MORPHOMETRIC ANALYSIS OF LUMBAR PEDICLES AMONG ADULT KENYANS USING COMPUTER TOMOGRAPHY SCANS AND DRY BONE SPECIMENS

BY

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DECLARATION

Declaration by the Student

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DEDICATION

The researcher dedicates this study to his wife, son, daughter, parents and siblings who have shown great support and encouragement throughout the research and training period.

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LIST OF ABBREVIATIONS AND ACRONYMS

APD	Antero-Posterior Body Diameter
IPD	Interpedicular Distance
IREC	Institution Research and Ethics Committee
KNH	Kenyatta National Hospital
L1-L5	Lumbar 1 to Lumbar 5
LBP	Lower Back Pain
MSD	Midsagittal Diameter
PL	Pedicle Length

DEFINITION OF KEY TERMS

Chord length	- It is the distance from the most posterior aspect of the junction of the superior facet and the transverse process to the anterior cortex of the vertebral body along the pedicle axis.
Pedicle height	- It is the vertical distance between superior and inferior border of pedicle at its midpoint.
Pedicle width	- It is the distance between medial and lateral surfaces of pedicle at its midpoint, measured at right angles to the long axis of the pedicle.
Transverse pedicle angle	- It is the angle between a line passing through the pedicle axis and a line parallel to the vertebral midline in the transverse plane.

ABSTRACT

Background: There is a rise in the number of spine surgeries performed in kenya. Complications arising from misplaced lumbar pedicle screws are projected to rise with the use of free hand technique. This study was designed to provide accurate measurements of the adult kenyan lumbar pedicle.

Objectives: To determine the width, height, angulation and chord length of the lumbar vertebrae pedicle from L1 to L5 in adult Kenyans using Computer tomography scans and dry bone specimens.

Methods: This was a cross sectional descriptive study conducted at the Nairobi National Museum and St. Luke's Hospital from January 1st – 31st December 2016. Ethical clearance was granted from IREC.Lumbar pedicle dimensions from L1-L5 were measured.100 dry bone specimens and 100 computer tomography scans were used. Data was recorded in data collection sheets, extracted and entered into Microsoft Excel then transferred to SPSS version 21 for analysis. Results from the analysis were summarized as means, standard deviations and presented in line and bar graphs**.**

Results: One hundred dry bones were used for the study. Out of the 100 dry bones, 55 were male, with an age range of 31-89 years.100 computer tomography scans were used for the study with 49 males, with an age range of 18-63 years. Pedicle width mean measurements were L1-8.6mm, L2-9.6mm, L3-11.4mm, L4-13.5mm, L5-16.3mm on dry bone specimens. On computer tomography scans, pedicle width mean measurements were L1-7.2mm, L2-7.6mm, L3-9.2mm, L4-10.8mm, L5-14. 6mm.Pedicle height mean measurements on dry bone specimen were L1-16.2mm, L2-15.4mm, L3-14.5mm, L4-13.5mm, and L5-12.1 mm. The mean angle of insertion on computer tomography scans was L1-19.7^o, L2-20.5^o, L3-22^o, L4-24.1^o, L5-29.8^o. Pedicle chord length measurements obtained were L1-47.9mm, L2-48.9mm, L3-48.9mm, L4-47.7mm, and L5-47.0 mm on dry bone specimen. On computer tomography scan it was, L1-48.6mm, L2-49.9mm, L3-50.1mm, L4-49.8mm, and L5-50.1 mm.

Conclusion: The pedicle width on computer tomography scan measurements increased from 7.2mm to 14.6mm and on dry bone specimen it increased from 8.6mm to 16.3mm between L1 to L5. The pedicle height decreased from 16.2mm to 12.1mm between L1 to L5 on dry bone specimen measurement. The angulation increased from L1 to L5 on computer tomography scan measurements from 19.7^o at L1 to 29.8^o at L5**.** The chord length range measurement on dry bone specimen ranged from 47.9mm to 48.9mm and on computer tomography scans from 48.6mm to 50.1mm.

Recommendations: The minimum size of screw diameter that should be used is 6.5mm with a length of 45mm angulated between 20^o to 30^o from L1 to L5. Based on the variation there is need for measurements of the pedicle dimensions before trans-pedicular instrumentation. Further research should be carried out on lumbar pedicle dimensions based on age, weight and height as there exists variations.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study.

The pedicle is part of the lumbar vertebral bone that separates the transverse process and lamina from the body of vertebral bone (S Standring, Ellis, Healy, Johnson, & Williams, 2008).

The pedicle forms the strongest part of the lumbar vertebra, made up of entirely cortical bone with a small core of cancellous, thus vertebral pedicles offer unique fixation site for implants on the vertebrae(Inceoglu, Burghardt, Akbay, Majumdar, & McLain, 2005).

As pedicle is the strongest part of lumbar vertebrae, it acts as a strut to transmit forces between the body and neural arch. The transfer of compressive forces between the body and neural arch takes place through the pedicle, which acts as a beam connecting the two columns; anterior and posterior columns(Singel, Patel, & Gohil, 2004).

In spinal injuries, degenerative disorders, congenital disorders with neurologic impairment spinal instrumentation through the pedicle helps in stabilizing the impaired segment maintaining stability of the spine and allowing recovery of neurological deficits and proper rehabilitation(Taghva, Hoh, & Lauryssen, 2012).

Spinal fusion surgery via transpedicular fixation is the most commonly used technique for surgical treatment of degenerative, vascular, infectious, metastatic, congenital, and traumatic pathologies affecting the lumbar spine(Park, Garton, Gala, Hoff, & McGillicuddy, 2004).

The number of patients with degenerative diseases of the lumbar spine is increasing, which seems to be a natural consequence of aging due to the increase in life expectancy. It is estimated that between 70-90% of the general population suffer from low back pain and that approximately 4% require surgery at some time. One treatment option for these degenerative disorders is lumbar fusion surgery which can be performed with an open or minimally invasive technique(Humphreys et al., 2001).

In 2003,spinal fusion surgery via transpedicular fixation became the nineteenth most performed surgical procedure in the United States, and it increased from 22 to 51 procedures performed per 100,000 inhabitants (Santoni et al., 2009).

There are various ways of performing spinal surgery with anterior and posterior approaches being the major ones. When stabilizing posteriorly transpedicular screw fixation has been shown to be superior to other surgical approaches(Santoni et al., 2009).A thorough knowledge of anatomic orientation and dimensions of lumbar vertebrae is necessary for precise clinical and surgical management spine pathology.

Lumbar pedicle fixation is considered one of the most stable and versatile methods for stabilization of lumbosacral spine. The procedure involves the introduction of pedicle screws through a point located at the junction of the transverse process and mid-point of the pars. The screw crosses the pedicle to reach the vertebral body providing stability and internal fixation of the affected vertebral segment(Lien, Liou, & Wu, 2007).

Among the advantages of this procedure are stabilization of affected vertebral segments, biomechanical superiority of this system, potential three-dimensional correction of vertebral deformities, reduction of postoperative complications and a shorter hospital stay, and greater clinical improvement(Gómez et al., 2006).

The lumbar pedicle also plays an important role in transmission of body weight from the neural arch to the anterior part of the vertebral column as reported from the biomechanical study by Sinnatamby (Sinnatamby, 2011).Approximately 60% of fixation strength of the lumbar pedicles lies in the pedicle, whereas 20-25% of the fixation strength is derived from the anterior cortex and the rest 15-20% of strength comes from the cancellous bone(Aydogan et al., 2009).

In lumbar region, where the curvature is posterior a part of compressive force of the body (anterior column) is transmitted to the neural arch (posterior column) through the pedicles. This transfer of load between body and neural arch (i.e. between anterior and posterior columns) tends to approach the line of gravity. The characteristic morphology of lumbar pedicles decides and hence dictates its importance. The size of lower lumbar pedicle, particularly L5, helps in preventing forward slide of L5 over S1(Aydogan et al., 2009).

The morphometric characteristics of the vertebrae, and especially the pedicle, determine the size of pedicle implants both in width and length, and the shape, direction, and ideal angulation at the moment of introduction. Knowledge of these features is important for the surgeon to avoid pedicle cortex violation that would lead to dural tears, nerve root injuries, viscera or adjacent vascular structure lesions due to poor placement or improper screw orientation(CASTRO-REYES et al., 2015).

The lumbar pedicle fixation can be used in various clinical conditions to provide spine stability. This disorder including traumatic vertebral fractures, scoliosis, spondylolisthesis and degenerative disorders such as vertebral compression fractures. Various pedicle screw fixation systems involve insertion of screw through the pedicle into the vertebral body from the posterolateral aspect for vertebral immobilization and stabilization to allow recovery(CASTRO-REYES et al., 2015).

The success of the transpedicular screw fixation technique depends on the size of the pedicle, the trajectory, the screw size used and the quality of the vertebral body (S. Wray et al., 2015).

The pedicle is also used as an access for procedures performed within the vertebral body, such as biopsies or vertebroplasty (Lien, Liou & Wu, 2007).

1.2 Problem Statement.

Spine surgeons have been hesitant in placing transpedicular screws for lumbar spine stabilization. This is because studies have shown variations in the dimensions and orientation of the lumbar pedicle in different races, gender and even within the same population group. As such this study sought to conduct a morphometric analysis of lumbar pedicles among adult Kenyans using computer tomography scans and dry bone specimens as accurate anatomic knowledge of the pedicle is required in order to avoid injuries to the neurovascular structures. With detailed knowledge, transpedicular screw surgery will finally be adopted as the preferred and safe option of lumbar spine surgery in Kenya as other countries have done, such as India, Mexico, America, Korea.

1.3 Justification of the Study.

This research would provide accurate knowledge about the different measurements of the pedicle to assist the spine surgeon know the right size of screw diameter to use, the angle of entry (trajectory) and extent he has to advance into the pedicle in performing transpedicular stabilization of the vertebral column to reduce risk of iatrogenic injury to the aorta, inferior vena cava and spinal cord.

The results on pedicle width would provide information on the diameter of the pedicle screw to be used at the five levels of lumbar vertebrae in order not to perforate the medial pedicle wall and cause damage to the spinal cord that is situated within the neural arch.

The chord length will be used to select a screw of the appropriate length to avoid going beyond the vertebral body and cause damage to the aorta or inferior vena cava which lie anterior to the vertebral bodies.

The findings on pedicle angle would be used to provide information on the angle at which the screw is angulated to prevent pedicle violation and damage to the spinal cord within the vertebral canal.

The findings on the pedicle height will be used to determine the size of the largest screw diameter to be used so as to avoid pedicle wall violation.

Finally, with the increase in number of specialists in orthopaedic spine surgery and training institutions locally more spine surgeries will be performed thus this study would provide the Kenyan surgeon with accurate information about the pedicle dimensions and orientation to enable him/her to perform surgeries with good outcomes for the patient, meaning less post-operative complications, quick recovery and better rehabilitation to the patient.

1.4 Research Question.

What are the anatomical dimensions and orientation of the Lumbar vertebral pedicle from L1 to L5 in adult Kenyans using Computer tomography scans and dry bone specimens?

1.5 Objectives

1.5.1 Broad Objective.

To determine the anatomical dimensions and orientation of the lumbar vertebrae pedicles from L1 to L5 in adult Kenyans using Computer tomography scans and dry bone specimens.

1.5.2 Specific Objectives.

The specific objectives of the study were:

1. To measure the width of the lumbar pedicle amongst the Kenyan population.
2. To measure the vertical height of the lumbar pedicle amongst the Kenyan population.
3. To measure the angulation of the pedicle from the midline amongst the Kenyan population.
4. To measure the absolute chord length of the lumbar pedicle amongst the Kenyan population.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

2.1.1 Anatomic description of the lumbar vertebrae

The lumbar vertebrae are 5 in number designated as L1 to L5. They differ from the other vertebrae in various ways; they have:

a) Vertebral body is large, wider from side to side and little thicker in front than behind

b) The pedicles are very strong directed backwards.

c) The laminas are broad, short and strong.

d) The vertebral foramen is triangular

e) The spinous process is thick, broad and somewhat quadrilateral

f) The transverse processes are long and slender

g) There are 3 tubercles noticed in the transverse process: The lateral costiform process; The mammillary process is on the back of the posterior articular process; and The accessory process is on the back of the transverse process

h) The first lumbar vertebra is characterized by a strong pedicle which springs from the posterolateral aspect of the body just below its upper border. The spinous process is broader and more in line with the vertebral body and slightly inclined downwards as compared to L5. Vertebral body is smaller and less thick than L5.

i) The fifth lumbar vertebra is characterized by its body being deeper in front than behind, smaller spinous process, thick transverse processes, wide inferior articular processes. This vertebra is a more common site for spondylolysis and spondylolisthesis (Lakkol et al., 2011).

The pedicle lies between transverse process and body of the vertebrae. They are short, thick, rounded dorsal projections from the superior part of the body at the junction of its lateral and dorsal surfaces: the concavity formed by the curved superior border of the pedicle is shallower than the inferior one. The vertebrae articulate with the intervertebral disc and facet joints; these adjacent vertebral notches contribute to an intervertebral foramen. The complete perimeter of an intervertebral foramen consists of the notches, the dorsolateral aspects of parts of adjacent vertebral bodies and the intervening disc, and the capsule of the synovial facet joint (Susan Standring, 2015).

The intervertebral disc which connects the two vertebral bodies is separated from each vertebral body by a hyaline cartilage plate. It is made up of an outer fibrous casing the annulus fibrosis and an inner gelatinous tube the nucleus pulpous. The anterior fibers are strengthened by the powerful anterior longitudinal ligament. Posterior longitudinal ligament affords only weak reinforcement especially at L4-L5 and L5-S1. As the cartilage is avascular it derives its nutrition from the body of the vertebra through the end plates by diffusion. The nucleus pulposus dissipates mechanical stresses. The annulus fibrosis acts as a shock absorber and is subjected to repeated stress(Susan Standring, 2015).

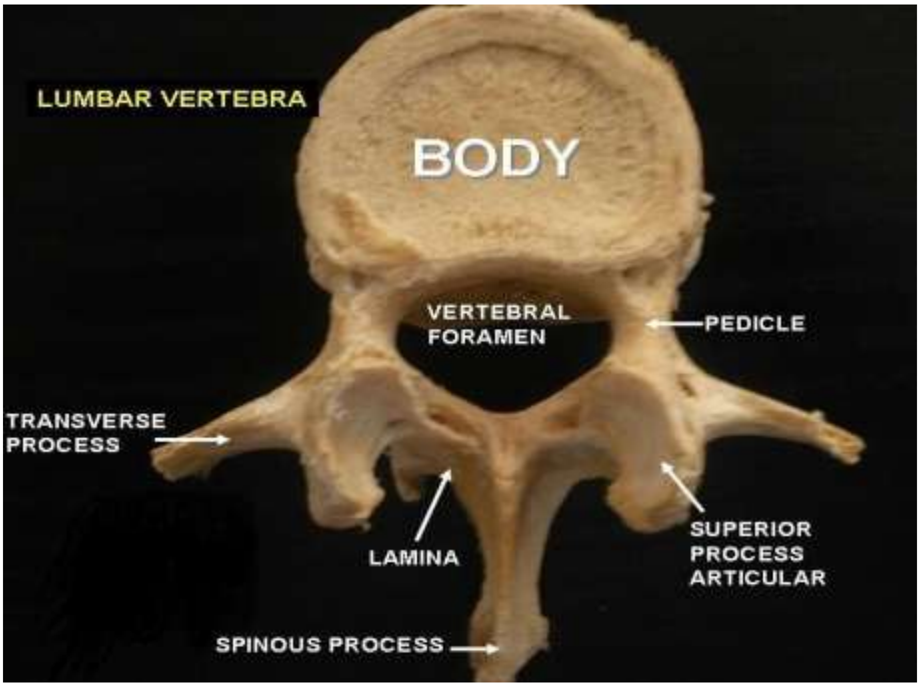

Figure 2.1: Lumbar Pedicle, Vertebral Canal, Body, Lamina and Spinous Process (Susan Standring, 2015).Page 725, Gray's Anatomy,41st Edition.

The vertical height of the pedicle is less than that of the body, to allow room for passage of the spinal nerve through the intervertebral foramen between the pedicles of adjacent vertebrae. The pedicle connects the vertebral bodies to the posterior elements. It is a cylinder-like structure and its medial cortex is thicker than the lateral cortex. They are oval in cross section, having larger heights and smaller widths. However, its elliptical shape is highly variable. The medial wall of the pedicle is bounded by the exiting nerve roots and the dural sac. Superiorly and inferiorly, the pedicle is bounded by the adjacent neural foramen(Sinnatamby, 2011).

The pedicle is strongest part of a lumbar vertebra. It is made up of entirely cortical bone with a small core of cancellous bone. The upper margins form the superior vertebral notch, and lower margins form the inferior vertebral notch, both contribute to corresponding intervertebral foramen(Inceoglu et al., 2005).

The pedicle according to Miller *et al*., (2012), angulate more as one moves distally

L1: 12 degrees.

L5: 30 degrees.

The width of the pedicle increases from L1 to L5.Lumbar vertebrae 1 has smallest diameter in lumbar spine (T4 has smallest diameter overall) (Miller, Thompson, & Hart, 2012). Sacral vertebrae 1 has an average diameter of ~19mm (Miller *et al.*, 2012). The transverse (width) and vertical (height) parameters of pedicle dictate the screw diameter but since we have a smaller width than the height at each lumbar vertebra, the width, mainly dictates the screw diameter.

2.1.2 Functions of the Pedicle in Weight Transmission.

As the pedicle is the strongest part of the lumbar vertebrae, it acts as a strut to transmit forces between the body and the neural arch. Pal and Routal (1987 & 1986) using the morphometric methods studied the role of the neural arch in weight transmission. According to them, the load in thoracic and lumbar regions is transmitted through two vertical running columns, anterior of which is formed by vertebral bodies and intervertebral discs while posterior column is formed by successive articulations of neural arch elements (facet joints, laminae, and ligamentous complex). Both of these columns are involved in load transmission. Their studies have also shown that the relative magnitude of compressive force passing through the body and neural arch alters with the change of curvature at cardiothoracic and thoracolumbar junction.

The transfer of compressive forces between the body and the neural arch takes place through the pedicle, which acts as a beam connecting the two columns. Due to anterior curvature in the thoracic region, the weight in thi***s*** region is transmitted from the neural arch to the body through the inclined pedicles. In the lumbar region, where the curvature is posterior, a part of compressive force of the body (anterior column) is transmitted to the neural arch (posterior column) through the pedicles. This transfer of load between the body and the neural arch (i.e. between anterior and posterior columns) tends to approach the line of gravity(Singel et al., 2004).

According to Schneck (1989) the characteristic dimensions and orientation of the pedicle dictates the size and angle of screw entry to the lumbar pedicles. The size of the lower lumbar pedicle, particularly L5, helps in preventing forward slide of L5 over S1. Schneck adds to this, the tripod system of vertebra is made more stable, by the diverging alignment of pedicles in antero-posterior plane, thus bringing the superior articular facet anteriorly. The interpedicular distance is maximum in its posterior part, affecting this tripod system for support (Zamani et al., 1998).

Schneck added to above one fact that the lower lumbar pedicles have their medial aspects going obliquely away from the canal as the pedicles go inferiorly which altogether helps in sacro iliac load transmission. Bogduk and Twomey (1992) mentions that all forces sustained by any of the posterior elements are ultimately channeled to the pedicles, which then go to the body of the vertebra. They also found that the pedicles transmit both tension and bending forces (Zamani et al., 1998).

2.1.3 Benefits and challenges of Transpedicular instrumentation.

The use of pedicle screws has brought about great clinical improvements in the management of various spinal disorders including traumatic vertebral fractures, scoliosis, spondylolisthesis, spondylosis and osteoporotic vertebral collapse among many more other vertebral pathologies.

In addition, the lumbar vertebral pedicle is used as an access port for procedures performed inside the vertebral body including biopsies, vertebroplasty and kyphoplasty. The choice of the screw diameter is determined by the minimum diameter (width) of the pedicle, whereas the pathway of screw was decided by both the horizontal vertical diameters and angulation (width, height). Transpediciular screw placement has great benefits including:

- The pedicle screws traverse all three columns of the vertebrae, thus they can rigidly stabilize both the ventral and dorsal aspects of the spine.
- The pedicle also represents the strongest point of attachment of the spine and thus significant forces can be applied to the spine without failure of the bone-metal junction.
- Furthermore, the rigidity of pedicle fixation allows for the incorporation of fewer normal motion segments in order to achieve stabilization of an abnormal level.
- Pedicle screw fixation does not require intact dorsal elements (lamina and spinous process). Thus, it can be used after a laminectomy or traumatic disruption of laminae, spinous processes and/or facets.
- Additional advantages include fewer requirements for postoperative bracing and improvements in fusion rates.

The challenges of using pedicle screws are:

- Steep learning curve so as to correctly master the ability to place the screws correctly.
- Caudal or medial penetration of the pedicle cortex can result in dural or neural injury.
- Placement of pedicle screws requires extensive tissue dissection to expose the entry points and to provide the required lateral to medial orientation for optimal screw trajectory.

- Lengthy operative time with potential for significant blood loss and increased risk of infection.
- Postoperative imaging studies (especially MRI) are, in part, obscured by the implants.
- Rigid fixation can accelerate adjacent motion segment degeneration.
- Costly procedures.

In order to perform a lumbar fusion by minimally invasive surgery technique it is necessary to have precise anatomical knowledge of lumbar pedicles. The computer tomography scan evaluation represents the most frequent procedure before the surgery, and fluoroscopy is used during the surgical procedure to guide surgeon in screw fixation (Fluoroscopy is not yet available in Eldoret Moi teaching and referral hospital).

2.1.4 How lumbar Pedicle morphometry influences transpedicular instrumentation.

Surgical anatomical landmarks are key in localization and placement of pedicle screws for instrumentation, vertebral body biopsy, kyphoplasty and vertebroplasty. The gradual anatomical narrowing of the vertebral canal or intervertebral foramina of the lumbar vertebrae is called lumbar spinal stenosis resulting in compression of the spinal cord that traverses the centrally located vertebral canal or lumbosacral spinal nerve roots that traverses the laterally located intervertebral foramina. Clinical symptoms of lumbar spinal stenosis include low back ache, bilateral lower limbs pain, paresthesia amongst other neurologic anomalies (De Schepper et al., 2013).

Knowledge of the dimensions and orientation of this part of the vertebral column is crucial in avoiding damage to delicate structures around it. The biomechanical superiority of transpedicular screw fixation over other methods of spinal fixation, along with increasing surgeon comfort with pedicle screw techniques, has driven the popularity of this technique (Eldin, Mohamed, & Ali, 2014).

However, anatomic variations can make screw placement challenging, and retrospective studies have demonstrated that even in experienced hands, pedicle wall violations can occur in up to 29% of cases (Castro et al., 1996).From the study it was pointed out that the key to a successful transpedicular procedure is that with small pedicle, especially at the deep isthmus section, the medial wall can safely be penetrated; otherwise, incapacitating complications, such as nerve, vascular, and visceral injuries, can occur. The trajectory should ideally be placed along the axis of the pedicle, incorporating the largest available transverse and sagittal pedicle dimensions. According to a study carried out by Amato *et al*., (2010) the rate of frank pedicle screw misplacement was 5%. The rate of minimal or questionable pedicle wall violation was 2.8% (Vincenzo Amato, Luigi Giannachi, Claudio Irace, & Claudio Corona, 2010).

Among the frank misplacements, 6 were classified as minor, 12 as moderate, and 3 as severe penetrations. Two patients (2%) had radicular pain and neurological deficits (inferomedial and inferolateral minor misplacement at L-4 and L-5, respectively), and 5 patients (4.9%) complained only of radicular pain. The foremost concern of a surgeon during pedicle screw fixation is safety. At the follow-up examination all patients had completely recovered their neurological function and radicular pain was resolved in all cases (Vincenzo Amato et al., 2010).

Assistive modalities, especially intraoperative electromyographic monitoring can function as an essential tool to recognize screw malposition that compromise neural integrity, so that the screws can be repositioned immediately rather than later. There are various studies that seek to investigate the efficacy of intraoperative monitoring to detect potential pedicle breach and evaluate whether reoperation rates were significantly reduced(CASTRO-REYES et al., 2015).

Intraoperative electromyographic monitoring can be an essential tool to recognize screw malposition that compromise neural integrity. The technique is used for lesion excision, corpectomy, vertebral body reconstruction with cages, realignment, and/or plating or screwing(CASTRO-REYES et al., 2015).

Another study conducted a morphometric analysis of Lumbar Vertebrae in Adult South African Subjects. The measurements were obtained from lumbar vertebrae from the osteological collections in the Discipline of Clinical Anatomy, Nelson Mandela School of Medicine using a digital caliper. The antero-posterior body diameter (APD), interpedicular distance (IPD), midsagittal diameter (MSD) and pedicle length (PL) were measured while ratio of MSD to APD was calculated. Results showed gradual increase from L_1 to L_5 for mean APD and IPD, and a decrease for mean PL from L_1 to L_5. Mean MSD was observed to present a "U" curve pattern from L_1 to L_5, while MSD/APD ratio decreased from L_2 downwards (Azu et al., 2016).

Azu *et al.*, (2016) established the complications related to screw malposition were 2 pedicle fractures (2% of patients), 1 nerve root injury (1%), and 1 dural laceration (1%). Five patients (4.8%) had postoperative anemia and required transfusions. Superficial or deep wound infection was noted in 3 patients (2.9%). Late hardware failure occurred in 2 patients (2%). One patient developed adjacent segmental instability and required additional surgery to extend the fusion (V. Amato, L. Giannachi, C. Irace, & C. Corona, 2010).

Transpedicular screw fixation, provides greater stability in spine surgeries and reduced incidence of implant loosening and pull out. With transpedicular screw placement cortical pedicle perforations rates range between 25% and 85%, this shows the importance of further anatomical studies to try and reduce this pedicle perforation rates (Vargas-Mena et al., 2011).

Intraoperative confirmation of secure screw placement can be obtained using fluoroscopic images, neural integrity or compromise needs to be checked. However, completely depending on fluoroscopic images may not be appropriate, especially when proper anatomy cannot be visualized.

A study conducted in 2010, concluded that the mortality from lumbar pedicle procedure was less than 1% and that lumbar pedicle fractures occur in 29% of patients undergoing transpedicular spinal fusion surgery. This causes a reduction in the fixation rate of affected vertebral segments and produces a higher incidence of acute and chronic complications related to surgery (ElRakhawy, ElShahat, Labib, & Abdulaziz, 2010).

Transpedicular instrumentation is done by use of the free hand technique which has a high risk of pedicle weakening and neurovascular injuries in comparison with pedicle screw placement using a drill guide (Merc, Recnik, & Krajnc, 2017).

The free hand technique carries a risk of pedicle perforation of about 30% which is associated with many complications. These complications are such as dural tears leading to cerebral spinal fluid leakage predisposing the patient to meningitis, loose screws leading to weak stabilization and neurological deficits from nerve damage (Merc *et al*., 2017).

2.1.5 Landmarks to the Pedicle Used Intra-Operatively

The midpoint of the transverse process is used to identify midpoint of pedicle in superior-inferior dimension. Lateral border of pars used to identify midpoint in medial-lateral dimension (Miller et al., 2012).

Several studies have investigated the morphometry of vertebrae using different experimental techniques such as plain film, computer tomography scan and direct cadaveric dissections to identify the precise insertion point of pedicle screws and to prevent postoperative sequelae (Amato *et al.,* 2010*;* Miller *et al.,* 2012; Castro-Reyes *et al.,* 2015; Merc *et al.,* 2017).

The anatomic distances between the pedicle and adjacent neural structures in the thoracolumbar spine has showed that true safe distances between the pedicle and neural structures exists (Steven Wray et al., 2015).

In clinical transpedicular procedures, such as revision of pedicle screws, bone biopsy, bone grafting, and restoration of vertebral body via vertebroplasty or kyphoplasty, which may not be limited to inside the pedicle in only; the extrapedicularly technique is used, which so called in-out-in technique(CNIM, Xiao-Feng Zhang MD, DABNM, & DABNM, 2012).

2.1.6 Other Related Studies

In a study titled morphological measurements of lumbar pedicles in Egyptian population using computerized tomography and cadaver direct caliber measurements studied 75 cases of lumbar disc patients and established that the axial length of pedicles (chord length), is around 50mm at all lumbar levels with negligible shortening at L_4 and L_5 (Maaly, Saad, & Houlel, 2010).

Zertuche, Aguirre, Cámara-Rodríguez, Vidal-Torres, Elizondo-Omaña and Guzmán-López (2014) investigated the morphometric characteristics of lumbar vertebral pedicles in Mexican population. The study analyzed 65 L1–L5 cadaver lumbar spines from a collection of bone specimens from the Department of Human Anatomy. Pedicle width, height, and length were determined bilaterally in each sample studied.

The measures of central tendency, and parametric correlation tests obtained by Zertuche et al., (2014) were performed with a 95% confidence interval to determine if significant differences exist between the lumbar vertebral levels. According to their results, the pedicle width increased from L_1 to L_5. They obtained a minimum mean value of 7.40 ± 1.84 mm at L_1 and a maximum mean value of 14.74 ± 3.77 mm at L_5. Pedicle height decreased from L_1 to L4 with a subsequent increase at L_5. They obtained a maximum mean value of 18.32 ± 4.15 mm at L_5 and minimum mean value of 14.09 mm ± 2.75 at L_4. Significant differences were observed ($P < 0.05$) when groups were compared.

Other related studies that have been carried out on Mexican Pedicle cortical width showed a gradual increase from L1 to L5 with results varying between 3mm at L1 smallest and 25 mm at L5 largest. They obtained a minimum mean score of 7.40 ± 1.84 mm in L1 and a maximum mean value of 14.74 ± 3.77 mm at L5 (CASTRO-REYES et al., 2015).

A similar study was also conducted in Saurashtra region in India that noted the height of pedicles decreases from L1 to L5; but the width for pedicles increased from L1 to L5. The mean vertical height of pedicle for males was maximum at L2 level with a measurement of 15mm. The minimum mean width of pedicle for males was recorded at L1 level that measured 8.2mm. The maximum mean width for males recorded was at L5 level that measured 18.2mm (Singel *et al.,* 2004).

Kenya, Morio, Kazuhiro, Yoshiaki and Suketaka (2005) carried out a comparative assessment of pedicle morphology of the lumbar spine in various degenerative diseases in Japan. The study gathered morphological data on thoracic and lumbar spines in a Japanese population that should serve as useful reference for posterior instrumentation surgery(Nojiri, Matsumoto, Chiba, Toyama, & Momoshima, 2005).

From the study of Kenya et al, one hundred and three dry bones were used to investigate the morphology of pedicle and facet in thoracic and lumbar spines. Measurements included the diameter and axial length of pedicle from T8 to L5, height and width of facets and thickness of articular processes from T1 to T12, and axial angle of pedicle from T1 to L5. According to the study by Kenya *et al.,* (2005) the diameter and axial length of pedicles were smallest at T8, diameter was largest at L5 and axial length was largest at L3. Height of facets and thickness of articular processes were largest at T12. Men tended to have larger pedicles and facets than women. Transverse angle of pedicle was smallest at T12(Nojiri, Matsumoto, Chiba, Toyama, et al., 2005).

Knowledge of pedicle dimensions and surface landmarks is crucial for the safe placement of screws therefore accurate knowledge about the dimensions and orientation of the lumbar pedicle amongst Kenyan population is required for better surgical outcome. There is documented significant statistical race and sex difference in the pedicle dimensions and orientation. Zertuche *et al.,* (2014), Azu *et al.,* (2016) and Kaliya *et al.*, (2017) have reported statistically significant sex differences in pedicle dimension and orientation.

Most of older studies on the morphometry of the pedicle were based on white populations. Thus according to (CASTRO-REYES et al., 2015); as the racial variations in skeleton are well known, hence the morphometry of the pedicle varies from population to population. Even within the same population, anatomical variations have been reported on the pedicular shape, size and angulations'.

From the foregoing, vertebral pedicles have been extensively used as fixation site for implants on spine, especially at lumbar spine level (Azu *et al.*, 2016).The vertebral pedicle has also been used as an access port for procedures performed inside the vertebral body, such as biopsies, vertebroplasties or kyphoplasties (CASTRO-REYES et al., 2015). Vertebral pedicle uses and acceptance is directly associated to the biomechanical advantages of pedicular fixation and to the potential to provide a three-dimensional correction of vertebral deformities. However, there are drawbacks in using vertebral pedicles, especially represented by the injury potential to this vertebral structure and to adjacent vascular or nervous structures.

The research is essential to spine surgeons having several studies that have been conducted in Africa, Europe, Asia and other continents on the dimension and orientation of the lumbar pedicle and have shown there exist variations in the dimensions among different population groups (Chazono, Tanaka, Kumagae, Sai, & Marumo, 2012).

Generally, a cephalocaudal increase of diameter and height of the pedicle was noted in both male and female populations and there exists a variation within various populations. Significant age-related variations of pedicle diameters were noted at all segmental levels (Amonoo-Kuofi, 1995).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Study Setting

The study was carried out in the Department of Human Anatomy Laboratory, Moi University School of Medicine, Nairobi national Museum, and St Luke's Hospital, Eldoret radiology and imaging department. St. Luke's Orthopaedic and Trauma Hospital is a modern private hospital started in the year 2012. The Human Anatomy department is one of the departments which constitute the College of Health Sciences (CHS) in Moi University.

The Human Anatomy department is well equipped with anatomy and histology laboratories that facilitate training of both undergraduate and postgraduate programmes. St Luke's is an orthopaedic and trauma Hospital based in Eldoret, well equipped and is a 64 bed capacity hospital majoring in orthopaedic and trauma.

The study also involved cases drawn from Nairobi National Museum department of anatomy. National Museums of Kenya (NMK) is a state corporation established by an Act of Parliament, the Museums and Heritage Act 2006. NMK is a multi-disciplinary institution whose role is to collect, preserve, study, document and present Kenya's past and present cultural and natural heritage. This is for the purposes of enhancing knowledge, appreciation, respect and sustainable utilization of these resources for the benefit of Kenya and the world, for now and posterity.

3.2 Study Design

The study done was a descriptive cross-sectional study that begun in January 2016 and ended in December 2016.

3.3 Study Population

The study included dry adult lumbar pedicle preparations in the department of Human Anatomy, Moi University School of medicine, Nairobi National Museum and computerized tomography scan images obtained at St. Lukes Hospital, Eldoret department of Radiology. The study included patients who had come for various medical conditions who required computer tomography Scan done. This included patients who had complaints of low back pain as well as traumatic injuries to the vertebral column and were fit enough to undergo computer tomography scan. The Computerized tomography scans were done on subjects from St Luke's Hospital. No scans were on the dry bone preparations from the anatomy laboratory.

The measurements from the dry bone preparations were done on vertebrae that have been well preserved since their collection by considering and keeping in mind various affection of external environments and other factors destroying preserved bones. The dry bone specimens had been collected in the 1950's from Central region of kenya and had been certified by a pathologist.

The data was therefore obtained from two main categories of subjects.

1. Dry bone preparation obtained in the human anatomy from the two institutions. These were Nairobi National Museum and Moi University Human Anatomy Laboratory.
2. Computerized tomography images of subjects obtained from St Luke's hospital.

3.4 Eligibility

3.4.1 Inclusion criteria

A) Computerized Scans

Patients whose age ranged between 18 and 65 years.

B) Dry Bones

The study included fully ossified and well preserved dry bones from the National Museum of Kenya, Nairobi. Those pedicles that had not been damaged by environmental factors.

3.4.2 Exclusion Criteria

A) Computerized scans

Patients scans with lumbosacral deformities such as scoliosis, spina bifida, traumatic fractures with damage to the middle and posterior columns, kyphosis and any other pathology that have destroyed the normal lumbar pedicle anatomy.

Expatriates were also excluded from the study.

Further, individual vertebrae with congenital anomalies (for example, hemi-vertebrae), fractures, metastasis from distant malignancies and pedicles destroyed by pathology.

B) Dry Bones

Dry bones that had been damaged by environmental factors such as heat, dust were excluded from the study. Bones that have their pedicle chipped and lost their original shapes and dimensions were not included in this morphological study.

3.5 Sample size and technique

In order to be 95% sure that the chord length of the lumbar pedicle at L_1 among the Kenyan population studied within Moi University, St. Lukes Hospital and Nairobi museum is within plus or minus 0.2mm of the population value of 5.2mm, (Maaly et al., 2010),we estimated the sample using the following formula.

$$n = \left(\frac{Z_{1-\alpha/2}\sigma}{\delta} \right)^2$$
$$= \left(\frac{1.96 \times 1}{0.2} \right)^2$$
$$= 97$$

Where σ is the standard deviation of the chord length assumed to be 1. This standard deviation is larger than what was reported. This would cushion the researcher against over-optimism that would results is small sample size. δ is the postulated margin of error. Thus the study size was 97.

This size was sufficient to answer the question whether there was any statistical difference in the dimensions and orientation of the lumbar pedicle amongst different population groups.

Consecutive sampling technique was used in selection of dry bone specimens and computer tomography scans.

3.6 Methods: Tools and Techniques of data collection

Data on the dimensions was obtained by use of a sliding caliper and a digital caliper for the dry bones and use of computerized tomography scan in St Luke's Data base. The computerized tomographic scans were made with a Phillips computer tomography scanner 16 slice. Cuts were made parallel to the planes of the superior end-plates of the vertebral bodies (to compensate for lordosis) and through the middle of the pedicles whenever possible. The gantry of the scanner was adjusted to align it parallel to the end-plates as accurately as possible. The techniques for making the computerized tomography scans were the same for all patients.

The vertebral columns were obtained from preserved sets of bones of individual dry bones received at Anatomy Department of Moi University and Nairobi National

Museum analyzed and certified by a qualified pathologist. The bones had been preserved since their collection by considering and keeping in mind various affection by external environments and other factors destroying preserved bones. All vertebrae bones were fully ossified and normal. The width and height of the dry bones were obtained using a sliding Vernier caliper and a digital caliper.

The measurements to be obtained using computerized tomography were done with the aid of installed software that was already preinstalled in the scanner to determine the various lengths and angles. This was the Digital geometry processing software that was used to generate a three dimensional radiographic image taken around a single axis of rotation with the aid of this software measurements could easily be obtained. The data was collected from patients who required computer tomography scans and met the inclusion criteria. Those with lumbar spine deformities, degenerative changes and fractures were not included in the study.

The dimensions of either male or female were obtained from the dry bone specimens and computerized tomography scans. Data was captured in designed forms entered into an electronic database. The database was encrypted with password to ensure confidentiality. The password was only accessible to the main investigator. The forms, once conversion to electronic database was complete, were destroyed. Below are the dimensions that were assessed. The measurements were done according to Hrdlicka`S Practical Anthropometry.

i. The transverse diameter (the medial-lateral outer cortical width of the pedicle), measured at the isthmus.

ii. The height (the superior-inferior outer cortical height, or sagittal diameter) of the pedicle, measured at the isthmus.

iii. The angulation of the pedicle, measured from the midline to the mid-axis of the pedicle.

iv. Chord length of the pedicle measured from the posterior cortical entry point of the pedicle to the anterior vertebral cortex in line with the axis of the pedicle.

3.7 Instruments that Were Used

Figure 3.1: Vernier Caliper

Figure 3.2: Digital goniometer

Figure 3.3: Sliding Vernier Caliper

3.8. Technique used to determine the dimensions.

The figure below, figure 3.4 illustrates how the pedicle width was measured at the isthmus.

Figure 3.4 showing how the pedicle width was measured

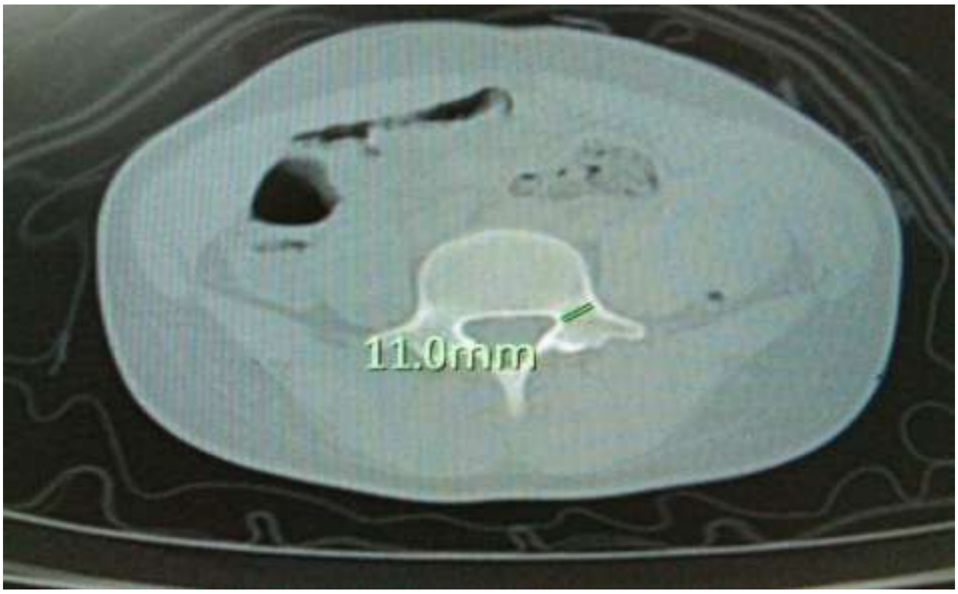

Figure 3.5 showing how the pedicle width was measured on computer tomography scan

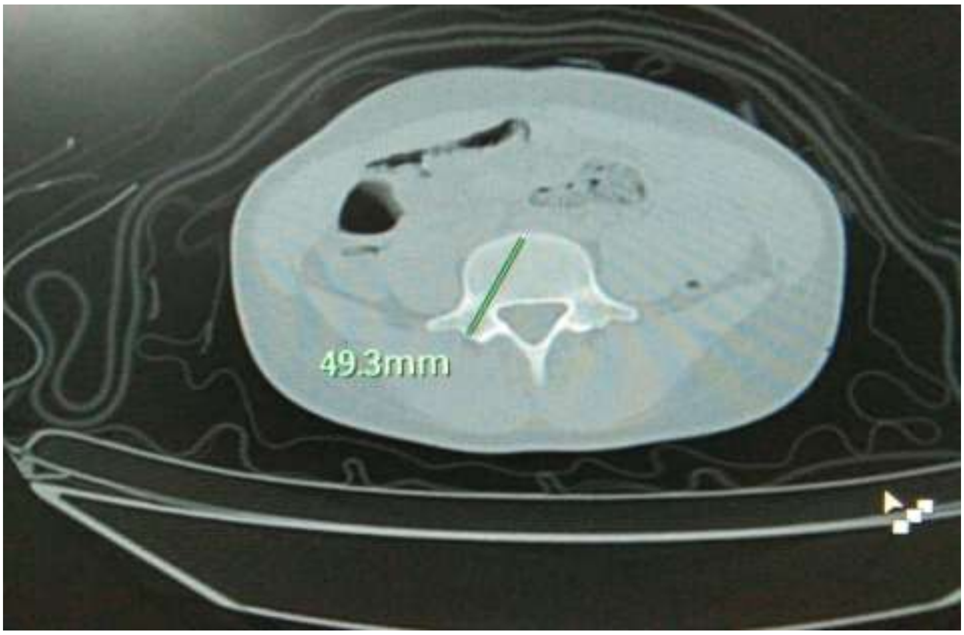

Figure 3.6 showing how the chord length was measured on computer tomography scan

Figure 3.7 showing how the chord length was measured using a sliding Vernier caliper.

3.9 Dry Bone storage

The data for the dry bones is considered reliable as the dry bones were well stored and preserved from destructive environmental factors as depicted in the storage facility below.

Figure 3.8: Dry Bone Storage

The bones were preserved since their collection by considering and keeping in mind various affection by external environments and other factors destroying preserved bones. The dry bones measured in this study had been stored in the boxes to protect them them from damage from the external environment.

3.9 Data Management

Data was captured using designed forms and entered into an electronic database. The database was encrypted with password to ensure confidentiality. The password was only accessible to the main investigator. The forms, once conversion to electronic database was complete, were stored and kept secure. The forms were filled by the investigator and later transferred to a computer database. The collected data was only available to the investigator and the supervisors. Data entry was done into a computer database designed in Microsoft Excel and then transferred to SPSS version 21 and analyzed.

3.10 Data Analysis

The data collected was first cleaned, then sorted and coded using numerical numbers. Data analysis was conducted on Statistical Package for Social Sciences (SPSS) version 21. Categorical variables such as gender were summarized as frequencies and represented in bar graphs with their corresponding percentages. Continuous variables such as, chord length, vertebral pedicle height, pedicle width, and angle of inclination were summarized as mean and the corresponding standard deviation if they had a Gaussian distribution. If Gaussian assumptions were violated, then the median and the corresponding inter quartile range was used to summarize these characteristics. Gaussian assumptions were assessed using Shapiro-Wilk test for normality. Results will be presented using graphs and tables.

3.11 Ethical Considerations

Prior to commencing the field data collection exercise, the researcher sought approval through a letter of recognition from Moi University and subsequently obtained a research permit from the relevant authorities in St. Luke's Hospital and Nairobi National Museum. Due to sensitivity of some information collected, the researcher held a moral obligation to treat the information with utmost propriety.

Ethical approval was sought from the Institution Research and Ethics Committee (IREC), Moi University the Department of Human Anatomy and Nairobi National Museum prior to commencement of the study. Data confidentiality was strictly maintained and included use of passwords in the database. The dry bones were not transported from Moi University or Nairobi National Museum to the radiology department for measurements. The measurements were obtained within the premise by the researcher.

Results obtained were disseminated through an oral defense of thesis and thereafter the results may be presented at relevant conferences/seminars and publication in a peer reviewed scientific journal.

3.12 Study Limitations

The pedicle angulation could not be obtained on the dry bone specimen as this would involve transecting the vertebrae hence destroying the bone. This data was only obtained on computer tomography images.

The technique used to perform the computerized tomography scan was assumed to be the same for all the scans used for the study.

CHAPTER FOUR

4.0 RESULTS

4.1 Overview

This chapter presents the findings of the study to determine the Anatomical dimensions and orientation of the lumbar pedicle amongst the Kenyan population. Analysis was done using statistical package for social sciences (SPSS) version 21. Each dimension tested was analyzed separately in order to bring it out clearly. The chapter further presents the findings from the tests drawn from the objectives. The data was gathered from the data collection sheet which was designed in line with the objectives of the study.

The specific objectives were to measure the width, vertical height, angulation and absolute chord length of the lumbar pedicle amongst the Kenyan population.

Results were obtained from 100 dry bone specimens and 100 computer tomography scans. The results were divided into two based on the subjects, that is computer tomography scans and dry bones. Since both groups had over 30 subjects’ normality, measurements were assumed to be normally distributed.

4.2 Demographic Characteristics of the Data collected

The demographic information captured in the study related to the gender and age distribution of both the dry bones and computer tomography scans.

4.2.1 Gender

Both the dry bones and computer tomography scans were categorized into their respective genders. The dry bones used were represented by 55 males and 45 female subject. The computer tomography scans were represented by 49 male and 51 female subjects.

4.2.2 Age Distribution

From the computer tomography scans, subjects' age ranged between 18 years to 49 years. The dry bones ranged between 31 years to 81 years.

4.3 Transverse dimension

The transverse diameter which is the medial-lateral outer cortical width of the pedicle was measured both on dry bone specimens and computer tomography scans.

The results shown in table 4.1 represent the mean, maximum and minimum measurements obtained on Computer tomography scans and table 4.2 for the dry bone measurements

Table 4.1: Transverse Dimensions Measured on computer tomography scans in mm(millimeters).

	L1	L2	L3	L4	L5
Mean	7.2	7.6	9.2	10.8	14.6
[95%C. I]	[6.8,7.6]	[7.2,8.0]	[8.7,9.6]	[10.3,11.3]	[14.1,15.2]
SD	1.5	1.5	1.6	1.8	2.1
Maximum	10.9	10.4	12.9	13.9	18
Minimum	4.8	4.9	5.5	7	8.6

From the results, Lumbar five (L5) had the widest diameter with a maximum of 18mm, a minimum of 8.6mm and an average of 14.6mm based on computer tomography scan measurements. Lumbar four (L4) had a maximum of 13.9mm, a minimum of 7.0mm and an average of 10.8 mm based on computer tomography scan measurements. Lumbar there (L3) had a maximum size of 12.9mm, a minimum of 5.5mm and an average diameter of 9.2mm based on computer tomography scan measurements. Lumbar two (L2) had a maximum diameter of 10.4 mm and a minimum of 4.9mm based on computer tomography scan measurements. Lumbar one (L1) had a minimum of 4.8mm and maximum of 10.8mm based on computer tomography scan measurements. A gradual increment was noted from L1 to L5 both on dry bone measurement and computerized tomography measurements.

Table 4.2: Transverse Dimensions Measured on Dry Bones in millimeters(mm).

	L1	**L2**	**L3**	**L4**	**L5**
Mean	8.6	9.6	11.4	13.5	16.3
[95%C. I]	[8.3,8.9]	[9.2,10.0]	[10.9,11.9]	[13.0,14.1]	[15.8,16.8]
SD	1.1	1.6	1.9	2.1	1.7
Maximum	10.8	12.8	14.8	16.3	20.2
Minimum	5.3	5.9	8	8	11.8

From the results depicted in Table 4.2 above, there is an increment in the average transverse dimensions of dry bones from 8.6mm to 16.3mm from L1 to L5 respectively. The minimum transverse dimensions of 5.3mm was recorded at L1. The maximum transverse dimensions of 20.2mm was recorded at L5.

4.3.1 Graphical Increment on Transverse Dimensions of the Pedicles

Graphical representation of the measurement obtained on the dry bone specimens and computer tomography scan is shown below.

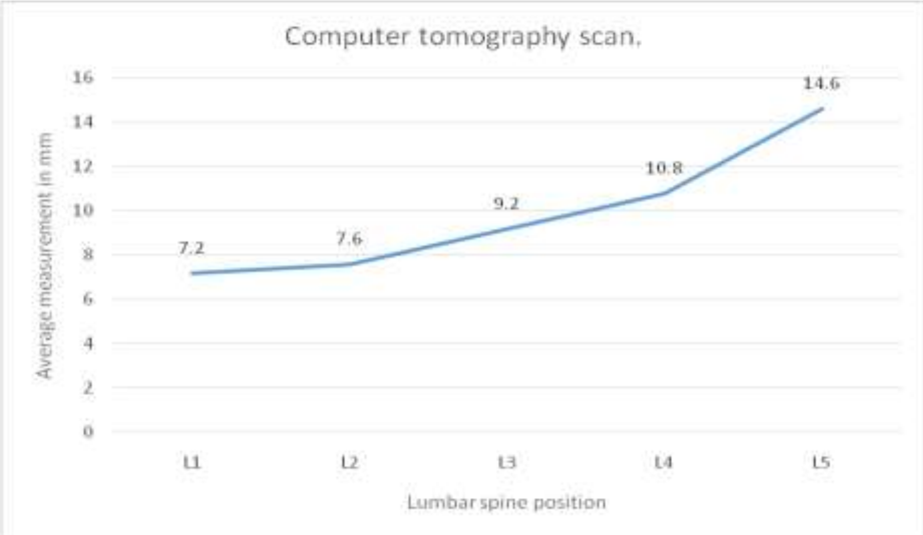

Figure 4.1: Graph of Lumbar Pedicle Diameters based on computer tomography Scan.

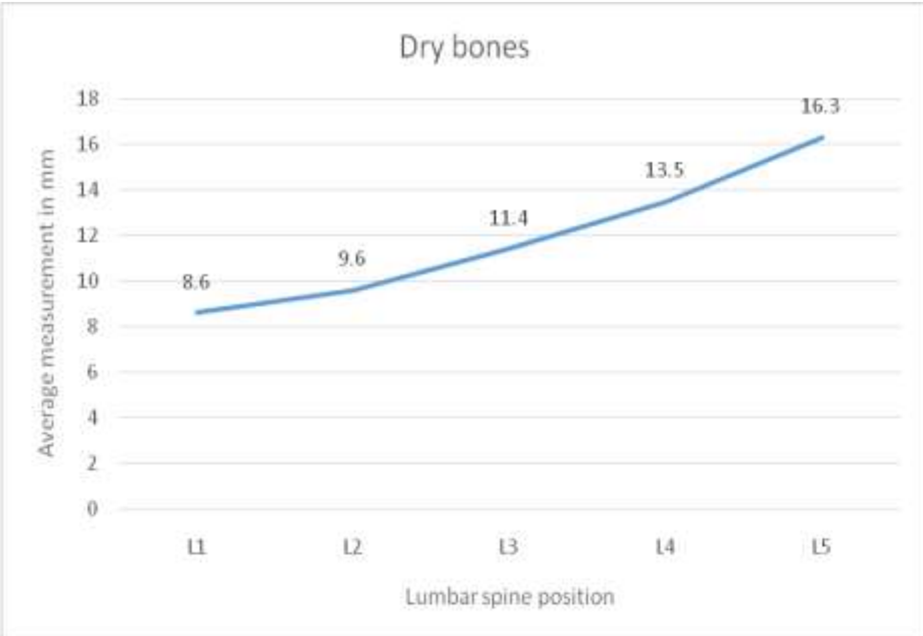

Figure 4.2: Graph of Lumbar Pedicle Diameters based on Dry Bones.

4.4 Vertical Height of the Pedicle

4.4.1 Measuring the Vertical Height of the Pedicle

The vertical height was recorded by a sliding caliper in mm as described by Hrdlicka`S Practical Anthropometry. First reading was taken for right pedicle and then for left. All these measurements were taken in millimeters. The mean and standard deviations for each side was calculated and student 't` test was used to determine the difference between right and left sides.

The researcher measured vertical height at the isthmus of the pedicle from the superior to inferior surface of the pedicle. The longest and shortest heights were recorded and the corresponding averages are represented as shown in Table 4.3 below.

Table 4.3: Descriptive Statistics for Vertical height of the Pedicle in mm(millimeters)

	L1	L2	L3	L4	L5
Mean Height	16.2	15.4	14.5	13.5	12.1
[95%C.I]	[16.0,16.5]	[15.2,15.7]	[14.3,14.8]	[13.2,13.9]	[11.7,12.5]
Longest length	18.2	17.2	16.9	15.1	14.9
Shortest length	13.3	12.3	12.1	11.3	8.2
SD	0.8	0.9	1.1	1.3	1.4

The longest mean vertical height was obtained at Lumbar vertebrae 1 with a mean of 16.2mm. There was a decrease from lumbar 1 vertebra progressively to Lumbar 5 vertebrae. A range between 18.2 mm to 8.2 mm was obtained between Lumbar 1 and Lumbar 5. The maximum longest height was 18.2 mm recorded at L1, while the minimum height was 8.2 mm at L5.

4.5 Angulation measurement

The study established the angulation of the pedicle, measured from the midline to the mid-axis of the pedicle. Results obtained were summarized in table 4.4 below

Table 4.4: Angle of Insertion in degrees

	L1	L2	L3	L4	L5
Mean	19.7	20.5	22	24.1	29.8
[95%C. I]	[19.1,20.4]	[19.8,21.1]	[21.4,22.6]	[23.6,24.7]	[29.0,30.6]
SD	2.4	2.4	2.2	1.9	2.9
Maximum.	25.4	25.9	26.9	28.3	36
Minimum.	15.4	12.5	18.4	20.2	23.1

The study observed an average subsequent increment of 2^0 in subsequent lumbar vertebrae. Lumbar five (L5) had the largest angle of insertion of 29.8^0 followed by lumbar four (L4) had an average of 24.1^0. Lumbar three (L3) had an average angle of insertion of 22.0^0 two (L2) had an average angle of insertion of 20.5^0 whereas lumbar one had an average angle of insertion of 19.7^0.

4.5.1 Angle of Insertion among Male and Female Population

The study measured angle of insertion and recorded the differences and variations in male and female gender. The results are as shown in table 4.5.

Table 4.5: Comparison between Angle of Insertion among Males and Females.

	L1		L2		L3		L4		L5	
	Mal	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**
Mean	19.3	20.1	20.6	20.3	21.8	22.2	23.8	24.4	29.4	30.2
Max	15.4	23.3	24.4	25.9	26.9	26.8	28.2	28.3	35.3	36
Min	25.4	16	17	12.5	18.8	18.4	20.2	21.5	24.6	23.1

From the above table, the study reveals that the female population has slightly wider angulations of the pedicle from the midpoint as compared to the male population. The angle of insertion in female pedicles range between 16^0 at L1 and 36^0 at L5.

The angle of insertion in the male population had a range between $15.4^0$to 35.3^0 from L1 to L5.

4.6 Chord Length of the Pedicle

4.6.1 Measuring the Pedicle Chord Length

The best method of determining true pedicle dimensions is by direct and careful measurement of cadaveric specimens. Means, standard deviation, and minimum to maximum values for each were measured and tables were constructed using these data. The mean and standard deviations for each side was calculated and students"t" test was used to determine the difference between right and left sides. As there was no significant statistical difference between the parameters for right and left sides; hence the data were pooled together.

The study sought to determine the mean values of the chord length from L1 to L5. The chord length of the pedicle was measured from the posterior cortex of the pedicle to the anterior surface of the lumbar vertebral body along the axis of the pedicle.

4.6.2 Chord Length Dimensions

The chord length measurements were obtained from 100 dry bone specimens and 100 Computer tomography scans. The mean was the obtained at each lumbar vertebral level and summarized in tables 4.6 and 4.7

Table 4.6: Average Chord Lengths of Dry Bone Specimens using Vernier Caliper in mm(millimeters)

Lumbar vertebrae	L1	L2	L3	L4	L5
Mean	47.99	48.9	48.9	47.7	47.0
[95%CI]	[47.3,48.6]	[48.4,49.5]	[48.4,49.5]	[47.2,48.2]	[46.5,47.5]
SD	2.3	1.9	2.1	1.9	1.8
Longest	54	55	55	54	54
Shortest	43	46	44	44	43

From the data collected on the dry bone specimens the longest mean length obtained was at Lumbar vertebrae 3 and Lumbar vertebrae 2 with a mean of 48.9mm. The range obtained was from 55mm to 43mm.The longest being at lumbar vertebrae 2 and lumbar vertebra 3-55mm and the shortest being at lumbar vertebrae 1 and lumbar vertebrae 5-43mm.

Table 4.7: Average Chord Lengths Based on Computer Tomography Scans in mm(millimeters)

Lumbar vertebrae	L1	L2	L3	L4	L5
Mean	**48.6**	**49.9**	**50.1**	**49.8**	**50.1**
[95%CI]	[47.4,49.8]	[48.9,50.9]	[49.3,50.9]	[48.9,50.7]	[49.1,51.0]
SD	4.2	3.5	2.8	3.2	3.3
Longest	**59.5**	**59.9**	**58.5**	**57.3**	**57.4**
Shortest	**38**	**42.3**	**44.8**	**43.8**	**41.9**

From the data collected on the computer tomography scans the longest mean length obtained was at Lumbar vertebrae 3 and Lumbar vertebrae 5 with a mean of 50.1mm. The range obtained was 59.9mm to 38mm. The longest chord length was at lumbar vertebrae 2 with-59.9mm and the shortest lumbar vertebrae being at L1-38.0mm.

4.6.3 Chord Length Dimensions between male and female subjects

The study also sought to establish the chord length of pedicles among the genders. Tables 4.8 and 4.9 below show the chord length comparison between male and female population.

Table 4.8: Gender Measurements obtained from Computer Tomography scans.

	L1		**L2**		**L3**		**L4**		**L5**	
	Mal	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**
Mean	51.1	46.5	51.9	48.2	51.7	48.7	51.3	48.5	51.3	49
Max	59.5	52.3	59.9	51.4	58.5	52.5	57.2	54.5	56.5	57.4
Min	43.1	38	47.2	42.3	48.3	44.8	45.3	43.8	46.3	41.9

As seen from the computer tomography scans in table 4.8, the chord length of pedicle for males was longest at L2 level (59.9mm). The shortest chord length of pedicle for males was recorded at L1 level (43.1mm). The longest chord length for female pedicle was found at L5 level (57.4mm). The minimum mean chord length for females was found at the L5 level (41.9mm).

Table 4.9: Gender Measurements obtained from Dry Bone Specimens

	L1		**L2**		**L3**		**L4**		**L5**	
	Mal	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**	**Mal**	**Femal**
Mean	49.3	46.9	50.3	47.9	50.3	47.9	48.9	46.8	48	46.2
Max	54	53	54	55	55	52	54	51	54	50
Min	43	44	48	46	46	44	46	44	45	43

From the dry bone specimens, the longest chord length for males recorded was at L3 level (55mm) and for the females was found to be maximum at L2 level (55mm). The minimum chord length of the dry bone specimens for males was recorded at L1 level (43mm) while the minimum chord length for females was found at the L5 level (43mm). From these results, it is evident that the male population has a longer mean chord length at each vertebral level as compared to the female population.

CHAPTER FIVE

5.0 DISCUSSION OF THE RESULTS

5.1 Overview

This chapter presents a discussion of the results based on the data obtained in the foregoing chapter with regard to lumbar vertebral morphology for the Kenyan adult population. Population specific variations are common in many body dimensions; hence it is imperative to generate populations specific measurements for body dimensions that could hold clinical relevance. The study obtained measurements on the width, height, angulation and chord length of the lumbar vertebrae pedicle from L1 to L5 in adult Kenyans using Computer tomography scans and dry bone specimens.

5.2 Morphometric Analysis Lumbar Pedicles.

The study evaluated lumbar vertebral pedicle width of the Kenyan population using computed tomography scans and dry bone measurement reporting a minimum mean value of 7.2mm and 8.6mm at L1 respectively and a mean maximum of 14.6mm and 16.3 mm at L5 on computer tomography scan based measurements and dry bone measurements respectively.

From the results shown there was variation in results dimension between L1 to L5 vertebra. This was in agreement with findings demonstrated in other studies done by Urrutia *et al.*, (2009).

The progressive increment noted both on computer tomography scan measurement and dry bone measurement was very similar to other results obtained in various other studies on other population study by Urrutia *et al.,* (2009). The findings are summarized in the tables below, table 5.1 and 5.2. The results of pedicle cortical width in different populations are shown below. As can be seen, these studies showed a progressive increase in width from L1 to L5.

Table 5.1: Results of Pedicle Cortical Width in Different Populations measured on computer tomography scans

Population (author, year)	L1	L2	L3	L4	L5
Kenyan (current study)	7.2	7.6	9.2	10.8	14.6
Mexicans.(y Fluoroscopía, 2009).	7.8	8.2	9.5	10.7	14.3
Koreans.(Kim, Lee, Chung, Kim, & Kim, 1994).	8.1	8.5	10.0	11.5	16.5
Israelites.(CASTRO-REYES et al., 2015).	5.6	7.7	8.9	11.4	13.7
Egyptians.(Maaly et al., 2010).	6.6	8.8	10.1	12.9	18.9

Table 5.2: Results of Pedicle Cortical Width in Different Populations measured on dry bone specimens

Population (author, year).	L1	L2	L3	L4	L5
Kenyan(current study).	8.6	9.6	11.4	13.5	16.3
Turkish.(Morales-Avalos et al., 2015).	6.4	6.6	8.6	10.8	12.4
Japanese.(Nojiri, Matsumoto, Chiba, & Toyama, 2005).	7.4	7.8	9.1	10.1	11.1
Indians.(Acharya, Dorje, & Srivastava, 2010).	7.2	7.6	8.9	11.1	13.9
Arabs.(El Sayed, Saab, El Shishtawy, & Hassan, 2014).	8.7	9	10.5	11.1	12.5
Americans (Olsewski, Villas Tomé, Beguristangurpide et al., 1990).	7.7	7.9	9.6	12.5	18.4
Mexicans.(CASTRO-REYES et al., 2015).	7.4	7.8	9.1	10.7	14.7

The results obtained from this study are in agreement with other previous studies showing that there is an increase in pedicle width from L1 to L5 pedicle with L5 having the largest width in all the populations studied. During growth and development of human body weight transmission and physical stress play important roles in morphological and functional adaptation of the vertebral column.

The means obtained on computer tomography scans and dry bone specimens were subjected to a t test which showed no significant difference between the two methods used to determine width of the pedicle. This is illustrated below.

T-value Calculation

$s2p = ((df1/(df1 + df2)) * s21) + ((df2/(df2 + df2)) * s22) = ((4/8) * 8.99) + ((4/8) * 9.59) = 9.29$

$s2M1 = s2p/N1 = 9.29/5 = 1.86$
$s2M2 = s2p/N2 = 9.29/5 = 1.86$

$t = (M1 - M2)/\sqrt{(s2M1 + s2M2)} = -2/\sqrt{3.72} = -1.04$

The t-value is -1.03754. The p-value is .164913. The result is not significant at $p < .05$.

From the results on computer tomography scan measurements our population and Mexican population have almost similar dimensions of the pedicle width from L1 to L5.

The study established that pedicle height mean measurements on dry bone specimen were L1-16.2mm, L2-15.4mm, L3-14.5mm, L4-13.5mm, and L5-12.1 mm. The pedicle height decreased from 16.2mm to 12.1mm between L1 to L5 on dry bone specimen measurement. This is in agreement with studies done by Singel, Patel and

Gohil (2004) of width and height of lumbar pedicles in Saurashtra region who observed that the height of pedicles decreases from L1 to L5. In their study, the mean height of the pedicle for females was found to be maximum at L1 level (15.5mm). The minimum mean height for females was found at L5 level (13.25mm).

The angulation increased from L1 to L5 on computer tomography scan measurements from 19.7^{o} at L1 to 29.8^{o} at L5. this increment as from L1 to L5 is in agreement to the study done by miller et al,.2012.

From the study the female population has slightly wider angulations of the pedicle from the midpoint as compared to the male population. The angle of insertion in female pedicles range between 16^{0} at L1 and 36^{0} at L5.

The angle of insertion in the male population had a range between $15.4^{0}$to 35.3^{0} from L1 to L5 as documented by miller et al.,2012

The chord length range measurement on dry bone specimen ranged from 47.9mm to 48.9mm and on computer tomography scans from 48.6mm to 50. 1mm.The male population has a longer mean chord length at each vertebral level as compared to the female population.

These results are in agreement with those by Amonoo-Kuofi (1995) who studied the lengths of pedicles on radiographs of 270 males and 270 females. He observed variations in different age groups and at different levels of lumbar spine. He also showed that there was a cephalocaudal increase of the length of pedicles from L1-L5 in males and females.

CHAPTER SIX

6.0 RECOMMENDATION AND CONCLUSIONS

6.1 Overview

This chapter addresses the recommendation and conclusions on the results obtained regarding width, height, angulation and chord length of the lumbar vertebrae pedicle dimensions among Kenyan populations using the dry bone specimens and computer tomography scans. Conclusion and recommendations are provided based on accurate anatomical knowledge of vertebral pedicles.

6.2 Conclusion

In conclusion, the present study accurately describes the dimension and orientation of the lumbar vertebral pedicle in Kenya.

The pedicle width increases from L1 to L5 with L5 having the largest width.The mean pedicle width measured on computer tomography scans at L1 is 7.2mm and at L5 its 14.6mm.The mean pedicle width obtained on dry bone specimens is 8.6mm at L1 and 16.3mm at L5.The height of the pedicle decreases from L1 to L5 and is consistently smaller than the width of the pedicle at all vertebral levels. The mean height at L1 is 16.2mm and 12.1mm at L5 on dry bone specimens. The angulation ranged between 15^{o} to 35^{o} being widest at L5.The female gender has a slightly wider angulation compared to the male gender. The chord length has a range of 45mm to 50mm.

There is no statistical significance in measurement of the dimensions using Computer tomography or dry bone specimen

Based on the results, it can be stated that there exists a variation in the dimensions of the pedicle within the population and also in different populations

6.2 Recommendations

From the results on pedicle dimension, appropriate screw sizes for our population would be a pedicle screws with a minimum diameter of 6.5mm, length of 45mm angulated between 15 to 35 degrees from L1 to L5.

However having noted variations in the dimensions, we further recommend ,preoperative computed tomography scans of the patients must be obtained and pedicle dimensions obtained in order to size the pedicle and determine its orientation. This will enable the operating surgeon know the most appropriate size of screw to use so as to avoid inadvertent complications.

Intraoperative use of fluoroscopy as its use will a guide the surgeon to know the position of the pedicle and its trajectory.

Intraoperative monitoring of neural electrical activities so as to avoid injury to the nerves. This can be done by placing electrodes at specific points that monitor neural activity and can be viewed as surgery continues. This will enable the surgeon know whether there is pedicle violation and make appropriate adjustments to prevent permanent neural damage.

Further research should be carried out to determine whether there exists a variation based on a person age, weight, height and gender.

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.*

Amato, V., Giannachi, L., Irace, C., & Corona, C. (2010). Accuracy of pedicle screw placement in the lumbosacral spine using conventional technique: computed tomography postoperative assessment in 102 consecutive patients.*Journal of neurosurgery spine:12(3), 306-313. doi:10.3171/2009.9.spine09261*

Amato, V., Giannachi, L., Irace, C., & Corona, C. (2010). Accuracy of pedicle screw placement in the lumbosacral spine using conventional technique: computed tomography postoperative assessment in 102 consecutive patients. *Journal of Neurosurgery: Spine, 12(3), 306-313.*

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*.

Aydogan, M., Ozturk, C., Karatoprak, O., Tezer, M., Aksu, N., & Hamzaoglu, A. (2009). The pedicle screw fixation with vertebroplasty augmentation in the surgical treatment of the severe osteoporotic spines. *Clinical Spine Surgery, 22(6), 444-447.*

Azu, O., Komolafe, O., Ofusori, D., Ajayi, S., Naidu, E., Abiodun, A.AJAYI, S. (2016). Morphometric Study of Lumbar Vertebrae in Adult South African Subjects.*International journal of morphology, 34(4), 1345-1351.*

Castro-reyes, c., Morales-avalos, r., Vílchez-cavazos, f., De la garza-castro, o., Salinas-zertuche, a., Aguirre, p., Guzmán-lópez, s. (2015). morphometric characteristics of lumbar vertebral pedicles in mexican population. implications for transpedicular lumbar fusion surgery.*Journal of morphology32(1), 37-42.*

Castro, W. H., Halm, H., Jerosch, J., Malms, J., Steinbeck, J., & Blasius, S. (1996). Accuracy of pedicle screw placement in lumbar vertebrae. *Spine, 21(11), 1320-1324*.

Chazono, M., Tanaka, T., Kumagae, Y., Sai, T., & Marumo, K. (2012). Ethnic differences in pedicle and bony spinal canal dimensions calculated from computed tomography of the cervical spine: a review of the English-language literature. *European Spine Journal, 21(8), 1451-1458.*

Cnim, D., Xiao-Feng Zhang MD, D., DABNM, F., & DABNM, F. (2012). Current trends in pedicle screw stimulation techniques: lumbosacral, thoracic, and cervical levels. *The Neurodiagnostic Journal, 52(2), 100.*

De Schepper, E. I., Overdevest, G. M., Suri, P., Peul, W. C., Oei, E. H., Koes, B. W., . . . Luijsterburg, P. A. (2013). Diagnosis of lumbar spinal stenosis: an updated systematic review of the accuracy of diagnostic tests. *Spine, 38(8), E469-E481.*

El Sayed, S., Saab, I. M., El Shishtawy, M., & Hassan, K. H. (2014). Morphometric study of the lumbosacral spine and some of its related angles in Lebanese adult females. *Italian Journal of Anatomy and Embryology, 119(2), 92-105.*

Eldin, M., Mohamed, M., & Ali, A. M. A. (2014). Lumbar transpedicular implant failure: a clinical and surgical challenge and its radiological assessment. *Asian spine journal, 8(3), 281-297.*

ElRakhawy, M., ElShahat, A. E., Labib, I., & Abdulaziz, E. (2010). Lumbar vertebral canal stenosis: concept of morphometric and radiometric study of the human lumbar vertebral canal. *Anatomy, 4(1).*

Gómez, d. l. R. A., Isla, A., Pérez-López, C., Ortega, R., Fernández-Miranda, J., & Heredero, J. (2006). Causes of reoperations in patients with lumbar spinal stenosis treated with instrumentations. *Neurocirugia (Asturias, Spain), 17(3), 232-239; discussion 239.*

Humphreys, S. C., Hodges, S. D., Patwardhan, A. G., Eck, J. C., Murphy, R. B., & Covington, L. A. (2001). Comparison of posterior and transforaminal approaches to lumbar interbody fusion. *Spine, 26(5), 567-571.*

Inceoglu, S., Burghardt, A., Akbay, A., Majumdar, S., & McLain, R. F. (2005). Trabecular architecture of lumbar vertebral pedicle. *Spine, 30(13), 1485-1490.*

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.*

Lakkol, S., Bhatia, C., Taranu, R., Pollock, R., Hadgaonkar, S., & Krishna, M. (2011). Efficacy of less invasive posterior lumbar interbody fusion as revision surgery for patients with recurrent symptoms after discectomy.*Journal of bone and joint surgery 93(11), 1518-1523.*

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.*

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.*

Merc, M., Recnik, G., & Krajnc, Z. (2017). Lumbar and sacral pedicle screw placement using a template does not improve the midterm pain and disability outcome in comparison with free-hand method. *European Journal of Orthopaedic Surgery & Traumatology, 1-7.*

Miller, M. D., Thompson, S. R., & Hart, J. (2012). *Review of orthopaedics:United states; Elsevier Health sciences*

Morales-Avalos, R., Galindo-Aguilar, O. U., Elizondo-Omaña, R. E., Villarreal-Silva, E. E., Ruiz-Herrera, V., Guzmán-López, S., . . . Vílchez-Cavazos, F. (2015). Morphometric assessment of the lumbar pedicle isthmus by reformatted CT: variations according to age and gender.*European journal of anatomy 277-286.*

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.*

Nojiri, K., Matsumoto, M., Chiba, K., Toyama, Y., & Momoshima, S. (2005). Comparative assessment of pedicle morphology of the lumbar spine in various degenerative diseases. *Surgical and Radiologic Anatomy, 27(4), 317-321.*

Park, P., Garton, H. J., Gala, V. C., Hoff, J. T., & McGillicuddy, J. E. (2004). Adjacent segment disease after lumbar or lumbosacral fusion: *Review of the literature. Spine, 29(17), 1938-1944.*

Santoni, B., Hynes, R., McGilvray, K., Rodriguez-Canessa, G., Lyons, A., Henson, M., . . . Puttlitz, C. (2009). Cortical bone trajectory for lumbar pedicle screws. *The Spine Journal, 9(5), 366-373.*

Singel, T., Patel, M., & Gohil, D. (2004). A study of width and height of lumbar pedicles in Saurashtra region. *Indian journal of anatomy, 53(1), 4-9.*

Sinnatamby, C. S. (2011). *Last's Anatomy: Regional and Applied(12thed).Edinburgh;New york:Elsevier.*

Standring, S. (2015). *Gray's anatomy:The anatomical basis of clinical practice (42nd ed);Philadelphia: Elsevier.*

Standring, S., Ellis, H., Healy, J., Johnson, D., & Williams, A. (2008). *Pelvic girdle and lower limb.Gray's anatomy:The anatomical basis of clinical practice;Philadephia:Elsevier.*

Taghva, A., Hoh, D. J., & Lauryssen, C. L. (2012). Advances in the management of spinal cord and spinal column injuries. *Handbook of clinical neurology, 109, 105.*

Vargas-Mena, R., Dufoo-Olvera, M., García-López, O., López-Palacios, J., Aburto-Trejo, J., & Carranco-Toledo, G. (2011). Morphometric analysis of cervical pedicles in a Mexican population. *Mexican orthopaedic journal, 25(6), 366-371*.

Wray, S., Mimran, R., Vadapalli, S., Shetye, S. S., McGilvray, K. C., & Puttlitz, C. M. (2015). Pedicle screw placement in the lumbar spine: effect of trajectory and screw design on acute biomechanical purchase. *Journal of Neurosurgery: Spine, 22(5), 503-510.*

Wray, S., Mimran, R., Vadapalli, S., Shetye, S. S., McGilvray, K. C., & Puttlitz, C. M. (2015). Pedicle screw placement in the lumbar spine: effect of trajectory and screw design on acute biomechanical purchase.*Journal of neurosurgery spine, 22(5), 503-510. doi:10.3171/2014.10.spine14205*

y Fluoroscopía, P. M. M. T. (2009). Morphometry of pedicle and vertebral body in a Mexican population by CT and fluroscopy. *International journal of orthopaedics, 27(4), 1299-1303.*

Zamani, A. A., Moriarty, T., Hsu, L., Winalski, C. S., Schaffer, J. L., Isbister, H., . . . Jolesz, F. (1998). Functional MRI of the lumbar spine in erect position in a superconducting open-configuration MR system: Preliminary results. *Journal of Magnetic Resonance Imaging, 8(6), 1329-1333.*

APPENDICES

Appendix 1: List of Equipment and Instruments

1. Measuring instruments: Vernier calipers, calibrated rulers, goniometer.
2. Digital camera
3. Stationery
4. Gloves
5. Printer

Appendix 2: Data Collection Sheet/Form

1. Date…………………………………………………………………………………
2. Identification

   Male………...   Female……….   Code………….

3. Measurements of the lumbar pedicle

   Chord length in mm

   L1………

   L2………

   L3………

   L4………

   L5………

   Vertical diameter of the pedicle in mm

   L1………

   L2……...

   L3………

   L4…….

   L5…….

   Transverse diameter of the pedicle in mm

   L1…….

   L2…….

   L3…….

   L4…….

   L5…….

   Angle of insertion into the pedicle in degrees

   L1…….

L2…….

L3…….

L4…….

L5…….

Length of the vertebral body

L1…….

L2…….

L3…….

L4…….

L5…….

Appendix 3: Budget

	Kshs
Four rims of plain paper	2,000
Pencils, pens, rubber	200
Vernier calipers	9,000
Folders	1,000
Computer	14,000
Flash Disc	4,000
Printing and binding services (proposal and thesis)	8,000
I.R.E.C fee	1,000
Data handling	14,000
Payment of clerks and secretaries	10,000
Transport and accommodation in Nairobi	40,000
Total	**104,700**

Note: All the budget costs will be financed by the researcher

Appendix 4: Work plan

Activity	Duration	Date	Participant
Selection of topic	1 month	0ctober 2014	Researcher and supervisor
Literature Review	2 months	November – December 2014	Researcher and supervisor
Proposal writing and presentation to department	3months	January –march 2015	Researcher and supervisor
Proposal submission to IREC	1 month	April 2015	Researcher
Approval by IREC	1 month	May 2015	Reviewers
Data collection	8 months	January –august 2016	Researcher
Data analysis	1 month	September 2016	Researcher
Thesis writing	4 months	October 2016- february 2016	Researcher and supervisor
Thesis submission	1 month	March 2017	Researcher

Appendix 5: Lumbar Pedicle Measurements

Figure showing the various measurements that will be measured on the lumbar pedicle using the direct caliber and computerized tomography scans.

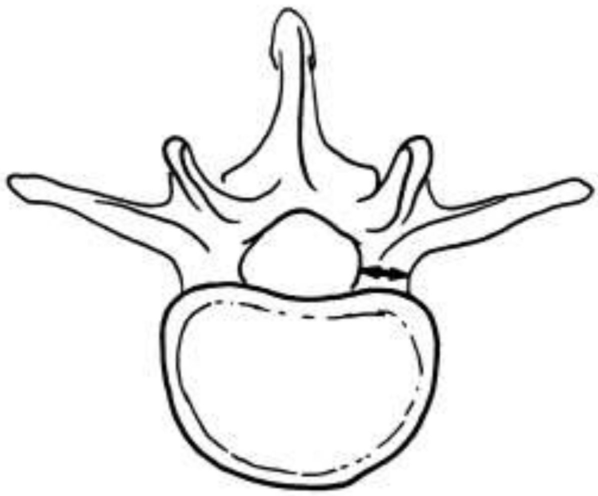

Figure 1: Measurement of the Transverse Width of the Pedicle

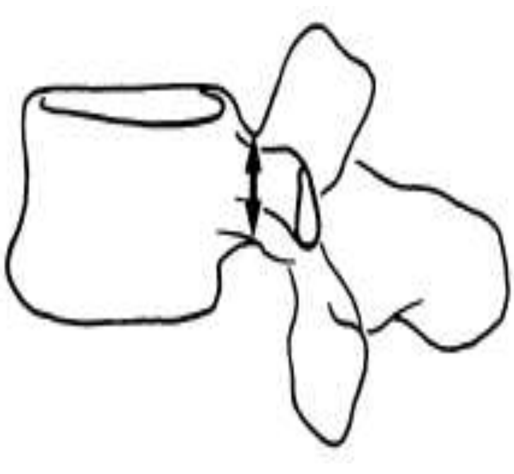

Figure 2: Measurements of the Pedicle Height

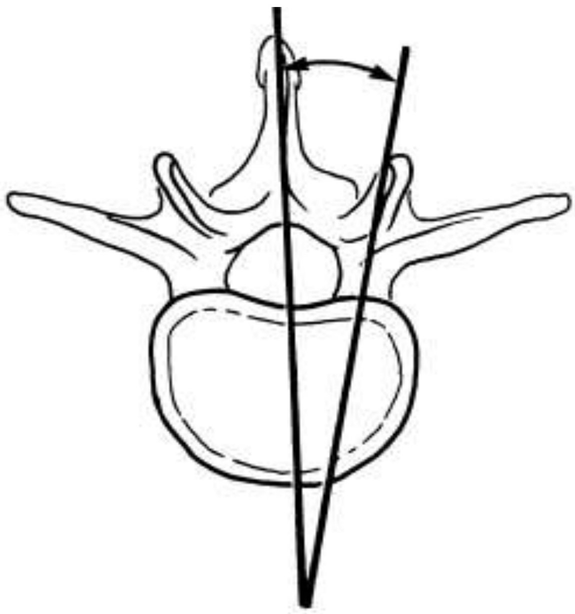

Figure 3: Showing Smallest Angle of Insertion to the Pedicle

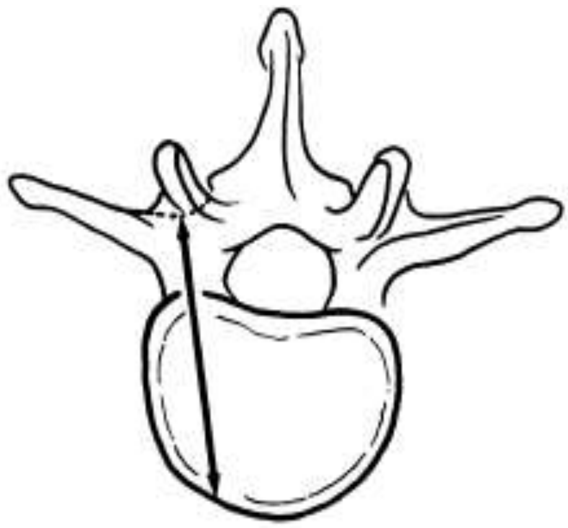

Figure 4: Showing Measurement of the Chord Length

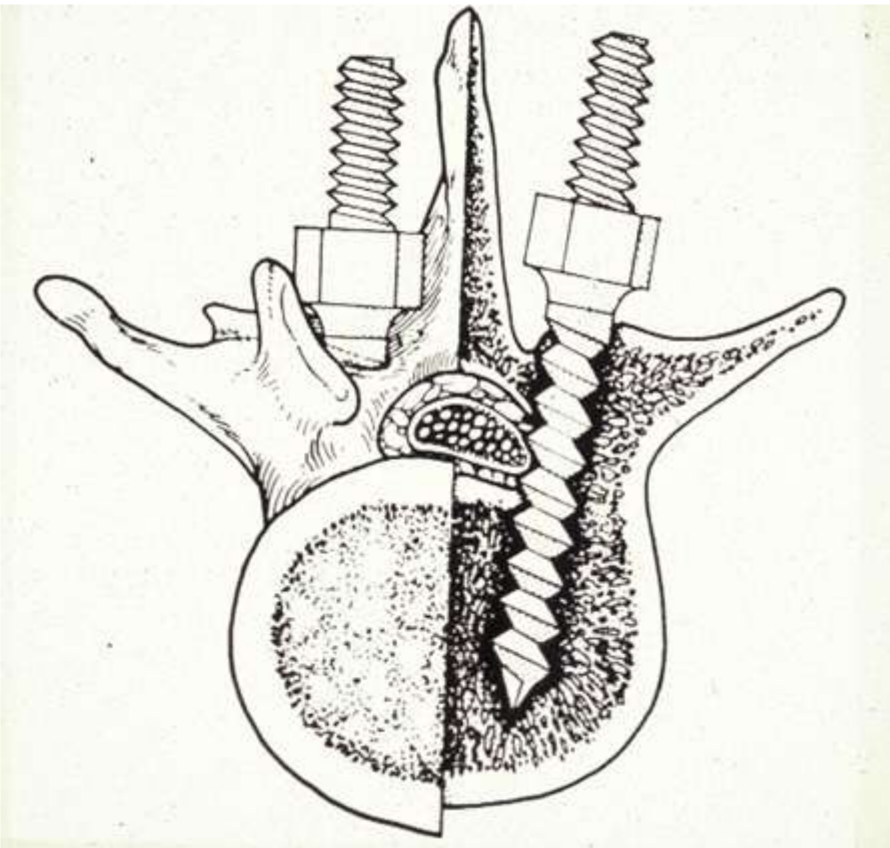

Figure 5: A Misplaced Pedicle Screw into the Neural Canal Injuring the Neural Structures Seen on the Right Side of the Image