 ± 2.26	0.0008
T2	25.36 ± 2.2	26.58 ± 1.68	25.39 ± 2.21	<0.0001
T3	21.38 ± 1.87	22.41 ± 1.74	21.58 ± 1.87	<0.0001
T4	18.9 ± 1.48	19.52 ± 1.08	19.04 ± 1.37	0.0009
T5	17.5 ± 1.52	18.13 ± 1.23	17.61 ± 1.42	0.0013
T6	16.73 ± 1.53	17.12 ± 1.15	16.63 ± 1.42	0.0174
T7	16.17 ± 1.67	16.49 ± 1.32	16.05 ± 1.39	0.0595
T8	15.7 ± 1.81	15.78 ± 1.23	15.45 ± 1.35	0.2273
T9	16.4 ± 1.81	16.29 ± 1.27	15.98 ± 1.53	0.1121
T10	17.46 ± 1.7	17.33 ± 1.33	17.19 ± 1.56	0.4331
T11	18.21 ± 1.75	18.27 ± 1.21	17.87 ± 1.67	0.1222
T12	18.9 ± 1.93	18.99 ± 1.18	18.76 ± 1.48	0.5314
L1	20.48 ± 1.24	20.24 ± 1.02	20.52 ± 0.99	0.1153
L2	21.34 ± 1.46	20.82 ± 1.14	21.41 ± 1.09	0.0005
L3	22.96 ± 1.98	22.2 ± 1.58	22.87 ± 1.39	0.0008
L4	25.63 ± 2.22	24.44 ± 1.96	25.18 ± 1.84	<0.0001
L5	31.21 ± 2.8	30.68 ± 2.74	30.88 ± 2.57	0.3181

Table 4.30: Pair wise (post hoc Bonferroni) comparison of the mean transverse angle among populations groups of South African.

Vertebral Levels	European Vs African	European Vs Mixed ancestry	African Vs Mixed ancestry
T1	0.001*	0.050	0.645
T2	<0.0001*	<0.0001*	1.000
T3	<0.0001*	0.002*	1.000
T4	0.001*	0.020*	1.000
T5	0.002*	0.017*	1.000
T6	0.084	0.024*	1.000
T7	0.263	0.069	1.000
T8	1.000	0.288	0.639
T9	1.000	0.397	0.128
T10	1.000	1.000	0.589
T11	1.000	0.167	0.307
T12	1.000	0.790	1.000
L1	0.296	0.170	1.000
L2	0.004*	0.001*	1.000
L3	0.002*	0.008*	1.000
L4	<0.0001*	0.019*	0.282
L5	0.403	1.000	1.000

*Statistically significant values

4.4.4 Sagittal angle

In all the populations, the mean sagittal angle was found to marginally decrease from vertebral levels T1 to T7 and then increased to vertebral level T12 in the thoracic spine. In the lumbar spine the mean sagittal angle slightly increased from vertebral levels L1 to L5 (Fig. 4.4D). There were statistically significant differences ($p \leq 0.05$) in the mean sagittal angle between African, European and Mixed ancestry populations at vertebral levels T1, T6 and T10 to T12 in the thoracic spine after conducting analysis of variance (Table 4.31). Bonferroni-corrected pairwise analysis revealed that the mean sagittal angle at vertebral levels T1, and T10 to T12 was significantly ($p \leq 0.05$) larger in European population than in African and or Mixed ancestry populations but at vertebral level T6, the mean sagittal angle was significantly larger in the Mixed ancestry population than in European and or African population (Table 4.32). No significant differences were found between the mean sagittal angles in the African and Mixed ancestry populations ($p \geq 0.05$) in all the vertebral levels.

Table 4.31: The ANOVA table showing comparison of the mean sagittal angle in the three population of South African.

Vertebral Level	African Mean ±SD (deg)	European Mean ±SD (deg)	Mixed ancestry Mean ±SD (deg)	P-Value
T1	2.83 ± 0.57	3.05 ± 0.63	2.98 ± 0.45	0.0099
T2	2.21 ± 0.47	2.31 ± 0.5	2.18 ± 0.41	0.0749
T3	2.07 ± 0.25	2.07 ± 0.25	2.08 ± 0.28	0.8574
T4	2.07 ± 0.34	2.05 ± 0.29	2.09 ± 0.29	0.5735
T5	2.04 ± 0.24	2.05 ± 0.22	2.07 ± 0.3	0.6065
T6	2.03 ± 0.24	2.03 ± 0.18	2.12 ± 0.35	0.0125
T7	2.03 ± 0.18	2.07 ± 0.25	2.07 ± 0.33	0.4356
T8	2.08 ± 0.29	2.11 ± 0.31	2.09 ± 0.32	0.7057
T9	2.19 ± 0.42	2.18 ± 0.39	2.25 ± 0.46	0.4338
T10	2.47 ± 0.56	2.78 ± 0.42	2.7 ± 0.5	<0.0001
T11	3.01 ± 0.48	3.19 ± 0.42	3.06 ± 0.38	0.003
T12	3.23 ± 0.64	3.43 ± 0.54	3.23 ± 0.47	0.0101
L1	4.49 ± 0.57	4.58 ± 0.5	4.43 ± 0.53	0.1067
L2	4.57 ± 0.51	4.64 ± 0.5	4.52 ± 0.52	0.1854
L3	4.65 ± 0.48	4.78 ± 0.46	4.69 ± 0.47	0.105
L4	4.67 ± 0.6	4.78 ± 0.42	4.75 ± 0.44	0.2076
L5	4.77 ± 0.56	4.86 ± 0.44	4.81 ± 0.44	0.3402

Table 4.32: Pair wise (post hoc Bonferroni) comparison of the mean sagittal angle among populations groups of South African.

Vertebral Levels	**European Vs African**	**European Vs Mixed ancestry**	**African Vs Mixed ancestry**
T1	0.009*	1.000	0.141
T2	0.280	0.092	1.000
T3	1.000	1.000	1.000
T4	1.000	0.883	1.000
T5	1.000	1.000	0.998
T6	1.000	0.041*	0.021
T7	0.946	1.000	0.697
T8	1.000	1.000	1.000
T9	1.000	0.696	0.887
T10	<0.0001*	0.841	0.001
T11	0.003*	0.051*	1.000
T12	0.025*	0.029*	1.000
L1	0.678	0.106	1.000
L2	0.769	0.210	1.000
L3	0.118	0.446	1.000
L4	0.269	1.000	0.610
L5	0.431	1.000	1.000

*Statistically significant values

4.4.5 Chord length

The mean chord length was found to gradually increase from vertebral levels T1 to T12 in the thoracic spine while in the lumbar spine it gradually increased from vertebral levels L1 to L3 and then slightly decreased from level L4 to L5 in all the three populations (Fig. 4.4E). There were statistically significant ($p \leq 0.05$) differences in the mean chord lengths between African, European and Mixed ancestry populations in all the vertebral levels after conducting analysis of variance (Table 4.33) and Bonferroni-corrected pairwise analysis showed that the mean chord length in the European population was significantly ($p \leq 0.05$) larger than in the African and or Mixed ancestry population at all the vertebral levels (Table 4.34). No significant differences were found between the mean chord length in the African and Mixed ancestry populations ($p \geq 0.05$) in the vertebral levels

Table 4.33: The ANOVA table showing comparison of the mean chord length in the three population of South African.

	African	European	Mixed ancestry	
Vertebral Level	**Mean ±SD (mm)**	**Mean ±SD (mm)**	**Mean ±SD (mm)**	**P-Value**
T1	30.46 ± 1.84	31.39 ± 2.29	30.15 ± 2.04	<0.0001
T2	32.66 ± 2.1	33.6 ± 2.6	32.38 ± 2.15	0.0002
T3	35.31 ± 2.16	36.72 ± 2.73	34.87 ± 2.47	<0.0001
T4	37.7 ± 2.39	40.03 ± 3.1	37.43 ± 2.59	<0.0001
T5	39.49 ± 2.48	42.58 ± 3.08	39.25 ± 2.76	<0.0001
T6	40.98 ± 2.46	44.24 ± 3.19	41.01 ± 2.92	<0.0001
T7	42.4 ± 2.46	45.95 ± 3.39	42.58 ± 3.11	<0.0001
T8	43.42 ± 2.68	47.11 ± 3.48	43.73 ± 3.11	<0.0001
T9	43.89 ± 2.69	48.08 ± 3.59	44.34 ± 3.08	<0.0001
T10	43.82 ± 2.71	47.89 ± 3.44	44.14 ± 3.1	<0.0001
T11	43.74 ± 2.62	48.06 ± 3.42	43.95 ± 3.04	<0.0001
T12	44.79 ± 2.56	49.3± 3.51	44.62 ± 2.93	<0.0001
L1	46.55 ± 2.43	50.79 ± 3.37	46.65 ± 2.87	<0.0001
L2	47.37 ± 2.58	51.05 ± 3.24	47.5 ± 2.78	<0.0001
L3	48.09 ± 2.62	51.38 ± 3	48.19 ± 2.99	<0.0001
L4	48.05 ± 2.68	50.89 ± 3.09	48.03 ± 2.86	<0.0001
L5	47.94 ± 2.97	50.13 ± 3.37	47.67 ± 3.14	<0.0001

Table 4.34: Pair wise (post hoc Bonferroni) comparison of the mean chord length among populations groups of South African.

Vertebral Levels	**European Vs African**	**European Vs Mixed ancestry**	**African Vs Mixed ancestry**
T1	0.002*	<0.0001*	0.747
T2	0.005*	<0.0001*	1.000
T3	<0.0001*	<0.0001*	0.544
T4	<0.0001*	<0.0001*	1.000
T5	<0.0001*	<0.0001*	1.000
T6	<0.0001*	<0.0001*	1.000
T7	<0.0001*	<0.0001*	1.000
T8	<0.0001*	<0.0001*	1.000
T9	<0.0001*	<0.0001*	0.843
T10	<0.0001*	<0.0001*	1.000
T11	<0.0001*	<0.0001*	1.000
T12	<0.0001*	<0.0001*	1.000
L1	<0.0001*	<0.0001*	1.000
L2	<0.0001*	<0.0001*	1.000
L3	<0.0001*	<0.0001*	1.000
L4	<0.0001*	<0.0001*	1.000
L5	<0.0001*	<0.0001*	1.000

*Statistically significant values

4.4.6 Inter-pedicular distance

In all the three populations, the mean inter-pedicular distance was found to gradually decrease from vertebral levels T1 to T6 then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.4F). In the lumbar spine, the mean inter-pedicular distance gradually increased from vertebral levels L1 to L5 (Fig. 4.4F). There were statistically significant differences ($p \leq 0.05$) in the mean inter-pedicular distances between African, European and Mixed ancestry populations in all the vertebral levels after conducting analysis of variance tests (Table 4.35). Bonferroni-corrected pairwise analysis showed that the mean inter-pedicular distances were significantly ($p \leq 0.05$) larger in European population than in African and or Mixed ancestry populations at all the vertebral levels (Table 4.36). No significant differences were found between the mean inter-pedicular distance in the African and Mixed ancestry populations in all the vertebral levels ($p \geq 0.05$).

Table 4.35: The ANOVA table showing comparison of the mean inter-pedicular distance in the three population of South African.

Vertebral Level	African mean ±SD (mm)	European mean ±SD (mm)	Mixed ancestry mean ±SD (mm)	P-Value
T1	20.05 ± 1.61	21 ± 2.81	19.94 ± 1.42	0.0104
T2	17.00 ± 1.55	18.07 ± 1.28	17.02 ± 1.13	<0.0001
T3	15.49 ± 2.11	16.81 ± 1.36	15.87 ± 1.12	<0.0001
T4	15.2 ± 1.43	16.24 ± 1.41	15.18 ± 1.01	<0.0001
T5	14.91 ± 1.45	16.04 ± 1.45	14.93 ± 1.03	<0.0001
T6	14.76 ± 1.43	16.01 ± 1.49	14.76 ± 1.15	<0.0001
T7	14.85 ± 1.43	16.16 ± 1.55	14.83 ± 1.17	<0.0001
T8	14.99 ± 1.45	16.37 ± 1.57	15.04 ± 1.22	<0.0001
T9	15.18 ± 1.4	16.64 ± 1.64	15.23 ± 1.3	<0.0001
T10	15.39 ± 1.31	16.88 ± 1.48	15.36 ± 1.22	<0.0001
T11	16.24 ± 1.62	18.2 ± 1.58	16.14 ± 1.36	<0.0001
T12	18.5 ± 1.93	21.25 ± 1.97	18.44 ± 1.49	<0.0001
L1	20.52 ± 1.57	22.7 ± 1.79	20.33 ± 1.32	<0.0001
L2	21.22 ± 1.59	22.87 ± 1.73	20.9 ± 1.5	<0.0001
L3	22(± 1.78)	22.94 ± 1.75	21.59 ± 1.7	0.0002
L4	22.91 ± 2.08	23.56 ± 2.07	22.43 ± 2.02	0.0142
L5	25.07 ± 2.61	26.2 ± 2.78	24.65 ± 2.45	0.0053

Table 4.36: Pair wise (post hoc Bonferroni) comparison of the mean inter-pedicular among populations groups of South African.

Vertebral Levels	**European Vs African**	**European Vs Mixed ancestry**	**African Vs Mixed ancestry**
T1	0.038*	0.020*	1.000
T2	<0.0001*	<0.0001*	1.000
T3	<0.0001*	0.006*	0.621
T4	<0.0001*	<0.0001*	1.000
T5	<0.0001*	<0.0001*	1.000
T6	<0.0001*	<0.0001*	1.000
T7	<0.0001*	<0.0001*	1.000
T8	<0.0001*	<0.0001*	1.000
T9	<0.0001*	<0.0001*	1.000
T10	<0.0001*	<0.0001*	1.000
T11	<0.0001*	<0.0001*	1.000
T12	<0.0001*	<0.0001*	1.000
L1	<0.0001*	<0.0001*	1.000
L2	<0.0001*	<0.0001*	0.865
L3	0.011*	<0.0001*	0.608
L4	0.250	0.012*	0.655
L5	0.057	0.006*	1.000

*Statistically significant values

4.5 INTERNAL PEDICLE MEASUREMENT IN AFRICAN POPULATION

4.5.1 Transverse inner cortical diameter

The mean transverse inner cortical diameter was found to gradually decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.5A). The largest mean transverse inner cortical diameter was seen at vertebral level T1 in both males (6.86 mm ±0.95) and females (6.3 mm ±0.99) and the least was at vertebral level T5 in both males (2.53 mm ±0.56) and females (2.24 mm ±0.78) (Table 4.37). In the lumbar spine, the mean transverse inner cortical diameter gradually increased from vertebral levels L1 to L5 (Fig. 4.5A). The largest mean transverse inner cortical diameter was seen at vertebral level L5 in both males (14.95 mm ±2.24) and females (14.19 mm ±1.64) and the least was at vertebral level L1 in both males (7.15 mm ±1.61) and females (5.57 mm ±1.19) (Table 4.37).

In almost all the vertebral levels, the mean transverse inner cortical diameter in males was larger than in females and the difference was statistically significant ($p \leq 0.05$) except at vertebral levels T10 to T12 (Table 4.38). Similarly, the mean diameters in the older age (51 to 65 years) group were larger than in the younger age (20 to 50 years) group with significant differences ($p \leq 0.05$) being observed from vertebral levels T1 to T9 (Table 4.38). No significant differences were seen between the right and left sides ($p \geq 0.05$).

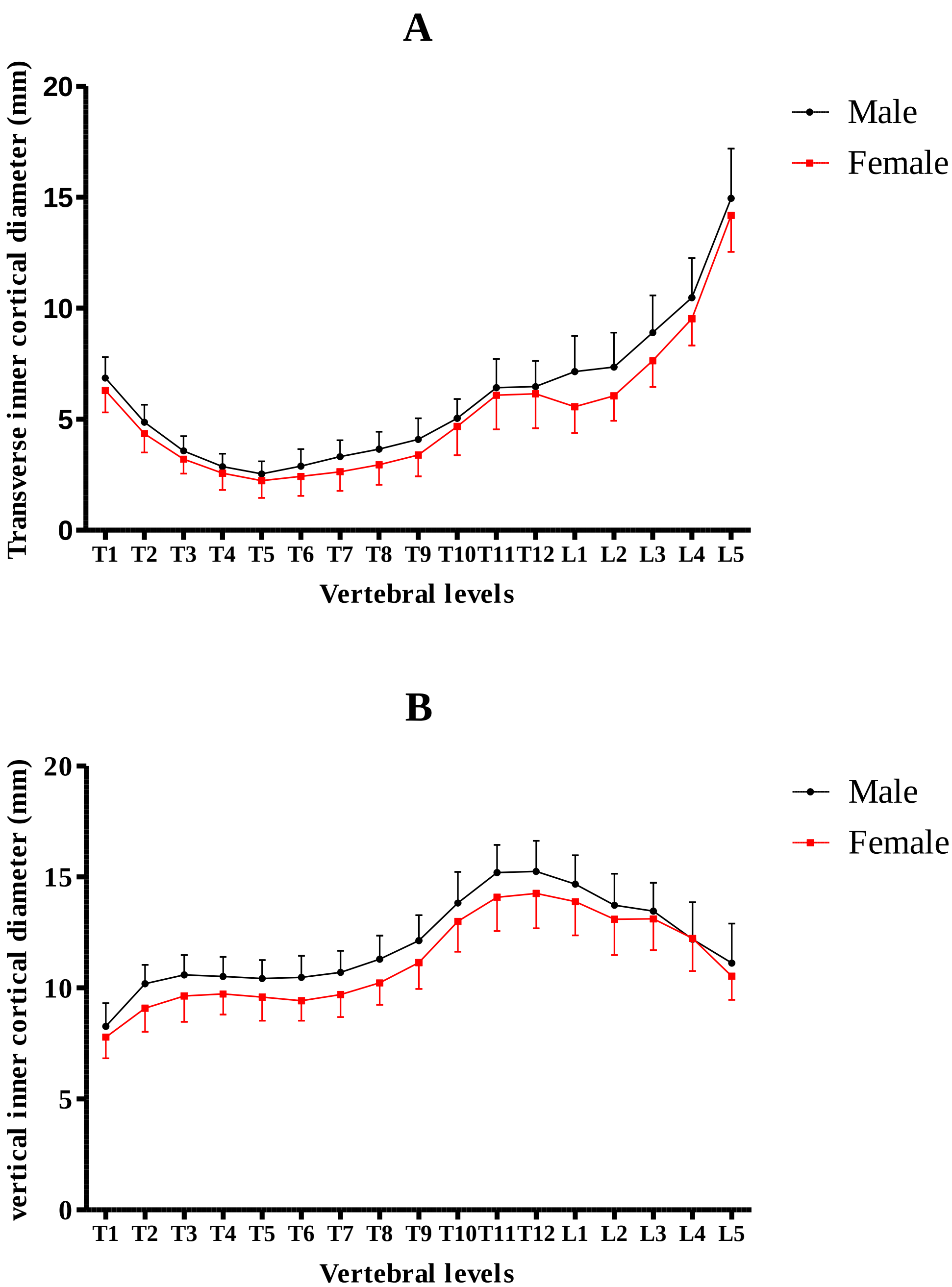


Figure 4.5. Graph showing the relationship between the transverse inner cortical diameter (**A**) and vertical inner cortical diameter (**B**) and the vertebral levels in both males and females of the African population.

Table 4.37: Comparison of mean transverse inner cortical diameter between males and females in the African population.

Vertebral Levels	Males Mean ±SD (mm)	Females Mean ±SD (mm)	P-value
T1	6.86 ± 0.95	6.3 ± 0.99	0.0020
T2	4.87 ± 0.79	4.36 ± 0.85	0.0008
T3	3.58 ± 0.67	3.2 ± 0.65	0.0025
T4	2.86 ± 0.58	2.57 ± 0.76	0.0188
T5	2.53 ± 0.56	2.24 ± 0.78	0.0188
T6	2.89 ± 0.77	2.43 ± 0.88	0.0031
T7	3.31 ± 0.74	2.64 ± 0.87	<0.0001
T8	3.65 ± 0.79	2.95 ± 0.9	<0.0001
T9	4.1 ± 0.94	3.38 ± 0.96	0.0001
T10	5.05 ± 0.86	4.68 ± 1.29	0.0661
T11	6.43 ± 1.3	6.09 ± 1.54	0.1953
T12	6.48 ± 1.15	6.15 ± 1.56	0.1925
L1	7.15 ± 1.61	5.57 ± 1.19	0.0000
L2	7.34 ± 1.56	6.06 ± 1.13	0.0000
L3	8.91 ± 1.67	7.63 ± 1.18	0.0000
L4	10.49 ± 1.79	9.53 ± 1.2	0.0009
L5	14.95 ± 2.24	14.19 ± 1.64	0.0348

Table 4.38: Comparison of mean transverse inner cortical diameter between the older (50 to 65 years) age group and the younger (20 to 50 years) age group in the African population.

Vertebral Levels	20-50yrs Mean ±SD (mm)	51-65yrs Mean ±SD (mm)	P-value
T1	6.37 ± 1.06	6.78 ± 0.91	0.0271
T2	4.37 ± 0.83	4.86 ± 0.82	0.0018
T3	3.17 ± 0.63	3.61 ± 0.67	0.0004
T4	2.52 ± 0.69	2.91 ± 0.63	0.0016
T5	2.19 ± 0.7	2.58 ± 0.63	0.0018
T6	2.44 ± 0.84	2.88 ± 0.82	0.0045
T7	2.67 ± 0.8	3.28 ± 0.85	0.0001
T8	3.05 ± 0.9	3.56 ± 0.86	0.0019
T9	3.45 ± 0.92	4.03 ± 1.03	0.0016
T10	4.81 ± 1.21	4.92 ± 1.01	0.5983
T11	6.28 ± 1.51	6.23 ± 1.36	0.8455
T12	6.3 ± 1.46	6.33 ± 1.29	0.9038
L1	6.31 ± 1.71	6.4 ± 1.53	0.7657
L2	6.6 ± 1.65	6.81 ± 1.34	0.4443
L3	8.28 ± 1.69	8.26 ± 1.47	0.9321
L4	10.02 ± 1.65	10 ± 1.54	0.9387
L5	14.7 ± 2.4	14.44 ± 1.48	0.4789

4.5.2 Vertical inner cortical diameter

The mean vertical inner cortical diameter was found to gradually increase from vertebral levels T1 to T12 in the thoracic spine (Fig. 5.5B). The largest mean vertical inner cortical diameter was seen at vertebral level T12 in both males (15.26 mm ±1.38) and females (14.27 mm ±1.58) and the least was at vertebral T1 in both males (8.28 mm ±1.04) and females (7.79 mm ±0.96) (Table 4.39). In the lumbar spine, the mean vertical inner cortical diameter gradually decreased from vertebral levels L1 to L5 (Fig. 5.5B). The largest mean diameter was seen at vertebral level L1 in both males (14.67 mm ±1.31) and females (13.89 mm ±1.51) and the least was at vertebral level L5 in both males (11.13 mm ±1.77) and females (10.54 mm ±1.07) (Table 5.39).

In almost all the vertebral levels, the mean vertical inner cortical diameter in males was larger than in females and the difference was statistically significant ($p \leq 0.05$) except from vertebral levels L3 to L4 (Table 4.59). However, there were no significant differences seen between the mean vertical inner cortical diameter in the older age (51 to 65 years) group and younger age (20 to 50 years) group (Table 4.40) and between the right and left sides ($p \geq 0.05$).

Table 4.39: Comparison of mean vertical inner cortical diameter between males and females in the African population.

Vertebral levels	Males Mean ±SD (mm)	Females Mean ±SD (mm)	P-value
T1	8.28 ± 1.04	7.79 ± 0.96	0.009
T2	10.19 ± 0.86	9.09 ± 1.07	<0.0001
T3	10.6 ± 0.89	9.65 ± 1.17	<0.0001
T4	10.52 ± 0.87	9.73 ± 0.93	<0.0001
T5	10.43 ± 0.83	9.59 ± 1.06	<0.0001
T6	10.48 ± 0.96	9.43 ± 0.9	<0.0001
T7	10.71 ± 0.96	9.71 ± 1.02	<0.0001
T8	11.3 ± 1.06	10.23 ± 0.99	<0.0001
T9	12.14 ± 1.14	11.14 ± 1.18	<0.0001
T10	13.83 ± 1.41	13 ± 1.36	0.0015
T11	15.21 ± 1.23	14.1 ± 1.54	<0.0001
T12	15.26 ± 1.38	14.27 ± 1.58	0.0004
L1	14.67 ± 1.31	13.89 ± 1.51	0.0027
L2	13.73 ± 1.43	13.1 ± 1.62	0.0277
L3	13.47 ± 1.28	13.12 ± 1.41	0.1614
L4	12.2 ± 1.67	12.24 ± 1.47	0.8784
L5	11.13 ± 1.77	10.54 ± 1.07	0.0294

Table 4.40: Comparison of mean vertical inner cortical diameter between the older (50 to 65 years) age group and the younger (20 to 50 years) age group in the African population.

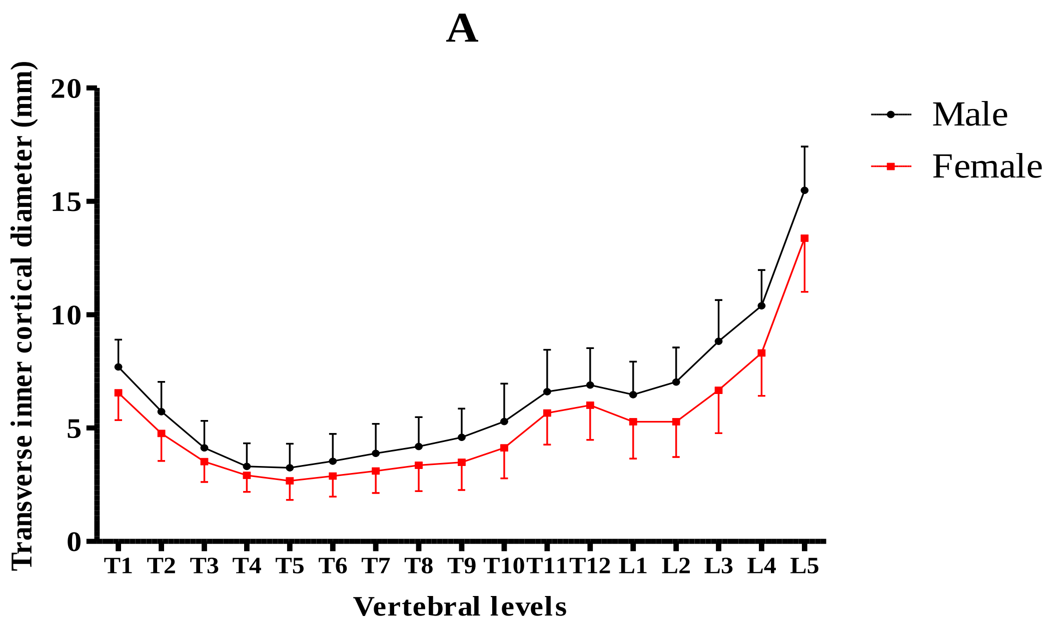
Vertebral levels	20-50 yrs. Mean ±SD (mm)	51-65 yrs. Mean ±SD (mm)	P-value
T1	8.16 ± 0.94	7.92 ± 1.1	0.2044
T2	9.6 ± 1.1	9.69 ± 1.13	0.6573
T3	10 ± 1.05	10.25 ± 1.22	0.225
T4	10.08 ± 1.01	10.17 ± 0.96	0.6153
T5	9.94 ± 1.06	10.08 ± 1.01	0.4457
T6	9.92 ± 1.08	9.99 ± 1.06	0.734
T7	10.17 ± 1.08	10.25 ± 1.15	0.6604
T8	10.79 ± 1.17	10.75 ± 1.14	0.8557
T9	11.64 ± 1.17	11.64 ± 1.36	0.9971
T10	13.53 ± 1.38	13.3 ± 1.5	0.3951
T11	14.65 ± 1.51	14.66 ± 1.5	0.9869
T12	14.74 ± 1.61	14.79 ± 1.51	0.8814
L1	14.31 ± 1.3	14.25 ± 1.62	0.8475
L2	13.42 ± 1.37	13.41 ± 1.72	0.9548
L3	13.12 ± 1.19	13.46 ± 1.49	0.1727
L4	12.01 ± 1.39	12.43 ± 1.71	0.1423
L5	10.77 ± 1.55	10.89 ± 1.43	0.6684

4.6 INTERNAL PEDICLE MEASUREMENT IN EUROPEAN POPULATION

4.6.1 Transverse inner cortical diameter

The mean transverse inner cortical diameter was found to gradually decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.6A). The largest mean transverse inner cortical diameter was seen at vertebral level T1 in both males (7.71 mm ±1.2) and females (6.57 mm ±1.21) and the least was at vertebral level T5 in both males (3.26 mm ±1.05) and females (2.67 mm ±0.84) (Table 4.41). In the lumbar spine, the mean transverse inner cortical gradually increased from vertebral levels L1 to L5 (Fig. 4.6A). The largest mean transverse inner cortical diameter was seen at vertebral level L5 in both males (15.49 mm ±1.93) and females (13.37 mm ±2.36) and the least was at vertebral level L1 in both males (6.47mm ±1.45) and females (5.28 mm ±1.62) (Table 4.41).

In all the vertebral levels, the mean transverse inner cortical diameter in males was larger than in females and the differences were statistically significant ($p \leq 0.05$) (Table 4.42). No significant differences between the mean transverse inner cortical diameters in the older (50 to 65 years) and younger (20 to 50 years) age group and between the right and left sides were observed ($p \geq 0.05$).



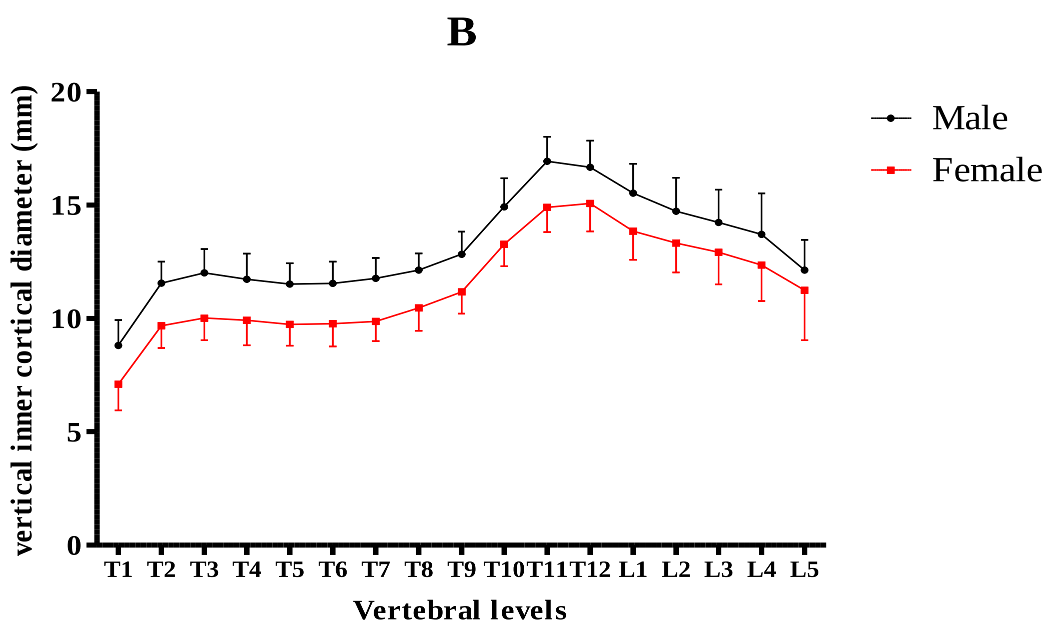


Figure 4.6. Graph showing the relationship between the transverse inner cortical diameter (**A**) and vertical inner cortical diameter (**B**) and the vertebral levels in both males and females of the European population.

Table 4.41: Comparison of mean transverse inner cortical diameter between males and females in the European population.

Vertebral Levels	Male Mean ±SD (mm)	Female Mean ±SD (mm)	P-value
T1	7.71 ± 1.2	6.57 ± 1.21	<0.0001
T2	5.74 ± 1.3	4.77 ± 1.22	<0.0001
T3	4.13 ± 1.19	3.53 ± 0.9	0.0023
T4	3.31 ± 1.02	2.92 ± 0.74	0.0166
T5	3.26 ± 1.05	2.67 ± 0.84	0.001
T6	3.54 ± 1.21	2.89 ± 0.92	0.0012
T7	3.89 ± 1.3	3.11 ± 0.97	0.0003
T8	4.19 ± 1.29	3.37 ± 1.14	0.0003
T9	4.6 ± 1.27	3.49 ± 1.21	<0.0001
T10	5.29 ± 1.68	4.13 ± 1.34	0.0001
T11	6.61 ± 1.83	5.67 ± 1.4	0.0018
T12	6.9 ± 1.63	6.01 ± 1.53	0.0026
L1	6.47 ± 1.45	5.28 ± 1.62	<0.0001
L2	7.04 ± 1.51	5.28 ± 1.56	<0.0001
L3	8.83 ± 1.81	6.67 ± 1.89	<0.0001
L4	10.39 ± 1.59	8.31 ± 1.89	<0.0001
L5	15.49 ± 1.93	13.37 ± 2.36	<0.0001

Table 4.42: Comparison of mean transverse inner cortical diameter between the older (50 to 65 years) age group and the younger (20 to 50 years) age group in the European population.

Vertebral levels	20-50 yrs. Mean ±SD (mm)	51-65 yrs. Mean ±SD (mm)	P-value
T1	7.14 ± 1.27	7.13 ± 1.4	0.9696
T2	5.24 ± 1.41	5.27 ± 1.29	0.9195
T3	3.76 ± 1.02	3.91 ± 1.17	0.4415
T4	3.13 ± 0.91	3.1 ± 0.91	0.8681
T5	3.01 ± 1.06	2.92 ± 0.93	0.6446
T6	3.22 ± 1.13	3.21 ± 1.11	0.9721
T7	3.57 ± 1.29	3.44 ± 1.13	0.5566
T8	3.78 ± 1.25	3.78 ± 1.33	0.9927
T9	3.98 ± 1.36	4.1 ± 1.36	0.6233
T10	4.71 ± 1.62	4.71 ± 1.64	0.988
T11	6.24 ± 1.8	6.05 ± 1.58	0.5442
T12	6.62 ± 1.58	6.29 ± 1.68	0.2689
L1	5.96 ± 1.68	5.79 ± 1.61	0.5902
L2	6.16 ± 1.78	6.16 ± 1.76	0.9967
L3	7.9 ± 1.9	7.6 ± 2.36	0.4419
L4	9.35 ± 1.92	9.35 ± 2.15	0.985
L5	14.16 ± 2.26	14.71 ± 2.51	0.2083

4.6.2 Vertical inner cortical diameter

The mean vertical inner cortical diameter was found to gradually increase from vertebral levels T1 to T11 and then slightly decreased at vertebral level T12 in the thoracic spine (Fig. 4.6B). The largest mean vertical inner cortical diameter was seen at vertebral level T11 in males (16.94 mm ±1.08) and at T12 in females (15.08 mm ±1.24) and the least was at vertebral level T1 in both males (8.82 mm ±1.11) and females (7.09 mm ±1.15) (Table 4.43). In the lumbar spine, the mean vertical inner cortical diameter gradually decreased from vertebral levels L1 to L5 (Fig. 4.6B). The largest mean diameter was seen at vertebral level L1 in both males (15.54 mm ±1.29) and females (13.85 mm ±1.26) and the least was at vertebral level L5 in both males (12.14 mm ±1.32) and females (11.24 mm ±2.2) (Table 4.43).

The mean vertical inner cortical diameters in males were larger than in females and the differences were statistically significant ($p \leq 0.05$) in all the vertebral levels (Table 4.43). Similarly, at vertebral level T2 the mean vertical inner cortical diameter in the older age (50 to 65 years) group was larger than in the younger age (20 to 50 years) group and the difference was statistically significant ($p \leq 0.05$) (Table 4.44). No significant differences were seen between the right and left sides ($p \geq 0.05$).

Table 4.43: Comparison of mean vertical inner cortical diameter between males and females in the European population.

Vertebral levels	Male Mean ±SD (mm)	Female Mean ±SD (mm)	P-value
T1	8.82 ± 1.11	7.09 ± 1.15	<0.0001
T2	11.56 ± 0.96	9.68 ± 0.98	<0.0001
T3	12.01 ± 1.05	10.01 ± 0.97	<0.0001
T4	11.74 ± 1.12	9.92 ± 1.1	<0.0001
T5	11.53 ± 0.91	9.74 ± 0.94	<0.0001
T6	11.55 ± 0.97	9.77 ± 1.01	<0.0001
T7	11.77 ± 0.91	9.86 ± 0.86	<0.0001
T8	12.13 ± 0.74	10.47 ± 1.02	<0.0001
T9	12.83 ± 0.99	11.17 ± 0.95	<0.0001
T10	14.94 ± 1.25	13.27 ± 0.97	<0.0001
T11	16.94 ± 1.08	14.91 ± 1.09	<0.0001
T12	16.68 ± 1.17	15.08 ± 1.24	<0.0001
L1	15.54 ± 1.29	13.85 ± 1.26	<0.0001
L2	14.72 ± 1.49	13.33 ± 1.29	<0.0001
L3	14.24 ± 1.45	12.93 ± 1.42	<0.0001
L4	13.72 ± 1.79	12.36 ± 1.59	<0.0001
L5	12.14 ± 1.32	11.24 ± 2.2	0.0078

Table 4.44: Comparison of mean vertical inner cortical diameter between the older (50 to 65 years) age group and the younger (20 to 50 years) age group in the European population.

Vertebral levels	20-50 yrs. Mean ±SD (mm)	51-65 yrs. Mean ±SD (mm)	P-value
T1	7.8 ± 1.46	8.11 ± 1.37	0.2415
T2	10.36 ± 1.35	10.88 ± 1.3	0.0308
T3	10.87 ± 1.63	11.16 ± 1.17	0.2701
T4	10.71 ± 1.56	10.96 ± 1.3	0.342
T5	10.46 ± 1.39	10.81 ± 1.16	0.1377
T6	10.59 ± 1.4	10.73 ± 1.26	0.5697
T7	10.78 ± 1.41	10.86 ± 1.2	0.7435
T8	11.19 ± 1.31	11.42 ± 1.12	0.2962
T9	11.82 ± 1.36	12.19 ± 1.17	0.1138
T10	14.1 ± 1.51	14.11 ± 1.27	0.9537
T11	15.92 ± 1.53	15.93 ± 1.45	0.9615
T12	16.03 ± 1.56	15.72 ± 1.32	0.2422
L1	14.87 ± 1.61	14.52 ± 1.43	0.2018
L2	14.19 ± 1.65	13.86 ± 1.45	0.2556
L3	13.71 ± 1.64	13.46 ± 1.5	0.3856
L4	12.99 ± 2.02	13.1 ± 1.61	0.7558
L5	11.61 ± 1.86	11.78 ± 1.88	0.6256

4.7 INTERNAL PEDICLE MEASUREMENT IN MIXED ANCESTRY POPULATION

4.7.1 Transverse inner cortical diameter

The mean transverse inner cortical diameter was found to gradually decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.7A). The largest mean transverse inner cortical diameter was seen at vertebral level T1 in both males (7.2 mm ±1.13) and females (6.21 mm ±0.96) and the least was at vertebral level T5 in both males (2.73 mm ±0.9) and females (2.21 mm ±0.76) (Table 4.45). In the lumbar spine, the mean transverse inner cortical diameter gradually increased from vertebral levels L1 to L5 (Fig. 4.7A). The largest mean transverse inner cortical diameter was seen at vertebral level L5 in both males (14.62 mm ±1.92) and females (13.85 mm ±1.84) and the least was at vertebral level L1 in males (6.89 mm ±1.68) and at L2 in females (5.97 mm ±1.3) (Table 4.45).

In almost all the vertebral levels, the mean transverse inner cortical diameters in males were greater than in females and the differences were statistically significant ($p \leq 0.05$) except at vertebral level T12 (Table 4.45). Similarly, the mean transverse inner cortical diameters in the older age (51 to 65 years) group were larger than in the younger age (20 to 50 years) group with significant differences ($p \leq 0.05$) being observed in almost all the vertebral levels except at vertebral level T1 (Table 4.46). No significant differences were seen between the right and left sides ($p \geq 0.05$).

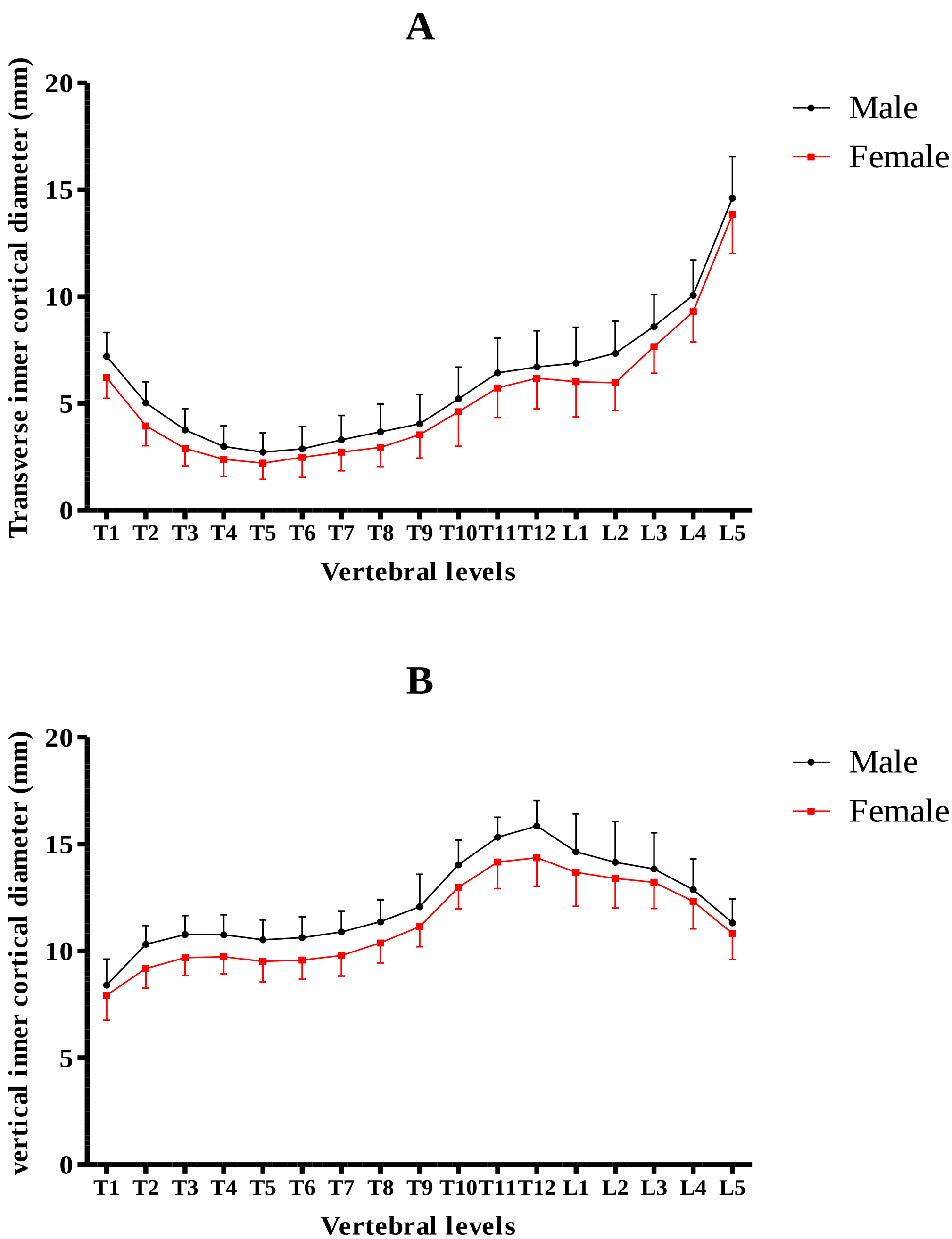


Figure 4.7. Graph showing the relationship between the transverse inner cortical diameter (**A**) and vertical inner cortical diameter (**B**) and the vertebral levels in both males and females of the Mixed ancestry population.

Table 4.45: Comparison of mean transverse inner cortical diameter between males and females in the Mixed ancestry.

Vertebral Levels	Male Mean ±SD (mm)	Female Mean ±SD (mm)	P-value
T1	7.2 ± 1.13	6.21 ± 0.96	<0.0001
T2	5.03 ± 1	3.96 ± 0.94	<0.0001
T3	3.77 ± 1	2.91 ± 0.83	<0.0001
T4	2.99 ± 0.96	2.39 ± 0.8	0.0007
T5	2.73 ± 0.9	2.21 ± 0.76	0.0019
T6	2.87 ± 1.05	2.48 ± 0.93	0.0448
T7	3.3 ± 1.15	2.72 ± 0.86	0.0046
T8	3.68 ± 1.3	2.96 ± 0.89	0.0014
T9	4.06 ± 1.37	3.54 ± 1.1	0.0344
T10	5.22 ± 1.48	4.62 ± 1.62	0.0457
T11	6.43 ± 1.63	5.73 ± 1.4	0.0197
T12	6.71 ± 1.69	6.18 ± 1.44	0.0853
L1	6.89 ± 1.68	6.02 ± 1.64	0.0082
L2	7.36 ± 1.49	5.97 ± 1.3	<0.0001
L3	8.6 ± 1.5	7.67 ± 1.25	0.0008
L4	10.07 ± 1.64	9.3 ± 1.41	0.0108
L5	14.62 ± 1.92	13.85 ± 1.84	0.0359

Table 4.46: Comparison of mean transverse inner cortical diameter between the older age group and the younger age group in the Mixed ancestry.

Vertebral Levels	**20-50 yrs.** **Mean ±SD (mm)**	**51-65 yrs.** **Mean ±SD (mm)**	**P-value**
T1	6.6 ± 1.1	6.95 ± 1.22	0.1194
T2	4.25 ± 1.15	4.93 ± 0.93	0.0011
T3	3.16 ± 1.02	3.67 ± 0.96	0.0092
T4	2.45 ± 0.82	3.05 ± 0.98	0.0007
T5	2.28 ± 0.82	2.76 ± 0.88	0.0042
T6	2.41 ± 0.89	3.06 ± 1.06	0.0008
T7	2.72 ± 0.84	3.46 ± 1.17	0.0002
T8	2.98 ± 0.97	3.83 ± 1.27	0.0001
T9	3.43 ± 1.19	4.32 ± 1.23	0.0003
T10	4.41 ± 1.35	5.64 ± 1.56	<0.0001
T11	5.56 ± 1.34	6.83 ± 1.54	<0.0001
T12	6.01 ± 1.35	7.06 ± 1.7	0.0005
L1	6.01 ± 1.58	7.12 ± 1.67	0.0007
L2	6.41 ± 1.54	7.15 ± 1.51	0.0131
L3	7.81 ± 1.37	8.65 ± 1.45	0.0026
L4	9.42 ± 1.51	10.11 ± 1.6	0.0234
L5	13.73 ± 1.89	14.96 ± 1.74	0.0008

4.7.2 Vertical inner cortical diameter

The mean vertical inner cortical diameter was found to gradually increase from vertebral levels T1 to T12 in the thoracic spine (Fig. 4.7B). The largest mean vertical inner cortical diameter was seen at vertebral level T12 in both males (15.86 mm ±1.2) and females (14.36 mm ±1.33) and the least was at vertebral level T1 in both males (8.4 mm ±1.22) and females (7.93 mm ±1.16) (Table 4.47). In the lumbar spine, the mean vertical diameter gradually decreased from vertebral levels L1 to L5 (Fig. 4.7B). The largest mean diameter was seen at vertebral level L1 in both males (14.65 mm ±1.78) and females (13.67 mm ±1.58) and the least was at vertebral level L5 in both males (11.32 mm ±1.12) and females (10.82 mm ±1.22) (Table 4.47).

In all the vertebral levels, the mean vertical inner cortical diameter in males was larger than in females and these differences were statistically significant ($p \leq 0.05$) (Table 4.47). Similarly, the mean vertical inner cortical diameters in the older (50 to 65 years) age group were larger in the younger (20 to 50 years) age group with statistical significance ($p \leq 0.05$) being observed from vertebral levels T1 to T4 and at T6, T8, T1 L1 and L2 (Table 48). No significant differences were seen between the right and left sides ($p \geq 0.05$).

Table 4.47: Comparison of mean vertical inner cortical diameter between males and females in the Mixed ancestry.

Vertebral Levels	Male Mean ±SD (mm)	Female Mean ±SD (mm)	P-value
T1	8.4 ± 1.22	7.93 ± 1.16	0.0447
T2	10.32 ± 0.87	9.18 ± 0.91	<0.0001
T3	10.77 ± 0.89	9.7 ± 0.84	<0.0001
T4	10.76 ± 0.94	9.73 ± 0.8	<0.0001
T5	10.54 ± 0.92	9.52 ± 0.96	<0.0001
T6	10.63 ± 0.98	9.58 ± 0.9	<0.0001
T7	10.9 ± 0.98	9.8 ± 0.97	<0.0001
T8	11.37 ± 1.03	10.38 ± 0.94	<0.0001
T9	12.08 ± 1.51	11.15 ± 0.94	0.0003
T10	14.05 ± 1.15	12.99 ± 1.01	<0.0001
T11	15.34 ± 0.92	14.17 ± 1.24	<0.0001
T12	15.86 ± 1.2	14.36 ± 1.33	<0.0001
L1	14.65 ± 1.78	13.67 ± 1.58	0.0037
L2	14.15 ± 1.91	13.4 ± 1.39	0.0238
L3	13.84 ± 1.71	13.21 ± 1.21	0.0342
L4	12.88 ± 1.43	12.33 ± 1.28	0.0381
L5	11.32 ± 1.12	10.82 ± 1.22	0.0293

Table 4.48: Comparison of mean vertical inner cortical diameter between the older (50 to 65 years) age group and the younger (20 to 50 years) age group in the Mixed ancestry.

Vertebral Levels	**20-50 yrs. Mean ±SD (mm)**	**51-65 yrs. Mean ±SD (mm)**	**P-value**
T1	7.85 ± 1.07	8.62 ± 1.26	0.0008
T2	9.54 ± 1.02	10.15 ± 1.01	0.0022
T3	10.03 ± 0.94	10.63 ± 1.02	0.002
T4	10.07 ± 0.82	10.59 ± 1.16	0.0073
T5	9.92 ± 1	10.29 ± 1.12	0.0743
T6	9.88 ± 0.96	10.53 ± 1.11	0.0015
T7	10.26 ± 1.01	10.59 ± 1.23	0.1319
T8	10.73 ± 0.99	11.18 ± 1.19	0.0318
T9	11.43 ± 1.58	11.96 ± 0.99	0.0463
T10	13.36 ± 1.21	13.85 ± 1.16	0.0334
T11	14.66 ± 1.25	15.02 ± 1.17	0.1291
T12	15.08 ± 1.43	15.33 ± 1.49	0.3662
L1	13.83 ± 1.82	14.7 ± 1.55	0.0104
L2	13.51 ± 1.69	14.2 ± 1.73	0.0399
L3	13.31 ± 1.64	13.87 ± 1.35	0.0597
L4	12.42 ± 1.5	12.9 ± 1.2	0.0759
L5	10.98 ± 1.06	11.25 ± 1.32	0.243

4.8 COMPARISON OF INTERNAL PEDICULAR MEASUREMENTS IN AFRICAN, EUROPEAN AND MIXED ANCESTRY POPULATIONS OF SOUTH AFRICAN

4.8.1 Transverse inner cortical diameter

In all the populations the mean transverse inner cortical diameter was found to gradually decrease from vertebral levels T1 to T5 and then gradually increased to vertebral level T12 in the thoracic spine (Fig. 4.8A). In the lumbar spine, the mean transverse inner cortical diameter gradually increased from vertebral levels L1 to L5 (Fig. 4.8A). The mean transverse inner cortical diameter showed a statistically significant difference between the three populations at vertebral levels T1 to T8 in the thoracic spine and at vertebral levels L2 and L3 in the lumbar spine after conducting analysis of variance test ($p \leq 0.05$) (Table 4.49). Bonferroni-corrected pairwise analysis revealed that the mean transverse inner cortical diameters at vertebral levels T1 to T8 were significantly larger in European population than in the African and or Mixed ancestry in the thoracic spine ($p \leq 0.05$). However, the mean transverse inner cortical diameters in the lumbar spine at vertebral levels L1 and L2 were significantly larger in the Mixed ancestry population than in the European and or African populations ($p \leq 0.05$) (Table 4.50). No significant differences were found between the mean transverse inner cortical diameters in the African and Mixed ancestry populations in all the vertebral level ($p \geq 0.05$).

Table 4.49: The ANOVA table showing the comparison of the mean transverse inner cortical diameter in the three populations of South African.

Vertebral Level	African Mean ±SD (mm)	European Mean ±SD (mm)	Mixed ancestry Mean ±SD (mm)	P-Value
T1	6.58 ± 1.01	7.14 ± 1.33	6.76 ± 1.16	0.001
T2	4.62 ± 0.86	5.25 ± 1.35	4.55 ± 1.1	<0.0001
T3	3.39 ± 0.68	3.83 ± 1.09	3.39 ± 1.02	0.0002
T4	2.72 ± 0.69	3.12 ± 0.91	2.72 ± 0.94	0.0002
T5	2.39 ± 0.69	2.97 ± 0.99	2.5 ± 0.88	<0.0001
T6	2.66 ± 0.86	3.21 ± 1.12	2.7 ± 1.01	<0.0001
T7	2.98 ± 0.88	3.5 ± 1.21	3.04 ± 1.06	0.0002
T8	3.3 ± 0.92	3.78 ± 1.28	3.36 ± 1.19	0.0022
T9	3.74 ± 1.01	4.04 ± 1.35	3.83 ± 1.28	0.146
T10	4.86 ± 1.11	4.71 ± 1.62	4.96 ± 1.56	0.4238
T11	6.26 ± 1.43	6.14 ± 1.69	6.12 ± 1.56	0.776
T12	6.31 ± 1.37	6.45 ± 1.63	6.48 ± 1.6	0.6742
L1	6.36 ± 1.62	5.88 ± 1.64	6.5 ± 1.71	0.0109
L2	6.7 ± 1.5	6.16 ± 1.76	6.74 ± 1.57	0.01
L3	8.27 ± 1.58	7.75 ± 2.14	8.18 ± 1.46	0.0517
L4	10.01 ± 1.59	9.43 ± 2.39	9.73 ± 1.58	0.0667
L5	14.57 ± 1.99	14.43 ± 2.4	14.28 ± 1.92	0.58

Table 4.50: Pair wise (post hoc Bonferroni) comparison of the mean transverse inner cortical diameter among population groups of South Africa.

Vertebral Levels	European Vs African	European Vs Mixed ancestry	African Vs Mixed ancestry
T1	0.001*	0.048*	0.730
T2	<0.0001*	<0.0001*	1.000
T3	0.001*	0.001*	1.000
T4	0.001*	0.001*	1.000
T5	<0.0001*	<0.0001*	0.992
T6	<0.0001*	<0.0001*	1.000
T7	<0.0001*	0.004*	1.000
T8	0.004*	0.017	1.000
T9	0.170	0.551	1.000
T10	1.000	0.593	1.000
T11	1.000	1.000	1.000
T12	1.000	1.000	1.000
L1	0.075	0.013*	1.000
L2	0.031*	0.023*	1.000
L3	0.068	0.191	1.000
L4	0.060	0.751	0.787
L5	1.000	1.000	0.891

*Statistically significant

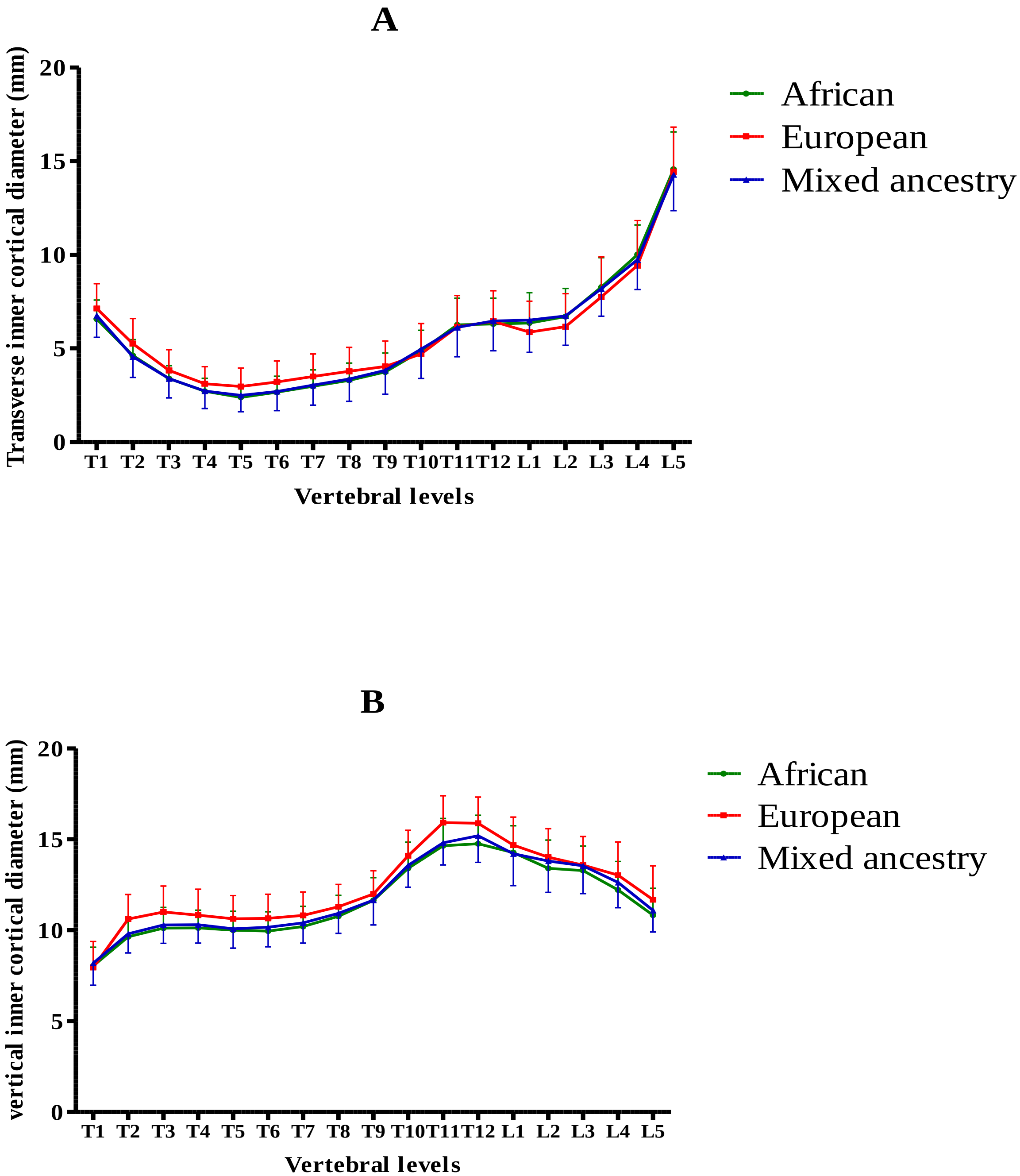


Figure 4.8. Graphs showing the relationship between transverse inner cortical diameter (**A**) and vertical inner cortical diameter (**B**) with vertebral levels in all the three population.

4.8.2 Vertical inner cortical diameter

In all the three populations the mean vertical inner cortical diameter was found to gradually increase from vertebral levels T1 to T12 in the thoracic spine whereas in the lumbar spine it gradually decreased from the vertebral levels L1 to L5 (Fig. 4.8B). In almost all the vertebral levels, the mean vertical inner cortical diameter showed a statistically significant difference between the three populations except at vertebral levels T1 and T9 in the thoracic spine and at vertebral level L3 in the lumbar spine after conducting analysis of variance ($p \leq 0.05$) (Table 4.51). Bonferroni-corrected pairwise analysis revealed that the mean vertical inner cortical diameters at vertebral levels T2 to T8 and at T10 to T12 in the thoracic spine were significantly larger in European population than in African and or Mixed ancestry populations ($p \leq 0.05$). Similarly, the mean vertical inner cortical diameters at vertebral levels L1, L4 and L5 in the lumbar spine were significantly larger in the European population than in African or Mixed ancestry populations ($p \leq 0.05$) (Table 4.52). No significant differences were found between the mean vertical inner cortical diameter in the African and Mixed ancestry populations in all the vertebral levels ($p \geq 0.05$)

Table 4.51: The ANOVA table showing the comparison of the mean vertical inner cortical diameter in the three populations of South African.

Vertebral Levels	African Mean ±SD (mm)	European Mean ±SD (mm)	Mixed ancestry Mean ±SD (mm)	P-Value
T1	8.04 ± 1.02	7.96 ± 1.42	8.19 ± 1.21	0.3491
T2	9.64 ± 1.11	10.62 ± 1.35	9.81 ± 1.05	<0.0001
T3	10.12 ± 1.14	11.01 ± 1.42	10.3 ± 1.02	<0.0001
T4	10.13 ± 0.98	10.83 ± 1.43	10.3 ± 1.01	<0.0001
T5	10.01 ± 1.04	10.63 ± 1.28	10.08 ± 1.07	<0.0001
T6	9.96 ± 1.07	10.66 ± 1.33	10.17 ± 1.08	<0.0001
T7	10.21 ± 1.11	10.82 ± 1.3	10.41 ± 1.12	0.0003
T8	10.77 ± 1.15	11.3 ± 1.22	10.93 ± 1.1	0.0014
T9	11.64 ± 1.26	12 ± 1.28	11.66 ± 1.37	0.0591
T10	13.42 ± 1.44	14.1 ± 1.39	13.58 ± 1.21	0.0003
T11	14.65 ± 1.5	15.92 ± 1.48	14.82 ± 1.22	<0.0001
T12	14.77 ± 1.56	15.88 ± 1.45	15.19 ± 1.46	<0.0001
L1	14.28 ± 1.46	14.7 ± 1.53	14.22 ± 1.75	0.0426
L2	13.41 ± 1.55	14.03 ± 1.55	13.82 ± 1.73	0.0123
L3	13.29 ± 1.35	13.59 ± 1.57	13.56 ± 1.54	0.2456
L4	12.22 ± 1.57	13.04 ± 1.82	12.63 ± 1.39	0.0005
L5	10.83 ± 1.49	11.69 ± 1.86	11.1 ± 1.19	0.0001

Table 4.52: Pair wise (post hoc Bonferroni) comparison of the mean vertical inner cortical diameter among population groups of South Africa.

Vertebral Levels	European Vs African	European Vs Mixed ancestry	African Vs Mixed ancestry
T1	1.000	0.457	1.000
T2	0.0001*	0.0001*	0.850
T3	0.0001*	0.0001*	0.858
T4	0.0001*	0.002*	0.775
T5	0.0001*	0.001*	1.000
T6	0.0001*	0.005*	0.523
T7	0.0001*	0.028*	0.619
T8	0.001*	0.047*	0.889
T9	0.098	0.151	1.000
T10	0.0001*	0.011*	1.000
T11	0.0001*	0.0001*	1.000
T12	0.0001*	0.002*	0.093
L1	0.126	0.068	1.000
L2	0.010*	0.979	0.183
L3	0.380	1.000	0.537
L4	0.0001*	0.168	0.161
L5	0.0001*	0.012*	0.589

*Statistically significant values

5 CHAPTER FIVE: DISCUSSION

5.1 Overview

Pedicle screw fixation has become increasingly popular method of internal fixation of the spine after decompression surgery for various disorders, including scoliosis, spondylolisthesis, fractures, tumor and iatrogenic or degenerative instability. However, population, sex and age variation in the pedicle morphometry may pose limitations to the application of pedicle screw fixation. Hence the objective of the current study was to determine the possibility of using pedicle screw fixation by analyzing the relationship between pedicle morphometry and demographics (sex, age and race) in South African populations and compare the results with the previous studies.

5.2 EXTERNAL MEASUREMENT

5.2.1 Pedicle width

In the current study, the mean pedicle width from vertebral levels T1 to T8 was significantly larger in the European population than in the African and or Mixed ancestry populations in the thoracic spine. In the lumbar spine, the mean pedicle width from vertebral levels L1 to L4 was significantly larger in African population than in the European population but at vertebral levels L1 and L2 it was larger in the Mixed ancestry population than in the European population. However, the values of the mean pedicle width examined in the current study were smaller compared to those reported in the American population by Zindrick *et al.* (1987) for the thoracic and lumbar spine and in the French population by Chaynes *et al.* (2001) for the thoracic spine (Table 5.1). European populations in the current study had marginally smaller values for the thoracic spine compared with that reported by Zindrick *et al.* (1987) in the American population. The trend of a gradual decrease from vertebral levels T1 to T5 followed by increase from vertebral levels T5 to T12 in the thoracic spine and then a gradual increase from vertebral levels L1 to L5 in the lumbar spine observed in the current study, was similar to those in American, Korean, Indian and French populations by Zindrick *et al.* (1987), Kim *et al.* (1994), Datir *et al.* (2004) and Chaynes *et al.* (2001) respectively (Table 5.1). The main reason for the variation in the values of the mean pedicle width with other previous studies may be due to difference in methods of study. Zindrick *et al.* (1987) used computed tomographic scan measurements from cadaveric specimens; nonetheless the magnification ratio was small making it difficult to compare with result from the direct measurements used in the present study.

Knowledge of the pedicle width is important for the selection of pedicle screw size. Using computed tomographic scans, Krag *et al.* (1988) showed that the pedicle width below T10 vertebral level were 5 mm or greater and even 7 mm or greater in the lower lumbar region and suggest that 5 mm and 7 mm pedicle screws could be used for the lower thoracic and lower lumbar vertebrae respectively. Similarly, the results from the current study showed that pedicle width from the lower thoracic vertebrae below T11, and from the upper lumbar vertebrae were greater than 5 mm and 7 mm respectively. Therefore, pedicle screws with a diameter of 5 mm may be safely introduced at the lower thoracic and upper lumbar vertebrae, and 7 mm diameter pedicle screw at the lower lumbar region in studied populations of South Africa. But the pedicle width at vertebral levels T2 to T10 were less than or equal to 5 mm (Kim *et al.*, 1994; Datir *et al.*, 2004) including in the current study, and at those levels it can be recommended that pedicle screws with diameters less than 5 mm be utilized to prevent fracturing of the bone.

Table 5.1: Comparison of pedicle width with those of other studies

	Direct measurements (mm)			**CT measurements (mm)**
Vertebral Levels	**Datir *et al.* (2004)**	**Kim *et al.* (1994)**	**Chaynes *et al.* (2001)**	**Zindrick *et al.* (1987)**
	Indian	**Korean**	**French**	**American**
T1	7.3	8.1	8.3	7.9
T2	6.3	6.1	6.5	7
T3	5.2	4.6	5.9	5.6
T4	4.8	4.2	5.4	4.7
T5	4.7	4.3	4.9	4.5
T6	5	4.7	5.1	5.2
T7	5.4	4.8	5.7	5.3
T8	5.4	5.1	6.4	5.9
T9	5.9	5.2	6.4	6.1
T10	6.7	6.3	7.4	6.3
T11	8.2	7.9	9.3	7.8
T12	8.7	7.9	8.9	7.1
L1	-	7	-	8.7
L2	-	7.5	-	8.9
L3	-	9.9	-	10.3
L4	-	12.7	-	12.9
L5	-	18.9	-	18

5.2.2 Pedicle height

In the current study, the mean pedicle height at vertebral levels T2 to T8 and T10 to T12 in the thoracic spine was significantly larger in European population than in African and or Mixed populations. Similarly, in the lumbar spine, the mean pedicle height at vertebral levels L1, L4 and L5 was significantly larger in the European population than in African and or Mixed ancestry populations. When comparing the result with the previous studies, the values in thoracic spine obtained in American populations by Zindrick *et al.* (1987) and in Indian populations by Datir *et al.* (2004) were larger than those in the current study. In the lumbar spine, Olsewski *et al.* (1990) reported larger values in American populations whereas in Taiwan population Lien *et al.* (2007) reported smaller pedicle height as compared to the current study at almost all the vertebral levels except at L5 (Table 5.2). The mean pedicle height showed a similar trend compared to those in previous studies (Zindrick *et al.*, 1987; Olsewski *et al.*, 1990; Hou *et al.*, 1993; Kim *et al.*, 1994; Datir *et al.*, 2004) whereby the pedicle height gradually increased from vertebral levels T1 to T12 in the thoracic spine and then decreased from vertebral levels L1 to L5 in the lumbar spine (Table 5.2). Because pedicles are oval-shaped with the narrowest diameter in the transverse plane, the pedicle height was greater than the width at all levels in all the studies. However, it carries little significance in deciding the pedicular screw diameter.

Table 5.2: Comparison of pedicle height with those of other studies.

	Direct measurements (mm)			CT measurements (mm)
Vertebral Levels	**Datir *et al.* (2004)**	**Lien *et al.* (2007)**	**Olsewski *et al.* (1990)**	**Zindrick *et al.* (1987)**
	India	**Taiwan**	**American**	**American**
T1	9.4	8.7	-	9.9
T2	12.1	10.3	-	12
T3	12.2	10.4	-	12.4
T4	11.8	10.2	-	12.1
T5	11.6	10.3	-	11.9
T6	11.7	10.1	-	12.2
T7	12.5	10.4	-	12.1
T8	13.2	10.9	-	12.8
T9	14.4	12.3	-	13.8
T10	16.6	13.6	-	15.2
T11	17.7	14.9	-	17.4
T12	18.7	15.2	-	15.8
L1	-	13.6	17	15.4
L2	-	14	16	15
L3	-	13.9	16.1	14.9
L4	-	12.5	16.4	14.8
L5	-	12.3	17.4	14

5.2.3 Transverse angle

In the current study, the mean transverse angles from vertebral levels T1 to T6 in the thoracic spine and vertebral levels L1 to L4 in the lumbar spine were significantly larger in European population than in African and or Mixed ancestry populations. The values of the mean transverse angle were larger than the values reported in the American population by Zindrick *et al.* (1987) and the Indian population by Mitra *et al.* (2002). However, it followed a similar trend to other previous studies in the lumbar spine but was different in the thoracic spine. The trend of gradual increase from vertebral levels L1 to L5 observed in the current study was in agreement with the findings of Olsewski *et al.* (1990) and Zindrick *et al.* (1987) in the American population, as well as in a study in Indian population by Mitra *et al.* (2002) (Table 5.3). In the thoracic spine the current study showed that the mean transverse angle of the pedicle gradually decreased from T1 to T8 followed by increase to T12 contrary to the report by Zindrick *et al.* (1987) and Mitra *et al.* (2002), where there was gradual decrease from T1 to T12. The differences between studies could be attributed to the methods of the study. Zindrick *et al.* (1987) used computed tomography and measured the angle between a line perpendicular to the transverse isthmus of the pedicle and a line parallel to the midline of the vertebral body in the transverse plane, while the current study we measured the angle between a line in midline of vertebral body and a line bisecting the pedicle, following Berry *et al.* (1987). Differences in the mean transverse angle should always be considered during surgery because any inadvertent medial angulation of the screw may lead to the breach of the pedicular cortex with resultant damage to the adjacent spinal cord.

Table 5.3: Comparison of transverse angle with those of other studies.

	Direct measurements (deg)			CT measurements (deg)
Vertebral Levels	**Mitra *et al.* (2002)**	**Olsewski *et al.* (1990)**	**Chaynes *et al.* (2001)**	**Zindrick *et al.* (1987)**
	India	**American**	**French**	**American**
T1	30	-	27.5	26.6
T2	19	-	17.3	19.1
T3	6	-	13	14.6
T4	4	-	8.1	12.6
T5	3	-	6.8	9.4
T6	1	-	6.7	9.6
T7	1	-	7.2	8.7
T8	1	-	7.1	8.1
T9	1	-	0.9	7.6
T10	1	-	7.7	4.6
T11	0	-	0.8	1.2
T12	0	-	2	-4.2
L1	9	6		10.9
L2	10.1	6		12
L3	12.3	7		14.4
L4	14.7	11		17.7
L5	29.3	22		29.9

5.2.4 Sagittal Angle

In the current study, the mean sagittal angle at vertebral levels T1, and T10 to T12 was significantly larger in the European population than in the African and or Mixed ancestry populations, but at vertebral level T6, the mean sagittal angle was significantly larger in the Mixed ancestry population than in European and or African populations. The values of the mean sagittal angle in the thoracic spine were smaller compared with the studies by Zindrick *et al.* (1987) in the American populations and Datir *et al.* (2004) in the Indian populations (Table 5.4). However, in the lumbar spine the trend of increasing gradually from L1 to L5 for the current study were in accordance with those mentioned by Olsewski *et al.* (1990). Sagittal angle variation is as important as transverse angle in accurate screw placement because inferior migration of the screw may result in injury to the nerve root. There were significant differences in the reported values in the previous studies (Zindrick *et al.*, 1987; Olsewski *et al.*, 1990; Ebraheim *et al.*, 1996) compared to the current study. These differences difficult to say for certain rather may be due to the method of the measurement employed. Ebraheim *et al.* (1996) found that the sagittal angle ranged from 2-9 degrees for the lumbar vertebrae by measuring the angle between a line passing along the central axis of the pedicle and a line parallel to the superior border of the vertebral body as described by Olsewski *et al.* (1990), while Zindrick *et al.* (1987) measured the sagittal angle as the angle between a line perpendicular to the vertical axis of the pedicle and a line drawn from the posterior border of the vertebral body in the sagittal plane and reported the values of 11 to 16 degree in the thoracic spine and from 2 to -1 degree in the lumbar spine. In the current study the sagittal angle was measured in accordance with Olsewski *et al.* (1990), and our results, particularly at the vertebral level L1 corroborate their reported findings. The method we employed was only used by Olsewski *et al.* (1990) in the lumbar spine, and there is no available data from the thoracic spine to compare with our findings. However, our findings in the thoracic spine were not comparable to other studies with different methods of sagittal angle measurement (Zindrick *et al.*, 1987; Mitra *et al.*, 2002; Datir *et al.*, 2004).

The sagittal angle of pedicles in the thoracic and upper lumbar spine was oriented caudally while it was oriented cephalad in the lower lumbar vertebra in all the studies including in the current study (Zindrick *et al.*, 1987; Olsewski *et al.*, 1990; Datir *et al.*, 2004). Therefore, the orientation of the pedicle in the sagittal plane should be considered during pedicle screw insertion because inaccurate placement of screw along the sagittal axis may result in injury to the nerve root, which is very close to the inferior border of the pedicle.

Table 5.4: Comparison of sagittal angle with those of other studies.

	Direct measurement (deg)		CT measurements (deg)	
Vertebral Levels	**Datir *et al.* (2004)**	**Olsewski *et al.* (1990)**	**Zindrick *et al.* (1987)**	**Mitra *et al.* (2002)**
	India	**American**	**American**	**India**
T1	9.6	-	12.6	7.7
T2	11.8	-	17.5	10.4
T3	10.4	-	17.3	9
T4	8.9	-	16.3	8.6
T5	9.4	-	15	8.2
T6	8.2	-	15	7.6
T7	9.2	-	15.7	8.3
T8	8.6	-	16.6	7.2
T9	7.6	-	16	6.7
T10	5.5	-	16.8	5.5
T11	6.3	-	15.4	6.1
T12	8.5	-	11.6	7.5
L1	-	5	2.4	-
L2	-	6	1.8	-
L3	-	6	0.2	-
L4	-	7	0	-
L5	-	8	-1.8	-

5.2.5 Chord length

In the current study, the mean chord length in the European population was significantly larger than in the African and or Mixed ancestry populations at all the vertebral levels. The values were larger at all vertebral levels when compared with the values obtained in Chinese and Indian populations by Datir *et al.* (2004) and Hou *et al.* (1993), and in the American population by Scoles *et al.* (1988). However, the trend of gradually increasing from vertebral levels T1 to T12 in the thoracic spine was consistent with the observation by Datir *et al.* (2004) (Table 5.5). In the lumbar spine, the trend varied from one vertebral level to another. According to Mitra *et al.* (2002), the chord length was longest at the vertebral level of L2 and was shortest at L5. Kadioglu *et al.* (2003) found that chord length was longest at vertebral level L1 and shortest at vertebral level L5. In the current study the longest chord length was found at vertebral level L3 and the shortest was at L5 in all the three studied populations of South Africa. Chord length correlates with the choice of pedicle screw length and is important in avoiding anterior vertebral cortex perforation and probable injury to vital organs and major blood vessels anterior to the vertebral body.

For optimal screw insertion, the screw length should include 50% of the vertebral body to prevent or minimize instrument failure (Zindrick *et al.*, 1987). Therefore, to avoid the anterior cortex of the vertebral body we suggest that pedicle screw length of 25 mm at the upper thoracic level and 30 mm at the mid and lower thoracic levels is safer, while in the lumbar spine the screw length ranging from 40 to 45 mm is recommended in all the South African populations studied.

Table 5.5: Comparison of chord length with those of other studies.

	Direct measurements (mm)			CT measurement (mm)
Vertebral Levels	**Datir *et al.* (2004)**	**(Mitra *et al.*, 2002)**	**Kadioglu *et al.* (2003)**	**Scoles *et al.* (1988)**
	India	**India**	**Turkey**	**American**
T1	29.9	-	-	32
T2	29.9	-	-	-
T3	30.3	-	-	31.6
T4	31.7	-	-	-
T5	33.7	-	-	-
T6	34.8	-	-	37.7
T7	34.4	-	-	-
T8	34.7	-	-	-
T9	35.5	-	-	41.9
T10	36	-	-	-
T11	37.3	-	-	-
T12	34.7	-	-	43.3
L1	-	46.01	42.7	-
L2	-	47.56	42.5	-
L3	-	46.9	41.6	-
L4	-	46.31	41.3	-
L5	-	45.87	40.8	-

5.2.6 Inter-pedicular distance

The mean inter-pedicular distance in the current study was significantly larger in the European population than the African and or Mixed ancestry populations at all the vertebral levels. But the values were smaller than those reported by Datir *et al.* (2004) and Mitra *et al.* (2002) in the Indian populations and Kadioglu *et al.* (2003) in the Turkish population. The observed trend in the current study whereby the mean inter-pedicular distance gradually decreased from vertebral levels T1 to T6 and then gradually increased to the vertebral level T12 in the thoracic spine, differed from that reported by Datir *et al.* (2004) in the Indian population and Chaynes *et al.* (2001) in the French population, who mentioned gradual increases from vertebral level T1 to T12 (Table 5.6). However, our findings were similar to those in the American and Turkish populations (Scoles *et al.*, 1988; Panjabi *et al.*, 1991; Ugur *et al.*, 2001) where the inter-pedicular distance gradually decreased from vertebral levels T1 to T6 followed by gradual increase to T12. In the lumbar spine, the trend of gradual increase from vertebral levels L1 to L5 observed in the current study was similar to that in reported in the American Population (Panjabi *et al.*, 1991) and Turkish population (Kadioglu *et al.*, 2003), but the values were larger. The variation in the values may be as a result of differences in population and methods of study. Kadioglu *et al.* (2003) used computed tomography scans of the Turkish population for their measurement whereas Panjabi *et al.* (1991) used computer software to calculate the mean inter-pedicular distance from three dimensional images obtained from radiographic specimens.

Inter-pedicular distance determines the length of the transverse fixator system which a three-dimensional rigid grid requires to minimize the length of the spinal segment involved by the Roy-Camille plate during pedicle screw instrumentation. Depending on the spinal level, the inter-pedicular distance ranges from 15 mm to 20 mm in African and Mixed ancestry populations and from 16 mm to 21 mm in European population in the thoracic spine.

Table 5.6: Comparison of inter-pedicular distance with those of other studies.

	Direct measurements (mm)		CT measurements (mm)	Three-diamensional measurement (mm)
Vertebral Levels	**Datir *et al.* (2004)**	**Chaynes *et al.* (2001)**	**Kadioglu *et al.* (2003)**	**Panjabi *et al.* (1991)**
	India	**French**	**Turkish**	**American**
T1	21.3	17.4	-	-
T2	22.3	19.3	-	-
T3	22.7	21.2	-	-
T4	23	21.8	-	-
T5	23.5	22.8	-	-
T6	23.7	22.9	-	-
T7	24.9	24.5	-	-
T8	25.7	24.9	-	-
T9	26.8	26.1	-	-
T10	28.1	27.8	-	-
T11	29	30.7	-	-
T12	-	-	-	-
L1	-	-	22.2	23.7
L2	-	-	22.1	23.8
L3	-	-	22.5	24.3
L4	-	-	23.7	25.4
L5	-	-	24.3	27.1

5.3 INTERNAL MEASUREMENTS

5.3.1 Transverse inner cortical diameter

In the current study, the mean transverse inner cortical diameters at vertebral levels T1 to T8 were significantly larger in the European population than in the African and or Mixed ancestry populations in the thoracic spine. But in the lumbar spine, at vertebral levels L1 and L2, the mean transverse inner cortical diameter was significantly larger in the Mixed ancestry population than in the European and or African populations. However, the values of the mean transverse inner cortical diameter were smaller than previously obtained in Chinese population by Hou *et al.* (1993) and in Indian population by Kim *et al.* (1994), but showed a similar pattern of changes with vertebral levels.

Although many authors (Acharya *et al.*, 2010; Christodoulou *et al.*, 2005; Nojiri *et al.*, 2005) used external pedicle width as a guide for the choice of screw size, Cheung *et al.* (1994) believed that the inner cortical diameter is a more appropriate guide for pedicle screw size as biomechanical studies have shown that a screw that exceeds the inner cortical diameter will over-burden the cortex and lead to micro-fractures (Zindrick *et al.*, 1986; Misenhimer *et al.*, 1989; Radek *et al.*, 1993). Overburdening also results in reduction in pull-out strength of the screw (Misenhimer *et al.*, 1989). Therefore, pedicle screw diameter should not exceed the inner cortical diameter in order to allow a good purchase of the cortical bone by the screw thread without breaching the cortex.

5.3.2 Vertical inner cortical diameter

In the current study, the mean vertical inner cortical diameter at vertebral levels T2 to T8 and at T10 to T12 in the thoracic spine was significantly larger in European population than in African and or Mixed ancestry populations. Similarly, the mean vertical inner cortical diameter at vertebral levels L1, L4 and L5 in the lumbar spine was significantly larger in the European population than in African or Mixed ancestry populations. However, reports from by Zindrick *et al.* (1987) in the American population were larger at all levels than those in the current study. The mean vertical inner cortical diameter showed similar trends compared to the reports by Zindrick *et al.* (1987) in American and by Hou *et al.* (1993) in Chinese populations. Vertical inner cortical diameter carries little significance for choice of the pedicle screw diameter because the diameter is larger than the transverse inner cortical diameter at all levels.

5.4 Effects of Sex, Age and population variations on pedicular measurements

The results from the current study showed that males had significantly larger pedicle dimensions than females. These findings were consistent with the report by Hou *et al.* (1993) in Chinese populations and Olsewski *et al.* (1990) in European populations. On the contrary Chadha *et al.* (2003), Ebraheim *et al.* (1996) and Chaynes *et al.* (2001) observed no such significant difference between males and females in the European population. Zhuang *et al.* (2011) found that body height was the main factor that contribute to the variation in the pedicle size among different sex groups while Charles *et al.* (2014) showed that male, taller and heavier individuals had larger pedicle dimensions

With regard to the population affinity, the current study showed significant differences among African, European and Mixed ancestry populations of South Africa with the mean pedicle dimensions (pedicle width, pedicle height, transverse angle, sagittal angle, chord length and inter-pedicular distance) generally being larger in European population than in African and or Mixed ancestry populations. Previous studies have shown the relationship between population affinity and pedicle dimensions. Kim *et al.* (1994) showed smaller pedicle dimensions in the Korean population compared to the European population. Chadha *et al.* (2003) and Acharya *et* *al.* (2010) reported smaller pedicle dimensions in the Indian population as compared to the European population. Liau *et al.* (2006) attributed height rather than the population affinity of the subjects to the variations in the pedicle dimensions among different groups. Although, no analysis of the correlation between the body sizes or height and pedicle dimensions was done in the current study, a possible conclusion that can be drawn from the finding is that not only the body size and height but the genetic makeup, lifestyle and diet of an individual population has the potential influence to the overall pedicle dimensions. This was also evident in the various other population groups studied by Cheung *et al.* (1994), Hou *et al.* (1993) and Kim *et al.* (1994) for Chinese, Indian and Korean respectively.

With regard to the age, the current study showed that the older age group has larger pedicle dimension than the younger age group, which was consistent with the study by Charles *et al.* (2014) which showed that pedicle dimensions increased with age and that pedicle width was wider in the older age groups (50 to 70 years) than the younger age groups. On the contrary, McLain *et al.* (2002) concluded that pedicle width in the elderly subjects (age between 62 to 85 years) was too small to admit 4.5mm pedicle screw in the thoracic spine but they did not compare their data with the younger subjects. The variation in the pedicle dimension could be due to age-related reduction in bone density and osteoporosis which lead to vertebral deformity and elevation in pedicle dimensions as people aged.

6 CHAPTER SIX: CONCLUSION AND RECOMENDATION

This study showed variations in pedicle dimensions among African, European and mixed ancestry South Africa populations and also compared the result with other Asian and European populations. The pedicle dimensions in South African populations were smaller compared to the European populations. In addition, there were significant differences between gender and age groups. These differences may have direct effect on the pedicle screw fixation. Therefore, it is essential for the orthopedic surgeon to use data obtained from local populations in order to ensure proper selection of pedicle screw size and trajectory. There are other variables such as weight and body mass index which may affect the size of the pedicle. This study did not take in to account the aforementioned variables. Therefore, further studies need to be carried out to analyze the effect of weight and body mass index on the pedicle dimensions in the South African population.

7 REFERENCES

Acharya, S., Dorje, T. & Srivastava, A. 2010. Lower dorsal and lumbar pedicle morphometry in Indian population: a study of four hundred fifty vertebrae. *Spine,* 35(10)**,** E378-E384.

Amonoo-Kuofi, H. 1995. Age-related variations in the horizontal and vertical diameters of the pedicles of the lumbar spine. *Journal of anatomy,* 186(Pt 2)**,** 321-328.

Andrea, L. H., Mehmet, Z., Charles, B. S. & Edward, C. B. 2005. *Spine Surgery: Techniques, Complication Avoidance, and Management.,* New York, Elesevier Churchill Livingstone.

Asmussen, E. 1959. The weight-carrying function of the human spine. *Acta Orthopaedica Scandinavica,* 29(1-4)**,** 276-290.

Barr, S. J., Schuette, A. M. & Emans, J. B. 1997. Lumbar pedicle screws versus hooks: results in double major curves in adolescent idiopathic scoliosis. *Spine,* 22(12)**,** 1369-1379.

Berry, J. L., Moran, J. M., Berg, W. S. & Steffee, A. D. 1987. A morphometric study of human lumbar and selected thoracic vertebrae. *Spine,* 12(4)**,** 362-367.

Blumenthal, S. & Gill, K. 1993. Complications of the Wiltse Pedicle Screw Fixation System. *Spine,* 18(13)**,** 1867-1871.

Bogduk, N. 2005. *Clinical anatomy of the lumbar spine and sacrum,* New York, Churchill Livinstone.

Bogduk, N. & Long, D. M. 1979. The anatomy of the so-called “articular nerves” and their relationship to facet denervation in the treatment of low-back pain. *Journal of neurosurgery,* 51(2)**,** 172-177.

Boos, N. & Aebi, M. 2008. *Spinal disorders: fundamentals of diagnosis and treatment*., Berlin, Springer.

Boos, N. & Webb, J. 1997. Pedicle screw fixation in spinal disorders: a European view. *European Spine Journal,* 6(1)**,** 2-18.

Boucher, H. 1959. A method of spinal fusion. *Bone & Joint Journal,* 41(2)**,** 248-259.

Brown, C. A., Lenke, L. G., Bridwell, K. H., Geideman, W. M., Hasan, S. A. & Blanke, K. 1998. Complications of pediatric thoracolumbar and lumbar pedicle screws. *Spine,* 23(14)**,** 1566-1571.

Chadha, M., Balain, B., Maini, L. & Dhaon, B. 2003. Pedicle morphology of the lower thoracic, lumbar, and S1 vertebrae: an Indian perspective. *Spine,* 28(8)**,** 744-749.

Charles, C. Y., Bajwa, N. S., Toy, J. O., Ahn, U. M. & Ahn, N. U. 2014. Pedicle morphometry of upper thoracic vertebrae: an anatomic study of 503 cadaveric specimens. *Spine,* 39(20)**,** E1201-E1209.

Chaynes, P., Sol, J.-C., Vaysse, P., Becue, J. & Lagarrigue, J. 2001. Vertebral pedicle anatomy in relation to pedicle screw fixation: a cadaver study. *Surgical and Radiologic Anatomy,* 23(2)**,** 85-90.

Cheung, K., Ruan, D., Chan, F. & Fang, D. 1994. Computed tomographic osteometry of Asian lumbar pedicles. *Spine,* 19(13)**,** 1495-1498.

Cho, W., Cho, S. & Wu, C. 2010. The biomechanics of pedicle screw-based instrumentation. *Bone & Joint Journal,* 92(8)**,** 1061-1065.

Christodoulou, A. G., Apostolou, T., Ploumis, A., Terzidis, I., Hantzokos, I. & Pournaras, J. 2005. Pedicle dimensions of the thoracic and lumbar vertebrae in the Greek population. *Clinical Anatomy,* 18(6)**,** 404-408.

Cinotti, G., Gumina, S., Ripani, M. & Postacchini, F. 1999. Pedicle instrumentation in the thoracic spine: a morphometric and cadaveric study for placement of screws. *Spine,* 24(2)**,** 114-119.

Cotrel, Y., Dubousset, J. & Guillaumat, M. 1988. New universal instrumentation in spinal surgery. *Clinical orthopaedics and related research,* 227, 10-23.

Datir, S. P., Mitra, S. R. & Jadhav, S. O. 2004. Morphometric study of the thoracic vertebral pedicle in an Indian population. *Spine,* 29(11)**,** 1174-1181.

Dayal, M. R., Kegley, A. D., Štrkalj, G., Bidmos, M. A. & Kuykendall, K. L. 2009. The history and composition of the Raymond A. Dart Collection of human skeletons at the University of the Witwatersrand, Johannesburg, South Africa. *American Journal of Physical Anthropology,* 140(2)**,** 324-335.

Drake, R., Vogl, W. & Mitchell, A. 2005. Grey's anatomy. Elsevier/Churchill Livingstone, Philadelphia.

Ebraheim, N. A., Rollins Jr, J. R., Xu, R. & Yesting, R. A. 1996. Projection of the lumbar pedicle and its morphometric analysis. *Spine,* 21(11)**,** 1296-1300.

Gaines, R. W. 2000. The use of pedicle-screw internal fixation for the operative treatment of spinal disorders. *J Bone Joint Surg Am,* 82(10)**,** 1458-1458.

Gertzbein, S. D. & Robbins, S. E. 1990. Accuracy of pedicular screw placement in vivo. *Spine,* 15(1)**,** 11-14.

Grey, H. 2008. *Grey anatomy: The anatomical basis of clinical practise,* Edinburgh, Elsevier Churchill Livingstone.

Harrington, P. R. 1988. The History and Development of Harrington Instrumentation. *Clinical Orthopaedics and Related Research,* 227, 3-5.

Herzog, W. 2000. *Clinical biomechanics of spinal manipulation*, Churchill Livingstone.

Hirano, T., Hasegawa, K., Takahashi, H. E., Uchiyama, S., Hara, T., Washio, T., Sugiura, T., Yokaichiya, M. & Ikeda, M. 1997. Structural characteristics of the pedicle and its role in screw stability. *Spine,* 22(21)**,** 2504-2510.

Hou, S., Hu, R. & Shi, Y. 1993. Pedicle morphology of the lower thoracic and lumbar spine in a Chinese population. *Spine,* 18(13)**,** 1850-1855.

John, P. S. 2008. *Design, Development and Application of Computer Assisted Pedicle Screw Fixation.* Doctor of Philosophy in Physics, Mahatma Gandhi University.

Kabins, M. B. & Weinstein, J. N. 1991. The history of vertebral screw and pedicle screw fixation. *The Iowa Orthopaedic Journal,* 11, 127-136.

Kadioglu, H., Takci, E., Levent, A., Arik, M. & Aydin, I. 2003. Measurements of the lumbar pedicles in the Eastern Anatolian population. *Surgical and Radiologic Anatomy,* 25(2)**,** 120-126.

Kang, K. S., Song, K.-S., Lee, J. S., Yang, J. J. & Song, I. S. 2011. Comparison of radiographic and computed tomographic measurement of pedicle and vertebral body dimensions in Koreans: the ratio of pedicle transverse diameter to vertebral body transverse diameter. *European Spine Journal,* 20(3)**,** 414-421.

Kim, N.-H., Lee, H.-M., Chung, I.-H., Kim, H.-J. & Kim, S.-J. 1994. Morphometric study of the pedicles of thoracic and lumbar vertebrae in Koreans. *Spine,* 19(12)**,** 1390-1394.

Kim, Y. J., Lenke, L. G., Bridwell, K. H., Cho, Y. S. & Riew, K. D. 2004. Free hand pedicle screw placement in the thoracic spine: is it safe? *Spine,* 29(3)**,** 333-342.

King, D. 1948. Internal fixation for lumbosacral fusion. *J Bone Joint Surg Am,* 30(3)**,** 560-578.

Kowalski, R. J., Ferrara, L. A. & Benzel, E. C. 2005. Biomechanics of the spine. *Neurosurgery Quarterly,* 15(1)**,** 42-59.

Krag, M., Weaver, D., Beynnon, B. & Haugh, L. 1988. Morphometry of the thoracic and lumbar spine related to transpedicular screw placement for surgical spinal fixation. *Spine,* 13(1)**,** 27-32.

Kramer, B. & Allan, J. 2005. *Fundamentals of Human Osteology,* Johannesburg, LexisNexis Butterworths.

Liau, K. M., Yusof, M. I., Abdullah, M. S., Abdullah, S. & Yusof, A. H. 2006. Computed tomographic morphometry of thoracic pedicles: safety margin of transpedicular screw fixation in malaysian malay population. *Spine,* 31(16)**,** E545-E550.

Lien, S.-B., Liou, N.-H. & Wu, S.-S. 2007. Analysis of anatomic morphometry of the pedicles and the safe zone for through-pedicle procedures in the thoracic and lumbar spine. *European Spine Journal,* 16(8)**,** 1215-1222.

Liljenqvist, U. R., Halm, H. F. & Link, T. M. 1997. Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. *Spine,* 22(19)**,** 2239-2245.

Lonstein, J. E., Denis, F., Perra, J. H., Pinto, M. R., Smith, M. D. & Winter, R. B. 1999. Complications associated with pedicle screws. *J Bone Joint Surg Am,* 81(11)**,** 1519-28.

Louis, R. 1986. Fusion of the lumbar and sacral spine by internal fixation with screw plates. *Clinical orthopaedics and Related research,* 203, 18-33.

Maaly, M. A., Saad, A. & Houlel, M. E. 2010. Morphological measurements of lumbar pedicles in Egyptian population using computerized tomography and cadaver direct caliber measurements. *The Egyptian Journal of Radiology and Nuclear Medicine,* 41(4)**,** 475-481.

Magerl, F. P. 1984. Stabilization of the lower thoracic and lumbar spine with external skeletal fixation. *Clinical orthopaedics and related research,* 189, 125-141.

Maillot, C. & Wolfram-Gabel, R. 1993. Pedicles of lumbar vertebrae. *Surgical and Radiologic Anatomy,* 15(4)**,** 295-300.

Marchesi, D., Schneider, E., Glauser, P. & Aebi, M. 1988. Morphometric analysis of the thoracolumbar and lumbar pedicles, anatomo-radiologic study. *Surgical and Radiologic Anatomy,* 10(4)**,** 317-322.

Mclain, R. F., Ferrara, L. & Kabins, M. 2002. Pedicle morphometry in the upper thoracic spine: limits to safe screw placement in older patients. *Spine,* 27(22)**,** 2467-2471.

Middleditch, A. & Oliver, J. 2005. *Functional anatomy of the spine*, Oxford,Elsevier Health Sciences.

Misenhimer, G., Peek, R., Wiltse, L., Rothman, S. & Widell Jr, E. 1989. Anatomic analysis of pedicle cortical and cancellous diameter as related to screw size. *Spine,* 14(4)**,** 367-372.

Mitra, S. R., Datir, S. P. & Jadhav, S. O. 2002. Morphometric study of the lumbar pedicle in the Indian population as related to pedicular screw fixation. *Spine*, 27(5)**,** 453-459.

Moore, K. L. 2013. *Moore clinically oriented anatomy*, Baltimore, Lippincott Williams & Wilkins.

Moran, J. M., Berg, W. S., Berry, J. L., Geiger, J. M. & Steffee, A. D. 1989. Transpedicular screw fixation. *Journal of orthopaedic research*, 7(1)**,** 107-114.

Netter, F. 2014. *Atlas of human anatomy*, Philadelphia, PA Saunders/Elsevier.

Nojiri, K., Matsumoto, M., Chiba, K. & Toyama, Y. 2005. Morphometric analysis of the thoracic and lumbar spine in Japanese on the use of pedicle screws. *Surgical and Radiologic Anatomy*, 27(2)**,** 123-128.

Olsewski, J., Simmons, E., Kallen, F., Mendel, F., Severin, C. & Berens, D. 1990. Morphometry of the lumbar spine: anatomical perspectives related to transpedicular fixation. *JBJS*, 72(4)**,** 541-549.

Panjabi, M. M., Takata, K., Goel, V., Federico, D., Oxland, T., Duranceau, J. & Krag, M. 1991. Thoracic Human Vertebrae. Quantitative Three-Dimensional Anatomy. *Spine*, 16(8)**,** 888-901.

Parham, R. 2013. *Design and Development of a Novel Expanding Pedicle screw for use in the Osteoporotic Lumbar Spine.* Master of Medical Biophysics, The University of Western Ontario.

Patil, D. K. & Bhuiyan, P. S. 2014. A morphometric study of the Pedicles of dry human typical lumbar vertebrae. *Indian Journal of Basic and Applied Medical Research,* 3(3)**,** 428-433.

Pennal, G., Mcdonald, G. & Dale, G. 1964. A method of spinal fusion using internal fixation. *Clinical Orthopaedics and Related Research,* 35: 86-94.

Petersilge, C. A., Lewin, J. S., Duerk, J. L., Yoo, J. U. & Ghaneyem, A. J. 1996. Optimizing imaging parameters for MR evaluation of the spine with titanium pedicle screws. *AJR. American Journal of Roentgenology,* 166(5)**,** 1213-1218.

Pihlajamäki, H., Myllynen, P. & Böstman, O. 1997. Complications of transpedicular lumbosacral fixation for non-traumatic disorders. *Bone & Joint Journal,* 79(2)**,** 183-189.

Radek, A., Maciejczak, A. & Laskowski, A. 1993. An internal fixator for posterior application to short segments of thoracic, lumbar and lumbosacral spine. Design and testing. *Neurologia i Neurochirurgia Polska,* 28(4)**,** 567-575.

Roy-Camille, R., Demeuleneare, C., Barcat, E. & Saillant, G. 1973. [Dorsal and lumbar spine osteosynthesis by posterior approach]. *La Nouvelle Presse Medicale,* 2(19)**,** 1309-1312.

Roy-Camille, R., Saillant, G. & Mazel, C. 1986. Internal fixation of the lumbar spine with pedicle screw plating. *Clinical Orthopaedics and Related Research,* 203: 7-17.

Saillant, G. 1976. [Anatomical study of the vertebral pedicles. Surgical application]. *Revue de Chirurgie Orthopedique et Reparatrice de l'appareil Moteur,* 62(2)**,** 151-160.

Schultz, A. B. & Ashton-Miller, J. A. 1991. Biomechanics of the human spine. *Basic Orthopaedic Biomechanics***,** 337-374.

Scoles, P., Linton, A., Latimer, B., Levy, M. & Digiovanni, B. 1988. Vertebral body and posterior element morphology: the normal spine in middle life. *Spine,* 13(10)**,** 1082.

Scott, J. E., Bosworth, T. R., Cribb, A. M. & Taylor, J. R. 1994. The chemical morphology of age-related changes in human intervertebral disc glycosaminoglycans from cervical, thoracic and lumbar nucleus pulposus and annulus fibrosus. *Journal of Anatomy,* 184(Pt 1)**,** 73-82

Singel, T., Patel, M. & Gohil, D. 2004. A study of width and height of lumbar pedicles in Saurashtra region. *Journal of the Anatomical Society of India,* 53(1)**,** 4-9.

Steinmann, J. C., Herkowitz, H. N., El-Kommos, H. & Wesolowski, D. P. 1993. Spinal pedicle fixation. Confirmation of an image-based technique for screw placement. *Spine,* 18(13)**,** 1856-1861.

Tan, S., Teo, E. & Chua, H. 2004. Quantitative three-dimensional anatomy of cervical, thoracic and lumbar vertebrae of Chinese Singaporeans. *European Spine Journal,* 13(2)**,** 137-146.

Toumey, J. 1943. Internal fixation in fusion of the lumbosacral joints. *Lahey Clinic Bulletin,* 3, 188-191.

Ugur, H. Ç., Attar, A., Uz, A., Tekdemir, I., Egemen, N. & Genç, Y. 2001. Thoracic pedicle: surgical anatomic evaluation and relations. *Clinical Spine Surgery,* 14(1)**,** 39-45.

Weinstein, J. N., Rydevik, B. L. & Rauschning, W. 1992. Anatomic and technical considerations of pedicle screw fixation. *Clinical Orthopaedics and Related Research,* 284, 34-46.

White, A. A. & Panjabi, M. M. 1990. *Clinical biomechanics of the spine*, Lippincott Philadelphia.

Xu, R., Ebraheim, N. A., Ou, Y. & Yeasting, R. A. 1998. Anatomic considerations of pedicle screw placement in the thoracic spine: Roy-Camille technique versus open-lamina technique. *Spine*, 23(9)**,** 1065-1068.

Zhuang, Z., Chen, Y., Han, H., Cai, S., Wang, X., Qi, W. & Kong, K. 2011. Thoracic pedicle morphometry in different body height population: a three-dimensional study using reformatted computed tomography. *Spine,* 36(24)**,** E1547-E1554.

Zindrick, M. & Hodges, S. 1996. Clinical Anatomy of the Lumbosacral Junction and Pelvis. *In:* Joseph, Y. M. E. A. (ed.) *Lumbosacral and spinopelvic fixation.* Philadelphia. New York: Lippincott-Raven.

Zindrick, M. R., Wiltse, L. L., Doornik, A., Widell, E. H., Knight, G. W., Patwardhan, A. G., Thomas, J. C., Rothman, S. L. & Fields, B. 1987. Analysis of the morphometric characteristics of the thoracic and lumbar pedicles. *Spine*, 12(2)**,** 160-166.

Zindrick, M. R., Wiltse, L. L., Widell, E. H., Thomas, J. C., Holland, W. R., Field, B. T. & Spencer, C. W. 1986. A biomechanical study of intrapeduncular screw fixation in the lumbosacral spine. *Clinical Orthopaedics and Related Research,* 203, 99-112.

8 APPENDICES

8.1 APPENDIX 1: ETHICS WAIVER

Human Research Ethics Committee (Medical)

Research Office Secretariat: Senate House Room SH 10005, 10th floor. Tel +27 (0)11-717-1252
Medical School Secretariat: Medical School Room 10M07, 10th Floor. Tel +27 (0)11-717-2700
Private Bag 3, Wits 2050, www.wits.ac.za. Fax +27 (0)11-717-1265

Ref: W-CJ-140604-1 25/01/2016

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: School of Anatomical Sciences (Head: Prof M Steyn - Previously Prof T J M Daly, initial approval 04/06/2014 – recertified 27/01/2016).

Project title: Research on Cadaveric Material.

Reason: In terms of Chapter 8, sections 62-64 of the National Health Act No 61 of 2003 donated bodies and their tissues may be used for, among other purposes, health, and research. Use of such Material is subject only to permission from the responsible person in the School of Anatomical Sciences – the Head or person designed by the Head.

Professor Peter Cleaton-Jones

Chair: Human Research Ethics Committee (Medical)

UNIVERSITY OF THE WITWATERSRAND
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29 JAN 2016
RESEARCH OFFICE HREC (Medical)
JOHANNESBURG

Copy - HREC (Medical) Secretariat: Rhulani Mkansi, Zanele Ndlovu.

8.2 APPENDIX 2: TINITIN REPORT

1332558:Dissertation_for_tinitin.pdf

ORIGINALITY REPORT

12%	7%	8%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	jeb.biologists.org Internet Source	1%
2	Submitted to University of Technology Student Paper	1%
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4	Submitted to North East Surrey College of Technology, Surrey Student Paper	<1%
5	Zerui Zhuang. "Thoracic Pedicle Morphometry in Different Body-height Population : A Three Dimensional Study using Reformatted Computed Tomography", Spine, 01/2011 Publication	<1%
6	Kenya Nojiri. "Morphometric analysis of the thoracic and lumbar spine in Japanese on the use of pedicle screws", Surgical and Radiologic Anatomy, 04/2005 Publication	<1%