MORPHOMETRIC STUDY OF LUMBAR VERTEBRAL PEDICLES USING COMPUTED TOMOGRAPHY AMONG ADULTS IN KANO, NIGERIA

LAWAL YUSUF (MB; BS, UDUSOK, 2006)

SPS/16/MAN/00027

A DISSERTATION SUBMITTED TO THE DEPARTMENT OF ANATOMY, FACULTY OF BASIC MEDICAL SCIENCES, COLLEGE OF HEALTH SCIENCES, BAYERO UNIVERSITY, KANO IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc.) DEGREE IN ANATOMY

JUNE, 2021

DECLARATION

I hereby declare that this research was conducted by me truthfully and in person; under the supervisions of Dr Musa Abubakar and Dr M.K. Saleh. This research work has not been done or presented anywhere for the award of a degree or certificate.

SIGNED_________________________________

Yusuf Lawal (SPS/16/MAN/00027)

CERTIFICATION

This is to certify that the research work for this Dissertation entitled "**MORPHOMETRIC STUDY OF LUMBAR VERTEBRAL PEDICLES USING COMPUTED TOMOGRAPHY AMONG ADULTS IN KANO-NIGERIA"** was carried out by **YUSUF** Lawal (SPS/16/MAN/00027) under our supervision.

Dr. Musa Abubakar MD.,MSc. Ph.D. Date

(Lead Supervisor)

Dr. M.K. Saleh MBBS,MSc., FWACS Date

(Co-Supervisor)

APPROVAL

This Dissertation titled "**MORPHOMETRIC STUDY OF LUMBAR VERTEBRAL PEDICLES USING COMPUTED TOMOGRAPHY AMONG ADULTS IN KANO-NIGERIA"** has been examined and Approved for the award of Master of Science in Anatomy.

______________________________ ______________________

Prof. S.A. Asala (MBBS., PhD.) Date

External Examiner

______________________________ ______________________

Dr. Abdullahi Gudaji (BSc., M.Sc. PhD.) Date

Internal Examiner

______________________________ ______________________

Dr. Badamasi Ibrahim (MBBS., M.Sc., Ph.D.) Date

Head of Department

______________________________ ______________________

Dr. Musa Abubakar (MD., M.Sc., Ph.D.) Date

Lead Supervisor

______________________________ ______________________

Dr. M.K. Saleh (MBBS., M.Sc., FWACS) Date

Co-Supervisor

______________________________ ______________________

Dr. B.G. Kurfi (BSc., M.Sc., Ph.D.) Date

SPS. Representative

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DEDICATION

TO

My teachers

For their advice and support

My parents

For their love and unconditional support

My loving family

My Dearest Wife and my Sons for their patience and understanding.

My friends and colleagues

For their support

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ABSTRACT

Precise anatomical knowledge of lumbar pedicle dimensions is necessary to make clinical diagnosis of lower back pain and any structural deviation of the pedicles may result in interference of the weight transmission mechanism and compression of neural structures. Morphometric study of pedicle dimensions of lumbar vertebrae of adult human subjects in Kano-Nigeria was carried out using their Computed Tomography (CT) Scan images to determine the pedicle dimensions with their variations across vertebral levels and explore the relationship of these dimensions with demographic factors like age, sex and ethnicity of adult Nigerians. A cross-sectional, descriptive study comprising of a total of 110 adults aged (18-75years) involving both sexes in Kano-Nigeria using their CT Scan images from L1 to L5. Each vertebral pedicle was measured in transverse and sagittal planes. The measurements included Pedicle width (PW), Sagittal Pedicle Height (SPH) and the Pedicle chord length

(PCL) of individual pedicle. The mean and standard deviations for each measurement parameter was determined and parametric correlation tests was performed to determine the relationships between the age, sex and ethnicity. Mean PW generally increased in size craniocaudally along the lumbar spine from L1 (7.49 ±1.52 mm) to L5 (14.31 ±1.93 mm). A gradual decrease in Mean SPH from L1 (14.53 ±1.32 mm) to L5 (11.73 ±1.38 mm) was noted. While mean PCL showed an irregular 'U' pattern with the smallest size at L4 (44.63 ±3.42 mm) and highest at L2 (46.80 ± 3.85 mm). All measured dimensions were significantly higher in the right pedicles and among male subjects ($p<0.05$). But Age and ethnicity did not consistently affect pedicle dimensions in a statistically significant manner. This study observed right pedicle dimensions and male subjects as having significantly larger pedicle diameters, with age and ethnicity not having significant effect on pedicle sizes across all vertebral levels.

CHAPTER ONE

1.0 INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

To ensure effective spinal surgical-anatomy practice, it is essential that individuals have an intimate knowledge of spinal anatomy and be able to localize the bony and neural structures accurately. This usually requires a blend of directly visualized anatomic landmarks, proprioceptive feedback, and radiographically acquired data.

The human vertebral column is a curved linkage of individual bones or vertebrae with a continuous series of vertebral foramina running through the articulated vertebrae posterior to their bodies, and collectively constitutes the vertebral canal, which transmits and protects the spinal cord and nerve roots, their coverings and vasculature((Standring, 2016). The Vertebral column morphology is influenced externally by mechanical and environmental factors and internally by genetic, metabolic and hormonal factors. These all affect its ability to react to the dynamic forces of everyday life, such as compression, traction and shear. These dynamic forces can vary in magnitude and are much influenced by occupation, locomotion and posture. The adult vertebral column usually consists of 33 vertebral segments or bones. Each presacral segment (except the first two cervical) is separated from its neighbour by a fibrocartilaginous intervertebral disc.

The functions of the column are to support the trunk, to protect the spinal cord and nerves, and to provide attachments for muscles. It is also an important site of hemopoiesis throughout life. Its total length in males is about 70 cm and in females about 60 cm. the spine consists of five types of vertebral bodies which are the cervical, thoracic, lumbar, sacral and coccyx with the latter two being fused and immobile with the former three are separated by an intervertebral disc at each level and they are slightly mobile.

The lumbar vertebrae are the third of the cranio-caudal order of arrangements of the bony spinal vertebral column. They consists of five serially arranged vertebral bodies on the lower aspect of the human spine and happens to be the most mobile portion of the entire vertebral column and accounting for approximately 12% of overall body length (Amonoo-Kuofi, 1995; Standring, 2016).

The pedicle of the lumbar vertebra which is the junction between the posterior and the anterior constructs of the spine, it's the strongest part of the lumbar vertebra is short, thick and are made of entirely cortical bone with a small core of cancellous bone (Singel *et al*, 2004; Standring, 2016). The upper margins form the superior vertebral notch, and lower margins form the inferior vertebral notch, and both contribute to corresponding intervertebral foramen. As pedicle is the strongest part of lumbar vertebrae, it acts as a strut to transmit compressive forces and muscular movements between the body and neural arch in which it serves as a beam connecting the anterior and posterior columns of the spine.

Also the pedicle is a key element for surgical management of lumbar spinal disorders, due to the use of pedicle screws as the main stream for lumbar fusion surgeries Singel *et al*., (2004). The fixation of lumbar spine is needed for various spinal problems like fractures in lumbar spine, resection of tumours in vertebral bodies, gross spondylolisthesis and lumbar instabilities (Singel *et al*., 2004; Jeffrey and Kevin, 2015;). In addition the pedicle serves as the main access port for surgical procedures performed in the vertebral body, such as biopsies, vertebroplasties and kyphoplasties (Sreevidya *et al*, 2017).

Also the inherent racial variations in human skeletal morphology has long been well known, hence the morphometry of the pedicle also vary from population to population, Even within the same population the anatomical variations have been reported on the pedicle shape, size and angulation within different sex, race, ethnic and regional groups (Singel *et al*., 2004).

Several authors (Soumya *et al*, 2015) studied the morphometry of the vertebral pedicle both in cadavers and radiological imagery examinations. Also, to date many morphological studies of the lumbar pedicles have been conducted to establish a reference for different ethnic populations around the world using radiological imaging modalities like Computed tomographic scan, fluoroscopy, plain conventional radiographs and magnetic resonance myelography as measurement tools following which there has been tremendous increase in the amount of information on the anatomic morphology of the pedicles as a result of the non-invasive measurement methods listed above.

Although the burden of low backache is equally prevalent all over the Universe, it appears few studies have been carried out among Egyptian-Arab population of North Africa while among black sub-Saharan African ethnic groups within and around Nigeria being next to none(Maaly *et al*, 2010; Soumya *et al*., 2015). Hence there is a need for our own local and ethnic specific metrical data specifically relevant to our north-western region, which may if generated appropriately fill up the existing knowledge void. The data generated will be relevant and come handy to the clinicians dealing with the problems/diseases of low backache, particularly due to bony abnormalities or deformities.

The present study will be Computed Tomographic scan based, which has been recognized as an excellent method of assessing pedicle morphometry, for measurement of relevant lumbar pedicle parameters (Bernard and Seibert, 1992; Acharya *et al*, 2010). It would also attempt to deduce more generalized and valid data on lumbar pedicle morphometry in hausa-fulani population of northern Nigeria by comparing with available literature. This can be used for development and fabrication of ethnic specific implant devises and will assist in reducing inadvertent surgical errors on account of variations in anatomy despite proper surgical techniques.

1.2. AIM AND OBJECTIVES

1.2.1. Aim

To evaluate the morphometric dimensions of lumbar vertebral pedicles among normal adults in Kano using computerized tomography scan Images.

1.2.2. Objectives

1- To determine the axial pedicle width of L1-L5 vertebrae using computed tomography.

2- To determine the sagittal pedicle height of L1-L5 vertebrae using computed tomography.

3- To determine the axial Pedicle-chord length of L1-L5 vertebrae using computed tomography.

4- To explore the relationship of pedicle width with age, sex and Ethnicity of subjects.

5- To explore the relationship of sagittal pedicle height with age and sex of study subjects.

1.3. JUSTIFICATION

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 in developing countries like Nigeria. It is estimated that between 70-90% of the general population suffer from low back pain at some point in their lifetime and that approximately 4% require surgery at some time (Garza and Guzm, 2009; Gelalis and Kang, 1998).

Moreover, the lumbar spine is the most mobile part of the vertebral column hence the most exposed to instability following trauma in particular that related to road traffic accidents, the use of heavy mechanical devices, and adventure sports. Apart from other surgical entities like laminectomies, degenerative conditions, congenital defects, and metastasizing malignant tumours of the prostate and other pelvic organs (Chawla & Mahesh, 2011). Therefore as the lumbar spine pathologies are most prevalent at this spinal region, the interventions aimed to alleviate the diseases is also more commonly done at this level (Sreevidya *et al*., 2017).

Being part of vertebral body, lumbar spine pedicle is subject to ethnic variations as reported in studies (Acharya *et al*., 2010). Hence, the need for ethnic specific data on pedicle morphometry to avoid misplacement and inappropriate size of implants, for it may cause injury to patients despite the best efforts of spine surgeons. The data which forms the basis of all the instrumentation system development is usually derived from Western population which may be different from other ethnic groups.

Most anatomic studies on the morphology of the lumbar pedicles have been reported in a white population, with a few reports in Asians but abysmally few reports in blacks and Nigerian ethnic population (Chadha *et al*., 2003; Cheung *et al*., 1994; Kim *et al*., 1994). Some of these are based on direct cadaveric measurements, some on radiologic measurements, and others on combined cadaveric and radiologic parameters (Panjabi *et al*., 1992; Robertson & Stewart, 2000). The accuracy of computed tomography (CT) measurements of the pedicle diameter, pedicle axis, and depth to the anterior cortex along the pedicle axis has established that Computed Tomographic scan is the best means of evaluating pedicle radiographic morphology (Bernard and Seibert, 1992; Chadha *et al*., 2003; Krag *et al*., 1986). Various authors have shown that no statistically significant difference exists between data obtained from CT scans and direct cadaveric measurements (Chadha *et al*., 2003; Krag *et al*., 1988; Marchesi., 1988).

The increasing use of pedicle screw in spinal stabilization surgical procedures has inherent risks as with all surgical procedures in medical practice, among which includes dural lacerations, chronic neurological irritations and cerebrospinal fluid leakages which occurs primarily due to the small space between the pedicle and the dural sac and screw misplacements during surgeries (Amonoo-Kuofi, 1995; Maaly *et al*., 2010; Yaoming *et al*., 1999). The amount of information on the anatomic morphology of the pedicles has greatly reduced the occurrence of these complications and consequently the surgical outcomes of procedures around the lumbosacral region of the spine (Yaoming *et al*., 1999).

To my knowledge and based on literatures search, no morphometric study of lumbar pedicle parameters in normal adult healthy population in Nigeria population has been published. For this reason, and because detailed knowledge of pedicle parameters is crucial for the care of spinal deformities and its complications, I aim to performed a prospective review to characterize the range of pedicle morphology in the lumbar vertebrae among normal adult population of Kano-Nigeria using their computed tomographs.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. EMBRYOLOGY OF LUMBAR VERTEBRAE

The axial skeleton includes the vertebrae, ribs, sternum, and skull. Embryologically the first structure of the future axial skeleton to form is the notochord which appears in the midline of the embryonic disc at 15days of development as a cord of cells budding off from a mass of ectoderm known as Hensen's node. The dorsal mesoderm on either side of the notochord becomes thickened and arranged into 42 to 44 pairs of cell masses known as somites (4 occipital, 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 8 to 10 coccygeal) between the 19th and 32nd day of development. The formation of these primitive segments, or somites, reflects the serial repetition of homologous parts known as metamerism, which is retained in many adult prevertebrates. The vertebrate embryo is fundamentally metameric, even though much of its segmentation is lost as development proceeds to the adult form (Lannotti and Parker, 2013).

The first significant change in the somite of the human embryo is the formation of a cluster of mesenchymal cells called sclerotome, on the ventromedial border of the somite. The sclerotomal cells migrate from the somites and become aggregated about the notochord to ultimately give rise to the vertebral column and ribs (Lannotti and Parker, 2013).

The vertebral column and ribs at about 4th week of development aggregate in to a clustering of sclerotomal cells derived from two adjacent somites on either side of the notochord becomes the primordium of the body, or centrum of a vertebra. Soon after a paired concentration of mesenchymal cells extend dorsally and laterally from the body to form the primordia of the neural arches and the costal processes. The costal process becomes a ribs, anterior part of the transverse foramen of the cervical vertebrae, transverse process of the lumbar vertebrae, and the lateral part of the sacrum (Lannotti and Parker, 2013).

The vertebrae and ribs in the mesenchymal, or blastemal, stage are one continuous mass of cells. This stage is quickly followed by the cartilage stage by becoming chondrocytes and produce cartilage matrix during the seventh week, beginning in the upper vertebrae. By 9th week the rib cartilages have become separated from the vertebrae. The clustering of sclerotomal cells to form the bodies of the vertebrae establishes intervertebral fissures that fill with mesenchymal cells to become the intervertebral discs. The notochord in the centre of the developing intervertebral disc expands as its cells produce a large amount of mucoid semifluid matrix to form the nucleus pulposus. The mesenchymal cells surrounding the nucleus pulposus produce proteoglycans and collagen fibres to become the fibrocartilage anulus fibrosus of the intervertebral discs. At birth, the nucleus pulposus makes up the bulk of an intervertebral disc. From birth to adulthood, it serves as a shock-absorbing mechanism, but by 10 years of age the notochordal cells have disappeared and the surrounding fibrocartilage begins to gradually replace the mucoid matrix (Lannotti and Parker, 2013; Netter, 2013).

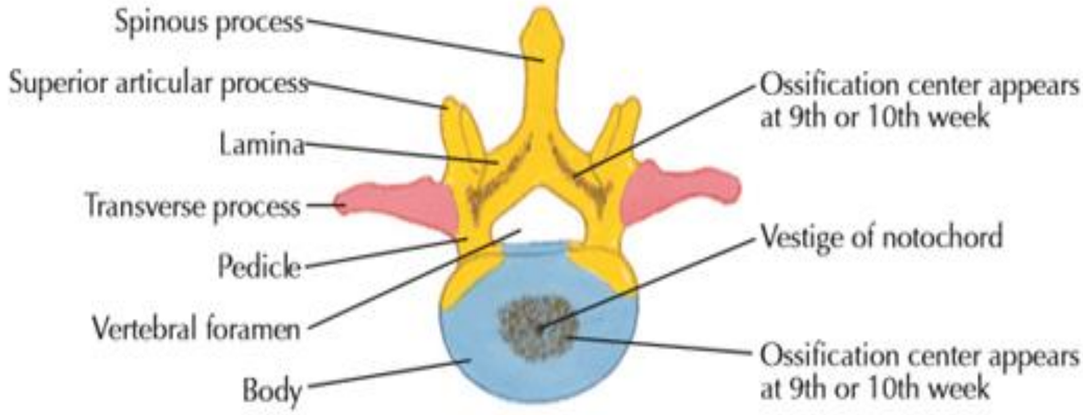

Plate I: A Typical Lumbar Vertebra (courtesy: Netter, 2013)

2.2 ANATOMY OF THE LUMBAR VETEBRAE

The vertebral column is built from individual units of alternating bony vertebrae and fibrocartilaginous discs. These units are intimately connected by strong ligaments and supported by paraspinal muscles with tendinous attachments to the spine. There are 33 vertebrae (7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal), although the sacral and coccygeal vertebrae are usually fused to form the sacrum and coccyx (Plate II). All vertebrae conform to a basic plan, but morphologic variations occur in the different regions. A typical vertebra is made up of an anterior, more-or-less cylindrical body and a posterior arch composed of two pedicles and two laminae, the latter united posteriorly in the midline to form a spinous process (Plate I). These processes vary in shape, size, and direction in the various regions of the spine. On each side, the arch also supports a transverse process and superior and inferior articular processes; the latter form synovial joints that are the posterior sites of contact (left and right) for adjacent vertebral segments. The disc is the anterior site of attachment. The spinous and transverse processes provide levers for the many muscles attached to them. The increasing size of the vertebral bodies from above downward is related to the increasing weights and stresses borne by successive segments, and the sacral vertebrae are fused to form a solid wedge-shaped base—the keystone in a bridge whose arches curve down toward the hip joints (Plate II). The intervertebral discs act as elastic buffers to absorb the many mechanical shocks sustained by the vertebral column. Only limited movements are possible between adjacent vertebrae, but the sum of these movements confers a considerable range of mobility on the vertebral column as a whole. Flexion, extension, lateral bending, rotation, and translation are all possible, and these actions are freer in the cervical and lumbar regions than in the thoracic region. Such differences exist because the discs are thicker in the cervical and lumbar areas and they lack the splinting effect produced by the thoracic rib cage and sternum. Additionally, the cervical and lumbar spinous processes are shorter and less closely apposed and the articular processes are shaped and arranged differently(Netter, 2013).

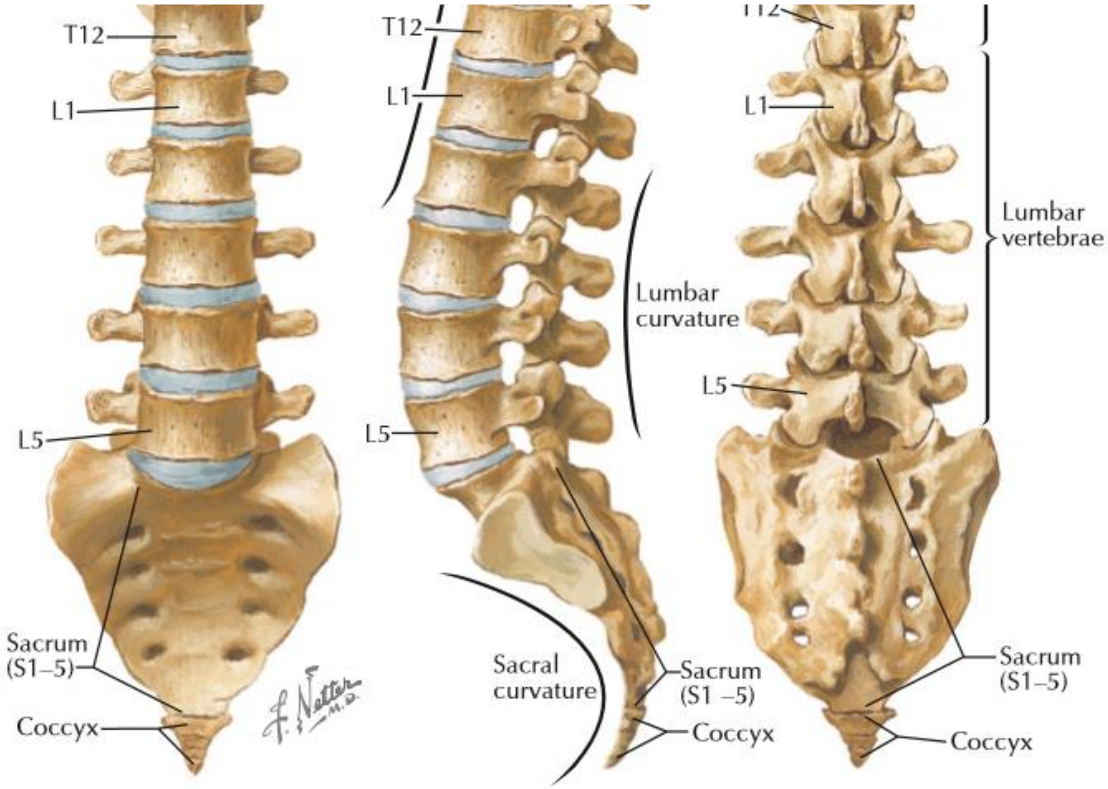

Plate II: Diagram showing the lumbar and sacral Vertebral curvatures (courtesy: Netter,2013)

The lumbar region of the vertebral column commonly referred to as the small back has five lumbar vertebrae (L1 to L5) which are the largest separate vertebrae receiving the most stress and are distinguished by the absence of costal facets (Plate III). The vertebral bodies are wider from side to side than from front to back, with upper and lower surfaces that are kidney shaped and almost parallel, except in the case of the fifth vertebral body, which is slightly wedge shaped. The vertebral foramina have a “teardrop” shape. The pedicles are short and strong, arising from the upper and posterolateral aspects of the bodies. The laminae are short, broad plates that meet in the middle to form nearly horizontal spinous processes that are perpendicular to the lamina. The intervals between adjacent laminae and spinous processes (interlaminar spaces) are wider than in the cervical and thoracic spine. The articular processes (which form the facet joints) project superiorly and inferiorly from the area between the pedicles and laminae. The facet joints are oriented relatively vertically, which allows for some flexion and extension but little rotation. The transverse processes of L1 to L3 are long and slender, whereas those of L4 and L5 are more pyramidal. Near the base of each transverse process are small accessory processes; other small, rounded mammillary processes protrude from the posterior margins of the superior articular processes. The fifth lumbar vertebra is atypical. It is the largest, with its body deeper anteriorly; its inferior articular facets face almost forward and are set more widely apart, and the roots of its stumpy transverse processes are continuous with the entire lateral surfaces of the pedicles (Marieb *et al.*, 2017; Netter, 2013).

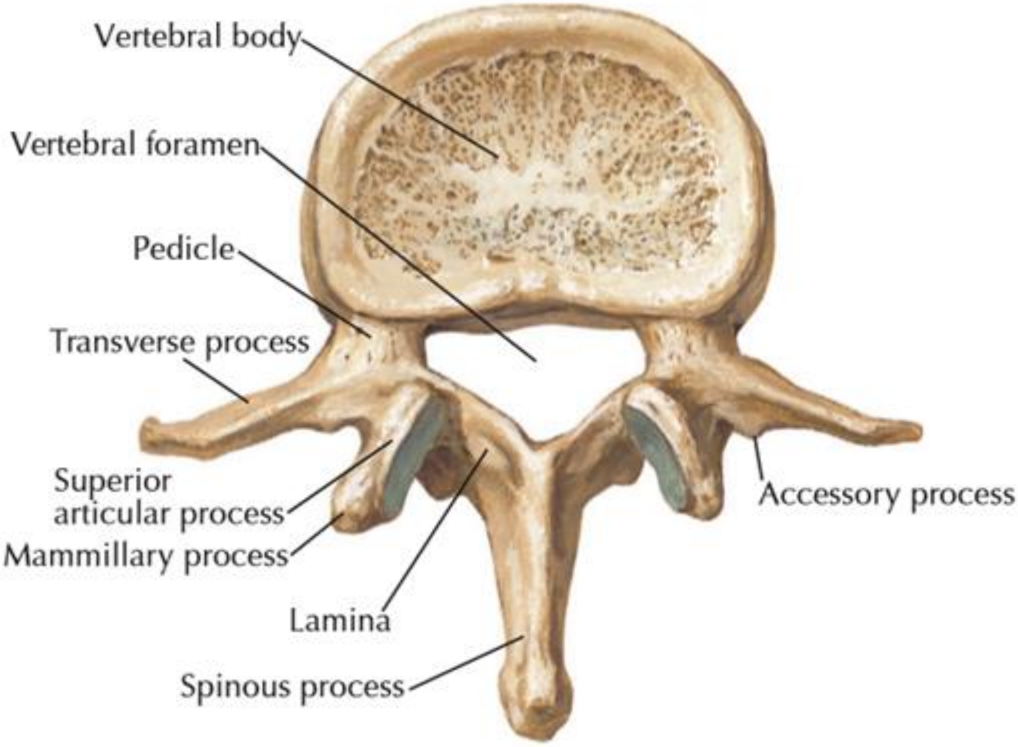

Plate III: Superior view of Lumbar Vertebra (Courtesy: Netter, 2013).

The lumbar vertebral pedicle has an intimate relationship with neural structures, since it is part of the intervertebral foramen, the intervertebral foramen has as its upper and inferior limit bounded by the pedicle of the vertebrae above and below respectively. The floor is made by the posterior-inferior edge of the vertebral body above, the intervertebral disc, and the posterior-superior border of the vertebra below. The ceiling is formed by the yellow ligament. The pedicle is laterally placed in relation to the dural sac. The closest lumbar root appears in an almost straight angle in relation to the dural sac, being shorter than the more distal ones. In its path inside the neural canal it is involved by epidural fat while the involving structure of the lumbar roots is inferiorly anchored to the subjacent pedicle, limiting the medial and superior mobility of the root. Also, the spinal ganglion has a preferentially intra-foraminal location, with exception of S1 that has a preferentially intra-spinal location. Thus, the spinal ganglion has an intimate relationship to the lumbar pedicle (Cláudia and Roberto, 2002).

2.3. HISTORY OF LUMBAR VERTEBRAL MORPHOMETRY

Historically morphometric measurements and observed variations in human lumbar spinal and pedicle anatomy using radiological imaging methods dates back to the 1950s when Caffey (Caffey, 1958) noted that interpedicular distance increases with caudal progression in non-achondroplastic patients. Similarly two decades later (Lutter and Langer, 1977) reported that pedicle diameters and spinal cross-sectional are in the lumbar spine increased with caudal progression among normal controls when compared to achondroplasts.

The shape of the human lumbar vertebrae is affected by gender due to genetic, hormonal and environmental factors responsible for growth-spurt timing (Scoles *et al*., 1991). Larger vertebral dimensions are usually observed in males when compared with females of same age, ethnicity and race (Masharawi *et al*., 2010) made a direct 3D digitized measurement of 4,080 thoracic and lumbar vertebrae age 20-80years obtained from 240 normal complete spines of adult human skeletons which were part of the Hamann–Todd Human (HTH) Osteological Collection housed at the Cleveland Museum of Natural History, Cleveland, Ohio. Found a significant gender differences in the morphological parameters of lumbar vertebrae with females having a thinner spinous process, greater interfacet spaces and inter spinous distances. In a similar study (Amonoo-Kuofi, 1995; Marasini *et al*., 2014) performed morphometric measurements in 540 persons (270 males and 270 females) with age ranging from 10-65 years by using plain X-ray AP view only to measure horizontal and vertical diameter of lumbar spine pedicles and found a significant variations between the different age groups and gender with males having higher values than females. (Marasini *et al*., 2014) in an observational study of lumbar pedicle morphometry of 246 ethnic Nepalese of different age groups (>10yrs) using plain radiographs showed a statistically significant difference in measured mean horizontal and vertical pedicle diameters at all levels between both genders with males having mean horizontal diameter varying from 7.73 mm (L1) to 10.89mm (L5) and in female from 6.57mm (L1) to 11.94 mm (L5) with overall increase in the dimensions as the age groups were followed from the youngest to the oldest. But Dimensions of the right and left sides were found to be different at all levels but the difference was not significant statistically (P-value >0.05 at 95% of confidence interval).

Similarly (Datir and Mitra, 2004) performed Morphometric study in the adult Indian population and found a significant difference in pedicle dimensions between males and female with mean horizontal diameter in male ranged from 7.05mm (L1) to 11.94mm (L5) and in female from 5.95mm (L1) to 10.61mm (L5).

Similarly, Sreevidya *et al.*,(2017) studied the pedicular dimensions of 20 adult cadaver lumbar specimens of both sexes of south Indian origin using direct calliper and CT scan images of same samples, direct measurements of the pedicle width ranged between 7.2 -13.9 mm from L1 to L5 level, height of pedicle ranged 13.7 to 13.1mm and length was 7.1 to 5.1 mm. The same measurements in CT images evaluation were 6.7 to 12.5 mm for pedicle width, 12.4 to 10.9 mm for pedicle height and 7.4 to 5.4 mm for pedicle height respectively. They found no statistically significant difference between measurements in male and female cadaver specimens and also between the direct calliper and CT measurements. However, the dimensions as a whole in this study were slightly lower when compared to studies in South American populations reiterating the existence of racial differences in the pedicle dimensions.

Alam *et al.*,(2014) conducted a cross sectional study of 220 vertebrae of 49 adult Pakistani patients aged (18-60years) using their computed tomographic images. Parameters analysed showed vertebrae sizes, vertebral canals and recesses to be greater in males, the differences in transverse, anteroposterior diameters of the vertebral bodies and sagittal diameter of pedicles on the left side were statistically significant ($p<0.05$). Comparison of populations revealed statistically significant differences in pedicle dimensions between Pakistani population and others with the former having.

Also, Urrutia *et al.*, (2009) evaluated 60 adult (40-78years) cadavers of Mexican population by fluoroscopy and CT scan from L1 to L5, with multiplanar measurements of lumbar minimum pedicle width, pedicle angle, distance to anterior cortex, anteroposterior and interpedicular spinal canal diameters. CT scan measurements showed a progressive and gradual increase in the width of the pedicles from L1 (7.81 ±1.30 mm) to L5 (14.36 ±14.36 mm), a progressive and gradual decrease of pedicle length from L1 (20.92 ±2.62 mm) to L5 (17.23 ±1.35 mm). When fluoroscopy was used there was the same relationship but the values were higher than those obtained by CT scan. The values for widths and lengths are slightly higher in males than in females, but did not attain significant difference.

In a related study, Fang *et al*.,(1994) in their evaluation of 100 adult Chinese patients ages 18-60years using computed tomography for pedicles morphometry found no demonstrable gender differences for dimensions or angular alignment of the pedicles. Although it revealed that Asian pedicles had a larger pedicle inclination angle from L1 to L4 (L1 = 16 degrees, L2 = 16 degrees, L3 = 19 degrees, L4 = 23 degrees and L5 =29 degrees) and there was a significant difference between the lumbar pedicles of Asians and whites.

The lumbar vertebral pedicle diameter is not uniform across all levels as revealed by findings of Several authors (Ban *et al*.,1999; Krag *et al*., 1986; and Zindrick *et al*., 1987) who studied the morphometry of the vertebral pedicle both in cadavers and imagery examinations, their findings showed the lumbar vertebral pedicle to increase its diameter from L1 to L5 in addition the transversal pedicular axis smaller than the sagittal one. They also found that the axis of the lumbar pedicle in the transverse plane ranges from 0-10° in L1, 10-20° from L2 to L4, and 20-30° in L5. At the pedicle axis, the distance between the lamina and the anterior part of the vertebral body increases 8 to 10mm. Matuoka *etal*.(2002) evaluated 100 lumbar vertebral pedicles of adults' ages 28-75years of mixed racial Brazilian origin by direct digital cadaveric measurements of specimens showed a statistically significant increase both in the transversal as in the longitudinal diameter from L2 to L5 with the minimum value of 9.2mm at L2 and maximum measured value of 14.9mm at L5 vertebra.

Although their study did not consider the racial variations in pedicle morphometry by obtaining measurements from both black and white raced cadavers. In a similar finding (Simpson *et al*., 2016) in New York studied the pedicle diameters from transverse and coronal Computed Tomographic image reconstructions of five (5) adult thoracolumbar spine cadaveric specimens and comparison of their degree of disparity with minimum pedicle diameter, noticed pedicle diameters varied significantly across vertebral levels with a steady increase from L1 through L4 in the lumbar region, in which mean L1 diameter was 9.8±1.6mm and L4 being 12.2±2.0mm, also with a significant difference ($p<0.001$) in minimum pedicle diameter existing between measurements from coronal and transverse reconstructions images.

Moreover, Acharya *et al*.,(2010) evaluated CT scans of the lower thoracic and lumbosacral spine of 450 vertebrae in 50 consecutive adults (20-70yrs) of north Indian origin free from spinal disorders. The transverse pedicle isthmus width, transverse pedicle angle, and depth to anterior cortex along the midline axis and the pedicle axis were obtained with help of computer aided software and revealed the mean pedicle isthmus width at L1 as 7.20± 0.93mm and 13.91±1.16mm at L5 level, the depth along pedicle axis was maximum at L2 level with mean of 49.03±2.79 and minimum at L1 mean 47.00± 3.39mm but measured 48.91± 4.42mm at L5. This study reveals a significant gradual increase in measured most measured pedicle parameters from L1 towards L5 vertebral levels. Also, it was observed that there are significant differences in pedicular morphology in Indian population when compared with western counterparts with the former recording lower values. However, no analysis of the correlation between the weights/sizes of investigated population or height and pedicle morphometry done in this study.

Srikumaran *et al*.(2007) in their retrospective study of lower thoracic-lumbar spine measured pedicle parameters on computed tomography images of 19 adult achondroplastic patients (16-58years) found transverse pedicle diameter increased from T9 (5.5mm) to L5 (14.2mm) but Sagittal pedicle diameter declined from L1(11.6mm) to L5 (7.8mm). Revealing that Achondroplastic pedicle morphology differs markedly from those of the normal spine with respect to shorter chord lengths, cranially inclined pedicles and pedicle shape transitions from vertically to horizontally oriented ellipsoids along the lumbar spine. Although the above study subjects had clinical symptoms of spinal stenosis.

In a different study Tan *et al*.(2004) carried out a quantitative three-dimensional measurements of anatomical parameters of the cervical (C3–C7), thoracic (T1–T12) and lumbar (L1–L5) spine of adult Chinese-Singaporean subjects based on 220 vertebrae specimen from 10 cadavers. The means and standard errors for linear, angular and area dimensions of the vertebral body, spinal canal, pedicle, spinous and transverse processes were obtained for each vertebra, in which all dimensions were found to be smaller being 31.7% for spinal canal area, 25.7% for pedicle width and 22.1% for length, when compared to Caucasian population.

Maaly *et al*.(2010) measured the axial lengths, angles, axial breath and endosteal thickness of lumbar pedicles in 5 adult Egyptian cadavers and 75 patients with disc diseases, using CT scan images/calliper measures and CT scan only for the cadaveric and disc disease patients respectively. They found the axial length of pedicles to be around 5 cm at all lumbar levels with negligible shortening at L4 and L5, angles of inclination of the lumbar pedicle axis on the midline were more obtuse than the known Western measurements and becoming more obtuse from L1 to L5, the pedicle breadth was progressively thicker from L1 (6.6 mm) to L5 (18.5 mm) and the endosteal thickness similarly became thicker at L5 (8.3 mm) than at L1 (3.8 mm). There was no statistically significant difference between all measurements by calliper of cadavers with its CT measurements and with patients CT scan images, showing a measurement difference of 0.03-1.18mm.

A number of morphologic studies of the lumbar vertebral pedicle have been reported in sub-Saharan African population with similar variations in age, sex and race noted. Azu *et al*.(2016) studied lumbar vertebral dimensions of a cohort of specimens of 107 adult individuals from the osteological collections in South Africa. Measurements made showed gradual increase from L1 to L5 for mean AP diameter and IPD, and a decrease in mean Pedicle length from L1 to L5. Mean midsagittal diameter was observed to present a "U" curve pattern from L1 to L5, while Midsagittal diameter/AP diameter ratio decreased from L2 downwards. Also observed that certain lumbar dimensions also showed significant correlation with age at distinct lumbar levels.

Abuelnour *et al*.(2016) measured antero-posterior diameter of lumbar vertebral canal of 102 adult normal and stenosis patients using Magnetic resonance imaging technique. There was increased anteroposterior diameter toward the caudal in both males and females with fifth lumbar vertebra showing the largest diameter. Also a significant correlation of lumbar spinal stenosis with age, it was noticed and females had higher incidence which occurred frequently at level of L5 due to degeneration and intervertebral disc herniation, indicating the aging as the main factor in lumbar stenosis.

Udoaka and Chisom, (2016) studied three hundred (300) standard lateral radiographs of adult cervical vertebrae C3-C5 that were randomly selected from the imaging archives of selected hospitals in Port Harcourt, for measurements of vertebral body length (VBL) and vertebral body height (H). In all measured parameters males had higher values, while spinal canal mid sagittal diameter was larger and at variance with other populations, in addition Torg – Pavlov's ratio was about the same in all the vertebral levels for both gender and younger adults having smaller vertebrae body size and spinal canal than the older ones. However, this Nigeria study dwelled on vertebral body and canal without evaluating pedicle parameters and used radiographs as instruments of measures which suffer from wide inter-observer variability and fluctuating image quality due to technical inadequacies.

Several morphometric studies of vertebral pedicles were performed by using plain radiographs to demonstrate pedicle horizontal and vertical dimensions, interpedicular distance and angles, moreover studies established that measurements obtained from the plain x-ray films correlated well with values measured from CT scan and cadavers and since plain x-ray is the cheap and easily available method and whole lumbar spine (L1-L5) can be included in the single x-ray film. But it suffers from image quality fluctuations and superimpositions making measurement errors more likely.

However morphometric methods like CT scan, fluoroscopy and direct calliper measurements of anatomic specimens have proven invaluable in the study of lumbar pedicles. Other radiological techniques of indirect assessment of lumbar spine morphometry are MRI and Myelography although they suffer from sub-optimal image resolutions, high costs and long image acquisition times. Also recently digital morphometry during a dual-energy X-ray absorptiometry (DXA) bone densitometry scan is a great opportunity for studying vertebral dimensions and fracture assessment of clinically unrecognized pathologies that could have relevant clinical implications Muszkat *et al.*(2015).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1. STUDY DESIGN

This was a cross-sectional, descriptive and hospital-based study conducted over a one (1) year period between the months of September 2018 and September 2019, were Adults aged 18-75years referred for Abdominopelvic CT Scan at CT Scan Unit of Radiology Department of Aminu Kano Teaching Hospital, with no history or clinical evidence of Lumbosacral disease or other systemic diseases affecting the vertebrae were recruited into the study with their informed consent.

3.2. STUDY AREA

Kano has its coordinates at 12.0022° N, 8.5920° E and is bordered on the East by Bauchi and Jigawa states, to the south by Kaduna state and to the West and North is by Katsina state. The total land area of Kano state is 21,276.87sq kilometers with a metropolitan population of 3,626,068 According to the National Bureau of Statistics, National Demographic Bulletin 2018, with an almost equal distribution of male (51%) and female (49%) individuals (National Bureau of Statistics, 2018).

Kano has a single federal Teaching Hospital Named Aminu Kano Teaching Hospital (AKTH), a tertiary health facility located within the Kano metropolitan area, Northwestern Nigeria.The hospital serves the population of about nineteen (19) million 2018 population estimates mainly from the states listed above.

The Radiology department of Aminu Kano Teaching Hospital is equipped with array of imaging facilities including modern state of the art equipment with both diagnostic and interventional procedures/services offered routinely. These include Conventional radiography, Fluoroscopy with tilting table and spot film devices, 2 Helical computed tomography scanners with 3D reformats and cardiac imaging protocols, Mammography, Ultrasonography (B-mode and Doppler) and conventional angiography with digital subtraction and interventional capabilities.

3.3. STUDY POPULATION

The study was conducted on all adult patients age 18-75years who met the inclusion criteria and consented to participate in the study. The subjects were recruited consecutively from the Muhammadu Sanusi-II CT Scan Unit of AKTH, Kano-Nigeria.

3.4. SAMPLE SIZE DETERMINATION

The minimum sample size for the study was calculated using Fisher's statistical formula for sample size determination for descriptive studies as follows:

$n = z^2 P(1- P)/ d^2$ (Daniel, 1999; Winn et al., 2006)

Where:

n = Minimum sample size

Z = Standard deviation (constant of 1.96 corresponding to 95% confidence interval).

P = Proportion in target population estimated to have a particular characteristic. No reasonable estimate 50% (0.5) was used.

d = precision of study (in proportion of one; if 5%, d = 0.05).

Therefore, $n = 1.96^2 \times 0.5 \times 0.5 / 0.05^2$

$= 384.16$

Rounded up to 385.

- Using the finite population correction formula to estimate the sample size (used for sampling from a population less than 10,000 without replacement)
- $N_0 = \underline{n \times N}$
- n+(N-1)
- Where N is the population size which is 130 [this was calculated from number of patients' attendees per day multiplied by number of days of data collection (within 13weeks i.e. 5 days =65days) ~ 65x2 = [130].
- n is d sample size as calculated using the 95% CI = 385.
- Therefore,
- $N_0 = \underline{385 \times 130}$

  385+(130-1)
- = 97.37
- Rounded up to = 100
- The finite corrected sample size is 100. An additional 10% sample was added to improve precision of the study.
- Ref: Estimation and sample size determination for finite populations. ** Available from http://wps.pearsoned.co.uk/wps/media/objects/10721/10978811/ch_08/levine-smume6_topic_08_07_2.pdf [Accessed on 11th June, 2017]

3.5. INCLUSION CRITERIA

1. Subjects between the ages 18-75years
2. Subjects who present for Abdominopelvic CT scans for indications other than diseases affecting lumbosacral spine.
3. Subjects who consent to be part of the study by signing an informed consent.

3.6. EXCLUSION CRITERIA

1. Subjects below age 18 or above 75years.
2. Pregnant women.
3. Subjects who declined informed consent for the study.
4. Subjects with clinical diagnosis of lumbosacral pathology or sacralization of last lumbar vertebrae.
5. History of lower back surgery.

3.7. SAMPLING TECHNIQUE

Independent convenient sampling technique was applied. Subjects who satisfied the inclusion criteria were recruited consecutively until the required sample size was achieved. Recruitment was done during working hours/days (i.e. 10am-4pm daily and Mondays through Fridays) only.

3.8. STUDY TOOLS/INSTRUMENTS

- Helical Computed Tomography machine – 164 slice Aquillion Prime Model TSX-303A, Toshiba Medical Systems Corporation, 1385, Shimoshigami, Otawara-Shi, Japan, 2014 (Plate IV).

- **Vitrea**-vital advanced Multi-modality visualization clinical imaging software/work station, version 6.6.3. (Vital Images Inc., Japan. ©2013). (Plate V)

Plate IV: 164-Slice Toshiba Aquillion Prime Computed Tomography Machine.

Plate V: Vitrea 6.6.3 WorkStation for Pedicle Measurements.

3.9. STUDY PROTOCOL

3.9.1. CT Scan Image Acquisition

After explaining examination/procedure to the research participants they were asked to wear comfortable clothing with loose fittings and remove all jeweleries/metals around the area to be examined for the period of the examination to prevent artefacts. One hundred (100) normal adult individuals underwent Abdominopelvic CT scan imaging (T12-S1 portions) using Helical Computed Tomography machine – 164 slice Aquillion prime TSX-303A, Toshiba Medical Systems Corporation, 1385, Shimoshigami, Otawara-Shi, Tochigi-Ken 324-8550, Japan, 2014. The scanning parameters for each patient were 120kV, tube potential; 200 effective mAs; collimation, 160 0.625mm; rotation time, 0.5s; Volume CT dose index, 7-8mGy; 3mm slice thickness and a pitch of 0.52. The axial images acquired would be reconstructed in the sagittal and coronal planes with a slice thickness of 1mm each from the primarily acquired native axial images of each patient at all lumbar vertebral segments (L1-L5), the pedicle axis was identified (Plate VI) and acquired.

Sagittal and coronal thin cut reconstructions (0.625 mm slice thickness and a field of view of $160mm^2$) were acquired from the entire raw data axial images of the lumbar spine (Woo *et al*., 2016).

3.9.2. Definition of Measured Parameters

Each set of axial and coronal/sagittal reconstructions were analyzed to determine which image best represented the mid-pedicle point (Isthmus) in bone window setting. In the axial views, this was determined by the increasing minimum pedicle diameter as the images were viewed cranio-caudally and the number of images required to view the entire pedicles was pegged. The pedicle width (PW) was considered as the distance between medial and lateral cortical surfaces of pedicle at its midpoint, measured at right angles to the long axis of the pedicle (Plate VI). (Marasini *et al*., 2014; Li, *et al*. 2004).

Sagittal Pedicle Height (SPH): In the sagittal view, the minimum pedicle Height was determined by the decreasing minimal pedicle height as the images were viewed from side to side (i.e. Medial-lateral). The minimal pedicle height was measured in the selected image as well as the adjacent images in the sequence for the sagittal views. The Pedicle height at the midpoint of the pedicle was considered as the vertical distance between superior and inferior border of pedicle at its midpoint (Plate VII). (Soumya *et al*., 2015; Zhuang *et al*., 2012).

Pedicle Width (PW): When the smallest/minimum pedicle diameter was ascertained in an axial view the PW was measured as the transverse distance between the medial and lateral bony cortex of the pedicle isthmus. It was also requiring that the image/adjacent image in the sequence contained the slice halfway between the cranial and caudal aspect of the pedicle to ensure that the minimum pedicle diameter closely traverses the pedicle's midpoint, also at the same point axial Pedicle-chord length (PCL) was measured (Plate VIII) (Zindrick *et al*., 1987).

The pedicle chord length (PCL): were measured as the distance between the posterior cortical entry point of the pedicle and the anterior vertebral cortex in line with the axis of the pedicle width. (Plate VIII) (Li *et al*., 2004).

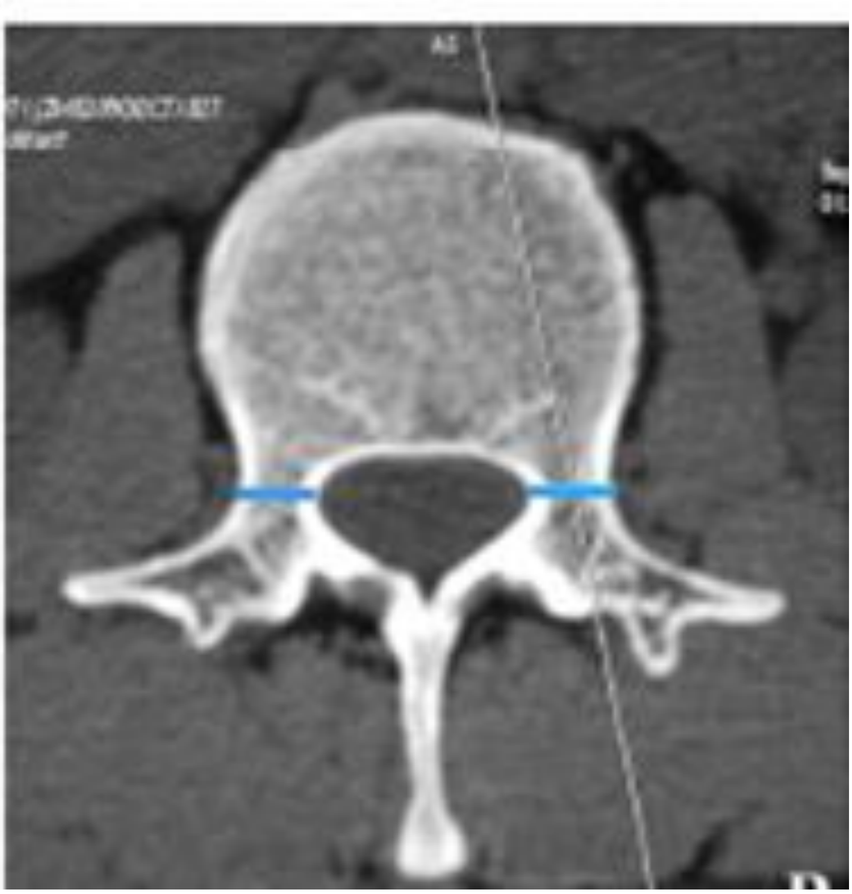

Plate VI: Axial Section of CT Scan image through the Pedicle Midpoint (Isthmus) showing Pedicle Width (PW) Measurement (horizontal short blue lines).

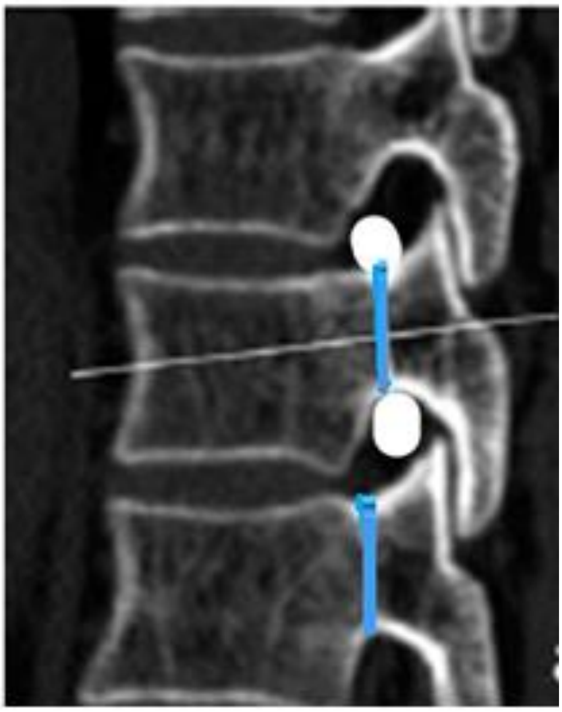

Plate VII: Sagittal Reformatted Section of Lumbar Spine CT Scan through the Pedicle showing Sagittal Pedicle Height (SPH) Measurement (vertical blue lines).

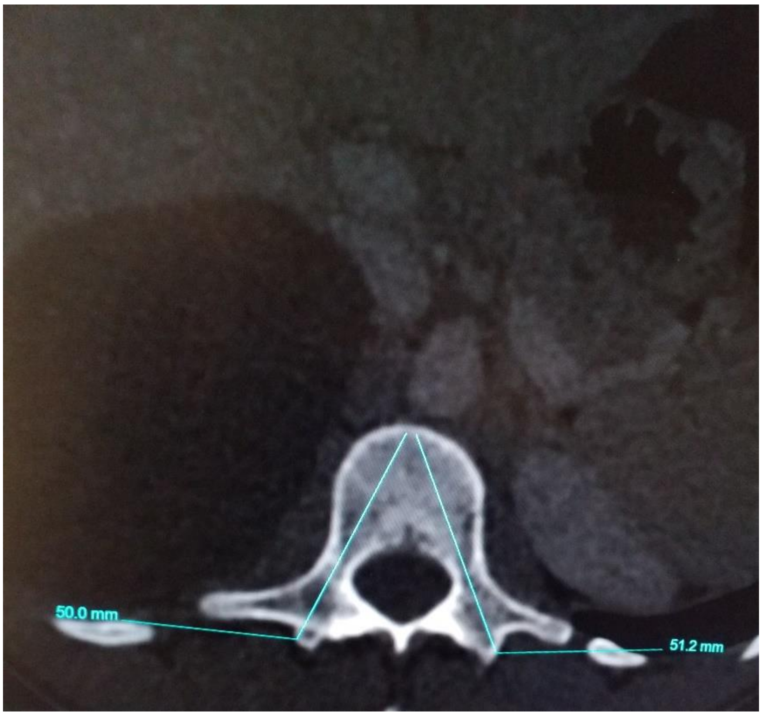

Plate VIII: Axial Section of CT Scan Image through the Pedicle Midpoint (Isthmus) showing Pedicle-Chord Length (PCL) Measurement.

3.10. DATA MANAGEMENT AND ANALYSIS

3.10.1 Data Collection

Data was collected using structured data collection sheet with demographic information entered and then data from Computed tomographic images which provided the radiological anatomic parameters under study (Appendix I). The forms were filled by the investigator and later transferred to a computer database. Variables collected included patients' demographic information, relevant surgical history and computed tomographic image tracking numbers. Collected data was only available to the Investigator and the Supervisors.

As a conservative measurement, at each vertebral level, the final minimal pedicle diameter and height were determined by the average of measurements from the three (3) consecutive images at a standard MM scale. This process was performed independently for each pedicle (left and right) as well as for each level (Simpson *et al*., 2016). All measurements were done manually with the Vitrea software calipers/rulers on the work-station monitor. The calibration of the workstation has been predetermined by the manufacturer.

Data was recorded using a computer spreadsheet program (Microsoft Office 2010 EXCEL; Microsoft Corporation; Redmond, WA. USA). Discrepancies were queried and corrected. Data analysis was performed using the statistical software package IBM SPSS Statistics version-23 for Windows, Chicago, IL. USA. Data was grouped and presented in figures, tables and charts.

3.10.2 Data Analysis

Data was analyzed for descriptive statistics and represented as mean ± standard deviations for continuous variables and as proportions/percentages for categorical data. Student's t-test was used to analyze for mean PW differences between gender/sex, while Pearson's correlation was used to check for association between age of subjects and pedicle parameters, also

ANOVA was used to determine variations in mean PW across vertebral levels and mean differences between tribes. Statistical significance was considered at $P<0.05$.

Data was kept in computer pass worded file, and hard copies of documents were made available upon request to the researcher and supervisors, to ensure confidentiality and safety of data.

3.11. ETHICAL CONSIDERATIONS

1. Ethics Approval was obtained from Research & Ethics Committee of AKTH/BUK (Appendix II).

2. Informed written consent was sought from all study participants with the aid of a consent form. (Appendix III)

3. Participation in the study was made voluntary and participants were at liberty to refuse or opt out of the study without negative consequences.

4. Confidentiality was observed strictly.

5. Data was used strictly for research purposes only.

6. The provisions of HELSINKI declaration were respected.

3.12. STUDY LIMITATIONS

1. Poor Image quality due to motional blurring of some images.

2. Cross sectional and hospital-based nature of the study.

3. Industrial action by some hospital workers during period of data collection.

4. Number of Participants was small due to high cost of the procedure (CT Scan).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 RESULTS

The mean ± standard deviation, and range of the pedicle morphometry and statistical analysis of 550 lumbar vertebrae of human subjects comprising of 1,100 lumbar pedicles and results of the measured parameters were presented as numerical values for each vertebral level, separately for the right and left lumbar pedicles as showed in the figures and tables in this chapter.

There was a total of 110 participants who met the inclusion criteria and were included in the study and whose data were subsequently analysed. These comprised of 51 males and 59 females accounting for 46% and 54% of the total study participants respectively (fig.4). The average age was 43.4 (SD: ±13.27) years with a minimum of 18 and a maximum of 70years. Majority of the participants were aged 45-54 and 55-64 years followed by aged 25-34 years (Fig. 5). Of the total number of participants, 99 (89.9%) were Hausa ethnic group while 5 (4.6%), 3 (2.7%), 1 (0.9%) and 2(1.9%) were Fulani, Igbo, Yoruba and other smaller tribes respectively (Table 1).

The mean Pedicle width (PW) diameter showed gradual increase from L1 to L5 on the right (L1=7.68 mm; L2=7.91 mm; L3=9.37 mm; L4=11.54 mm; L5=14.32 mm) and left (L1=7.49 mm; L2=7.78 mm; L3=9.21 mm; L4=11.14 mm; L5=14.31 mm) sides, with a range of 4.80-12.90 mm at L1 and 8.90-19.30 mm at L5 (Table 2). The mean sagittal pedicle height (SPH) showed steady decrease from L1 to L5 on the right (L1= 14.62 mm; L2=14.62 mm; L3=14.14 mm; L4=12.94 mm; L5=11.72 mm) and left (L1=14.53 mm; L2=14.45 mm; L3=14.15 mm; L4=12.91 mm; L5=11.73 mm) sides respectively, with a range of 11.20-14.62 mm at L1 and 8.60-15.70 mm at L5 (Table 2).

The mean pedicle chord length (PCL) diameter showed an irregular sinusoidal pattern; an increase at L2, then decrease at L3 and increase at L4 and L5 on the right (L1= 45.95 mm; L2=46.68 mm; L3=46.41 mm; L4=44.63 mm; L5=44.81 mm) and left (L1=45.41 mm; L2=46.80 mm; L3=46.06 mm; L4=44.72 mm; L5=44.81 mm) sides respectively, with a range of 36.20-57.90 mm at L1 and 35.70-58.90 mm at L5 (Table 2).

The gradual increase in PW was observed on both right and left sides of the measured vertebral pedicles with a statistically significant difference between right and left pedicles at L1 to L4 ($P<0.05$), but not significant at L5 (Table 3).

There was a steady decrease in SPH observed on both right and left sides of the measured vertebral pedicles with a significant difference between both sides of the measured SPH seen at all the lumbar level (Table 4).

The PCL oscillatory pattern was observed on both right and left sides of the measured vertebral pedicles, and significant difference in both sides values was noted at all lumbar level for PCL (Table 5).

In male subjects the pedicle width (PW), on right side was maximum at L5 (14.75 mm) and minimum at L1 (8.34 mm) and on left side it was maximum at L5 (14.70 mm) and minimum at L1 (8.14 mm). The difference in measurements between right and left PW was statistically significant ($p < 0.05$). Similarly, in females on right side it was maximum at L5 (13.95 mm) and minimum at L1 (7.10 mm) and on left side it was maximum at L5 (13.97 mm) and minimum at L1 (6.93 mm). The difference in measurements between right and left PW in females was statistically significant ($p< 0.05$). Two tailed Student's t-test was applied to compare the pedicle width (PW) between males and females and it showed statistically significant difference at all lumbar vertebral levels ($p < 0.05$) with males having a larger diameter for PW (Table 6).

In male subjects the Sagittal pedicle Height (SPH), on right side was maximum at L2 (15.17 mm) and minimum at L5 (12.07 mm) and on left side it was maximum at L1 (14.95 mm) and minimum at L5 (11.87 mm). The difference in measurements between right and left side was statistically significant ($p < 0.05$). Also, among females on the right side SPH was maximum at L1 (14.16 mm) and minimum at L5 (11.42 mm) and was maximum at L1 (14.26 mm) and minimum at L5 (11.61 mm) on the left. The difference in measurements between right and left SPH was also statistically significant ($p< 0.05$). Significant gender difference in SPH was thus observed at L1-L3 and right L5 levels ($P<0.05$) while L4 and left L5 did not attains statistical significance (Table 6), although males still had larger SPH diameter at those vertebral levels too.

The PW and SPH on both right and left sides were not significantly correlated with age at any lumbar vertebral level (Tables 7 & 8).

The mean pedicle width (PW) diameter of Igbos showed the largest measurements with the minimum at L1 (8.43 mm) and Maximum at L5 (14.13 mm) levels, followed by Fulani and Hausa groups having a minimum at L1 (7.80 and 7.79 mm) and maximum at L5 (14.34 and 14.31 mm) respectively. There was no Significant ethnic difference ($P>0.05$) observed at all lumbar vertebral levels (Table 9).

The pedicle width (PW) increased steeply from L1 to a maximum mean of 14.32 mm at L5. Significant mean difference in PW was observed between adjacent lumbar vertebrae levels across all segments (L1 vs. L2, L2 vs. L3, L3 vs. L4 and L4 vs. L5) with these differences arising maximally from L4 and L5 vertebrae levels on the right and left sides. The observed differences were significant at $P<0.001$ (Table 10).

Linear Regression Analysis of PW and SPH on both right and left Lumbar Pedicles showed no significant predictive relationship with Age of study subjects (Table 11).

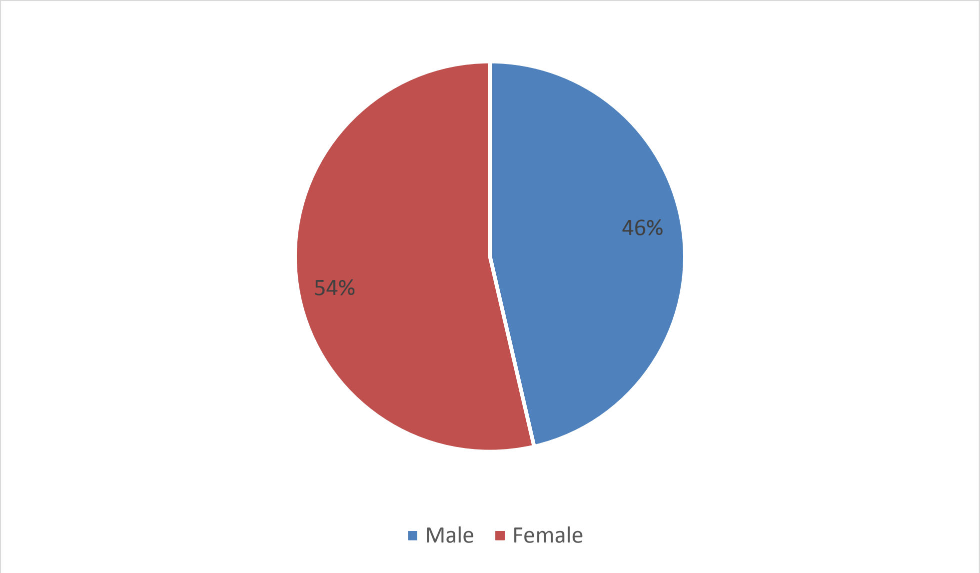

Figure 4.1: Percentage Distribution of Subjects by Gender

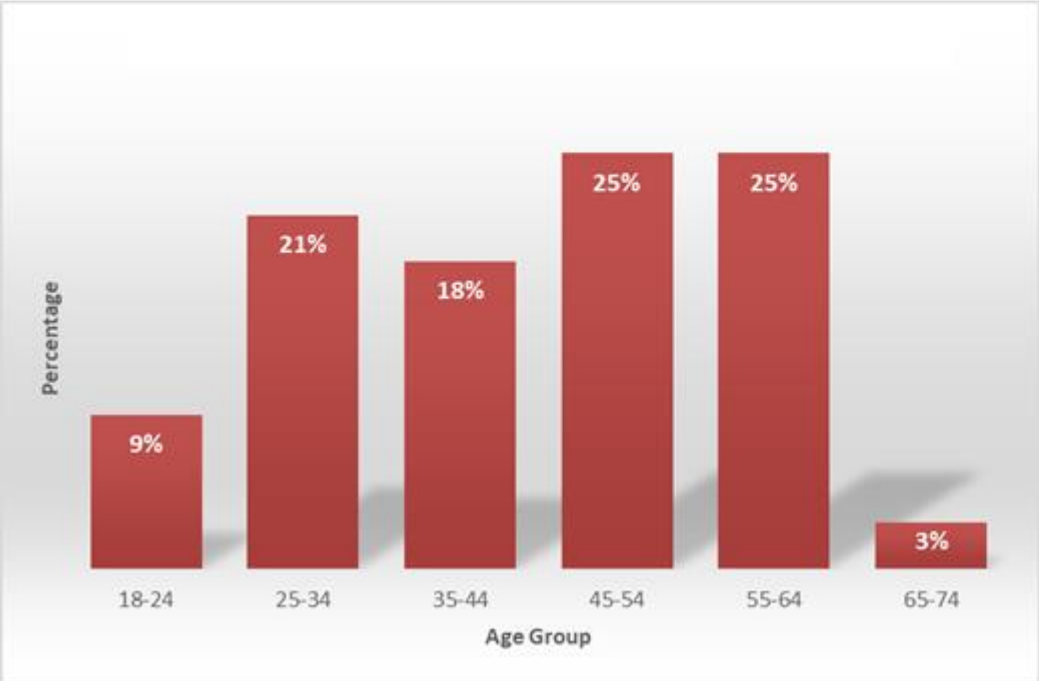

Figure 4.2: Percentage Distribution of Subjects by Age Groups

TABLE 4.1: Frequency Distribution of Participants by Ethnic Group

Tribes	Frequency	Percentage (%)
Hausa	**99**	**89.9%**
Fulani	**5**	**4.6%**
Igbo	**3**	**2.7%**
Yoruba	**1**	**0.9%**
Others	**2**	**1.9%**
Total	**110**	**100.0%**

TABLE 4.2: Descriptive Statistics of Computed Tomographic Measurements of Lumbar Vertebral Pedicle Parameters (mm) of Study Subjects

Vertebra		RPW	RPCL	RSPH	LPW	LPCL	LSPH	
L1 (n = 110)	Min	4.80	36.20	11.20	4.90	37.50	11.40	
	Max	12.90	57.90	18.70	12.50	55.60	18.00	
	Mean	7.68	45.95	14.62	7.49	45.41	14.53	
	SD	1.53	4.18	1.43	1.52	3.93	1.32	
L2 (n = 110)	Min	4.40	35.90	11.50	4.90	37.90	11.50	
	Max	13.20	56.60	18.00	13.40	57.50	18.80	
	Mean	7.91	46.68	14.62	7.78	46.80	14.45	
	SD	1.60	3.92	1.44	1.67	3.85	1.42	
L3 (n = 110)	Min	6.30	38.30	10.50	6.10	37.50	10.00	
	Max	13.90	57.70	21.80	13.10	57.20	18.20	
	Mean	9.37	46.41	14.14	9.21	46.06	14.15	
	SD	1.73	3.68	1.59	1.65	3.44	1.45	
L4 (n = 110)	Min	7.6010.32	3524.2308	9.5004	7.3096	17.6838	9.40	3.14
	Max	47.2114.40	5358.462	17.8042	15.8026	56.78	20.20	6.30
	Mean	11.5314.28	4163.32	12.0435	11.5495	27.73	12.91	4.47
	SD	3.812.45	32.421	1.5106	1.7622	3.304.36	1.62	0.70
L5 (n = 110)	Min	8.90	35.70	8.60	9.60	18.90	8.30	
	Max	19.30	58.90	15.70	20.20	58.20	14.90	
	Mean	14.32	44.81	11.72	14.31	44.81	11.73	
	SD	1.85	4.28	1.46	1.93	4.32	1.38	

RPW, Right pedicle width; RPCL, Right pedicle Chord length; RSPH, Right sagittal Pedicle height; LPW, left Pedicle width; LPCL, Left pedicle Chord length; LSPH, Left sagittal pedicle Height; NS, not significant.

TABLE 4.3: Comparison of Measurements of Lumbar Vertebral Pedicle Width (PW) on the Right and Left sides of Subjects on Computed Tomography (CT) Images (mm)

LEVEL		RIGHT	LEFT	P-VALUE
L 1	Median	7.45	7.10	<0.001
	IQR	6.60 – 8.50	6.58 – 8.23	
L 2	Median	7.75	7.55	<0.001
	IQR	6.70 – 8.93	6.60 – 8.63	
L 3	Median	9.25	9.20	<0.001
	IQR	8.18 – 10.50	8.0 – 10.40	
L 4	Median	11.10	10.85	0.002
	IQR	10.10 – 12.2	39.90 – 12.20	
L 5	Median	14.35	14.30	0.56
	IQR	13.1 – 15.3	12.98 – 15.50	

IQR, Interquartile range.

TABLE 4.4: Comparison of Measurements of Lumbar Vertebral Sagittal Pedicle Height (SPH) on the Right and Left Sides of Subjects on Computed Tomography (CT) Images (mm)

LEVEL		RIGHT	LEFT	P-VALUE
L 1	Mean	14.62	14.53	<0.001
	SD	±1.43	±1.32	
L 2	Mean	14.62	14.45	<0.001
	SD	±1.44	±1.42	
L 3	Mean	14.15	14.15	<0.001
	SD	±1.60	±1.46	
L 4	Mean	12.94	12.92	<0.001
	SD	±1.51	±1.62	
L 5	Mean	11.72	11.73	<0.001
	SD	±1.46	±1.38	

SD, Standard Deviation.

TABLE 4.5: Comparison of Measurements of Lumbar Vertebral Pedicle Chord Length (PCL) on the Right and Left sides of Subjects on Computed Tomography (CT) Images (mm)

LEVEL		RIGHT	LEFT	P-VALUE
L 1	Mean	45.95	45.41	<0.001
	SD	±4.18	±3.93	
L 2	Mean	46.68	46.80	<0.001
	SD	±3.92	±3.85	
L 3	Mean	46.41	46.06	<0.001
	SD	±3.68	±3.44	
L 4	Mean	44.63	44.72	<0.001
	SD	±3.42	±3.30	
L 5	Mean	44.81	44.82	<0.001
	SD	±4.28	±4.32	

SD, Standard Deviation.

TABLE 4.6: Comparison of Measurements of Lumbar Vertebral Parameters in Male and Female Subjects on Computed Tomography (CT) Images (mm)

Measurement	**Male (mean± SD)**	**Female (mean± SD)**	***p*-value**
L1			
RPW	8.34 ± 1.55	7.10 ± 1.25	< 0.001
RPCL	47.13 ± 4.23	44.94 ± 3.89	0.006
RSPH	15.15 ± 1.29	14.16 ± 1.39	< 0.001
LPW	8.14 ± 1.59	6.93 ± 1.22	< 0.001
LPCL	46.24 ± 4.17	44.69 ± 3.61	0.041
LSPH	14.95 ± 1.31	14.16 ± 1.22	0.001
L2			
RPW	8.59 ± 1.69	7.33 ± 1.28	< 0.001
RPCL	47.75 ± 3.78	45.75 ± 3.84	0.007
RSPH	15.17 ± 1.31	14.15 ± 1.38	< 0.001
LPW	8.44 ± 1.76	7.22 ± 1.38	< 0.001
LPCL	47.53 ± 3.75	46.17 ± 3.85	NS
LSPH	14.84 ± 1.42	14.11 ± 1.35	0.007
L3			
RPW	10.17 ± 1.68	8.68 ± 1.48	<0.001
RPCL	47.46 ± 3.63	45.51 ± 3.52	0.005
RSPH	14.53 ± 1.72	13.81 ± 1.41	0.019
LPW	9.85 ± 1.63	8.65 ± 1.47	<0.001
LPCL	46.92 ± 3.37	45.33 ± 3.35	0.015
LSPH	14.51 ± 1.36	13.83 ± 1.47	0.015
L4			
RPW	12.59 ± 5.17	10.64 ± 1.57	0.012
RPCL	45.64 ± 3.09	43.76 ± 3.47	0.003
RSPH	13.19 ± 1.54	12.72 ± 1.45	NS
LPW	11.69 ± 1.79	10.66 ± 1.60	0.002
LPCL	45.69 ± 3.37	43.89 ± 3.02	0.004
LSPH	13.14 ± 1.56	12.72 ± 1.67	NS
L5			
RPW	14.75 ± 1.81	13.95 ± 1.81	0.023
RPCL	46.24 ± 4.43	43.57 ± 3.76	< 0.001
RSPH	12.07 ± 1.64	11.42 ± 1.22	0.022
LPW	14.70 ± 1.81	13.97 ± 1.99	0.046
LPCL	46.18 ± 3.78	43.63 ± 4.45	0.002
LSPH	11.87 ± 1.62	11.61 ± 1.14	NS

Values are mean ± SD.

RPW, Right pedicle width; RPCL, Right pedicle Chord length; RSPH, Right sagittal Pedicle height; LPW, left Pedicle width; LPCL, Left pedicle Chord length; LSPH, Left sagittal pedicle Height; NS, not significant.

TABLE 4.7: Correlation of Age with Lumbar Pedicle Width (PW) Measurements

Lumbar Segment	**Age & RPW Coefficient of correlation(r)**	**p-value**	**Age & LPW Coefficient of correlation (R)**	**p-value**
L1	0.08	0.42	0.06	0.54
L2	0.03	0.72	0.03	0.78
L3	0.11	0.27	0.05	0.60
L4	0.10	0.32	-0.10	0.92
L5	0.04	0.69	-0.04	0.66

Pearson's correlation coefficient (r)

TABLE 4.8: Correlation of Age with Sagittal Pedicle Height (SPH) Measurements

Lumbar Segment	**Age & RSPH Coefficient of correlation(r)**	**p-value**	**Age & LSPH Coefficient of correlation (R)**	**p-value**
L1	0.17	0.69	0.21	0.27
L2	0.01	0.90	0.01	0.32
L3	0.10	0.31	0.05	0.64
L4	-0.03	0.74	-0.11	0.28
L5	-0.08	0.43	-0.01	0.96

Pearson’s correlation coefficient (r)

TABLE 4.9: Comparison of Mean Lumbar Vertebral Pedicle Widths (mm) among ethnic groups of Study Subjects on the Right and Left lumbar Pedicles.

TRIBES		**L1**	**L2**	**L3**	**L4**	**L5**	**P-VALUE**
HAUSA	RPW	7.43	7.89	9.35	11.51	14.31	
	LPW	7.79	7.71	9.22	11.13	14.29	
FULANI	RPW	7.40	7.82	9.06	12.52	14.42	
	LPW	7.80	8.28	8.86	11.84	14.34	>0.05
IGBO	RPW	8.43	9.00	10.03	11.40	14.10	
	LPW	8.47	8.90	9.47	11.13	14.13	
YORUBA	RPW	6.30	6.30	8.60	10.60	14.70	
	LPW	6.80	6.30	7.20	10.50	14.00	
OTHERS	RPW	7.20	8.50	10.65	11.55	14.70	
	LPW	8.15	9.30	10.15	10.40	15.20	

Values are means; RPW, Right pedicle width; LPW, left Pedicle width; NS, not significant.

TABLE 4.10: Analysis of Variance for the Measured Lumbar Vertebral Pedicle Parameters of Subjects

		Sum of Squares	df	Mean Square	F	Sig.	Inference
R-PW	Between Groups	381.201	4	95.300	6.233	.000	
	Within Groups	8332.774	545	15.289			S
	Total	8713.975	549				
R-SPH	Between Groups	697.570	4	174.392	78.803	.000	
	Within Groups	1206.089	545	2.213			S
	Total	1903.658	549				
L-PW	Between Groups	338.077	4	84.519	5.895	.000	
	Within Groups	7813.728	545	14.337			S
	Total	8151.806	549				
L-SPH	Between Groups	642.282	4	160.570	76.928	.000	
	Within Groups	1137.566	545	2.087			S
	Total	1779.848	549				

RPW, Right pedicle width; RPCL, Right pedicle Chord length; RSPH, Right sagittal Pedicle height; LPW, left Pedicle width; LPCL, Left pedicle Chord length; LSPH, Left sagittal pedicle Height; S, significant.

Variable	R^2	(95% CI)	P value
RPW	0.002	(-0.01-0.03)	0.269
LPW	0.000	(-0.02-0.02)	0.852
RSPH	0.001	(-0.01-0.02)	0.514
LSPH	0.001	(-0.01-0.02)	0.433

TABLE 4.11: Linear Regression Analysis of Lumbar Pedicle Parameters with Age.

4.2 DISCUSSION

The lumbar vertebrae have large kidney-shaped vertebral bodies. They have no costal articular surface but they have long spinous processes as well as pedicles and laminas, and the sizes of the lumbar vertebral pedicles varies from one vertebral segment to the next, as a result of these characteristics the lumbar vertebrae are different from the other vertebrae in the human spine (Elaine *et al*., 2017).

The main goal of this study was to quantify the dimensions of the lumbar pedicles and to better define the demographic factors that could ultimately govern caliber selection of pedicle screws in cases of surgical interventions.

Lumbar pedicle morphometry has been studied extensively during the past 2 decades, either directly or by radiological measurements like radiographs and MRI, with recent studies using CT scans (Catan and Buluc, 2007; Kim NH. *et al*., 1994; Zhuang *et al*., 2012; Zindrick *et al*., 1987). The differing sample sizes, methodologies and populations of the studies contributed to the wide disparity in the reported results. Populations specific variations in dimensions of body segments necessitates continuous studying of lumbar dimensions in various population groups. In addition, whilst most studies have utilized measurements from different imaging techniques, including radiographs(Amonoo-Kuofi, 1995; Oyakhire and Aigbogun, 2015; Udoaka and Chisom, 2016). only few studies have utilized CT scan measurements from the lumbar vertebrae in this region. It is argued that CT scan measurements give accurate and reproducible results as direct measurements from cadaveric specimens(Eldin, 2014; Maaly *et al*., 2010; Srikumaran *et al*., 2007). Also, in addition CT Scan is the established gold standard imaging modality for accessing pedicle morphology (Sarwahi *et al*., 2016). Hence it is necessary to have more data from CT scan measurements to compare with those from direct and conventional radiographic measurements techniques with a view to providing a reference standard for lumbar dimensions within the population group in Nigeria.

The participants included in this study were of mean age of 43.4(±13.27) years with most of them being 45-54 and 55-64 years age group accounting for a total of 50% of subjects who participated, this was similar to the mean age of subjects studied by Azu *et al* in Kwazulu Natal, South Africa. It's also in tandem with the adult age of 42.3years studied by Varol *et al.* (2006) in Turkey; But slightly different from the study of Chawla *et al*., (2011) in Northwest India who studied adult vertebrae greater than 25years of age using CT scan.

Our study found that mean PW gradually increases from L1-L5 in concordance with the work of Azu *et al.*(2016) from their direct calliper measurements of osteological specimens in south African subjects. Also (Gocmen-Mas *et al*., 2010), from their MRI studies of morphometric parameters of lumbar vertebrae of healthy adult Turkish population showed similar pattern of measured dimensions increasing cranio-caudally. Similarly, (Wolf *et al*., 2001) reported similar pattern of increments in PW diameter from L1-L5 among adult Israeli population using CT scan, thus suggesting similarity in trend of lumbar vertebral body sizes from both imaging and direct measurements. This increase may be due to more weight bearing capabilities of the lower lumbar vertebrae. However, overall pedicle width diameters in our population were considerably larger than those of Asian population reported.

The PW dimensions on the right pedicles in our study was higher than the left side from L1-L5 segments with L1-L4 attaining a statistical significance at $P<0.05$. These were a bit different from the study of (Marasini *et al*., 2014), in which they measured pedicle dimensions among Nepalese population using plain radiographs and found dimensions of the right and left lumbar pedicles to be different at all levels, but the difference was not found to be significant statistically. Also, (Chawla *et al.*, 2011) showed insignificant difference in measurements between the right and left lumbar pedicles ($p > 0.05$), among North-West Indian population. Similarly Tan *et al.* (2004) revealed close mean values for both the left and right pedicle parameters of height or width among Chinese Singaporean population, suggesting that among Asians measurements one pedicle at same vertebral level suffice in evaluation of morphometry.

This study observed Significant gender difference in PW measurements across all lumbar vertebral levels ($P<0.05$) with males having larger PW diameters on both right and left sides than females. However Azu *et al.* (2016) found significant difference at L1 and L3 vertebrae only among , while (Alam *et al.*, 2014) found overall Pedicle transverse diameters to be significantly greater in male Pakistani population at L2 and L5 vertebrae. In contrast, (Singel *et al.*, 2004) reported that the vertical height of the pedicle and its width among West-Indian population were greater in females than in males, although the difference was minimal. This gender differences could be due to inherent genetic and hormonal differences that has been found to have some influence on bone development among humans and also could be explained in terms of the greater upper body weight of males. There was no statistically significant correlation between age of subjects with PW in this study, in contrast (Amonoo-Kuofi, 1995) noted differences at all 5 lumbar levels between the mean diameters of the pedicles of the various age groups, in which differences between contiguous age groups were small in some cases. However, this could be as a consequence of inclusion of individuals in their early life (first decade) within his study population. The 10-

19.9years age group includes the period of the adolescent growth spurt during which there is accelerated growth activity resulting in marked bodily changes which could account for significant age differences seen in their study.

The SPH showed a significant gradient decrease from upper lumbar vertebrae to lower segments(L1-L5) on the right and left sides and among both genders in this study, except for male subjects were the mean horizontal diameter of the right L1 pedicle was similar to the diameter of the L2 pedicle. This cephalocaudal decreased diameter of SPH was also noted from L1-L4 by (Morales-Avalos *et al*., 2014) in their study of dried specimen of osteological collections among Mexican population, also noted that L5 vertebras exhibit the most evident variations in their dimensions in the different populations studied, hence should be given special importance, prior to a surgical approach. However, (Ban, *et al*., 1999) found similar SPH diameters from L1 to L5 vertebrae among dried human specimens among South Koreans. Also, Oyakhire *et al*.,(Oyakhire and Aigbogun, 2015) in their study by direct calliper measurements of dried thoracic vertebral specimens among adults in Nigeria's delta region, found a steady increase in the mean pedicle heights from T1-T3 followed by a decrease a T4, with mean values remaining closely equal from T4-T7, followed by a gradual increase from T8-T12. The difference in pattern of values among different studies may be due to different methodologies and spinal vertebrae studied. The observed progressive changes in the size of pedicles could also be due to increased muscle mass and dynamic skeletal modifications as an adaptive response need for weight bearing from the occipital region through thoracic down to the thoraco-lumbar junction of the spine to the lumbosacral transition area. With respect to age, (Yu *et al*., 2015) showed that PH generally increased with age among adult Americans studied in the US, but PW failed to consistently demonstrate statistically significant differences within age groups among measured bones of osteological collections (P>0.05). This is in contrast to this study which found no significant correlation of SPH with age of study subjects.

The study by (Amonoo-Kuofi, 1995) in Saudi Arabia also showed that the height of pedicles in males and females were maximum at L5 with 20.7mm & 17.5mm respectively, but on the contrary, the work of (Singel *et al*., 2004) revealed that the height of pedicles was maximum at L1, L2 & L3 levels and after which it goes on decreasing at L4 and L5 levels for both males and females. This contrast could be because of the difference in methods adopted by the different investigators. The former studied the plain radiographs of lumbar spine whereas the later studied dry cadaveric specimen by direct measurements of lumbar pedicles on the lumbar vertebrae.

The variations in the diameters of the pedicles associated with the different gender could therefore be attributed to the weight-bearing function of the spine, it seems reasonable to suggest that the vertical diameter probably contributes more to weight-bearing functions than the horizontal diameter. The larger vertical diameter of the pedicle of the 1st lumbar vertebra (in both males and females) as compared with the vertical diameters of the 2nd and 3rd lumbar pedicles in this study could also be explained by the weight-bearing function. The 1st lumbar pedicle is located at the thoracolumbar transitional junction. This junction is the site of a complex zygapophyseal joint (the thoracolumbar mortice joint) which is adapted to withstand marked compressive forces transmitted from the relatively immobile thoracic segment to the highly mobile lumbar segment of the vertebral column (Davis, 1955). It suggests that the vertebrae and pedicles at this junction were reinforced to withstand the forces that had to be transmitted across this junction.

This study showed the pedicle width to be lower than pedicle height in all vertebral levels, although various authors (Chadha *et al*., 2003; Esses and Bednar, 1989; Krag *et al*., 1988) have documented that the cross-section of the pedicles is oval; hence, the sagittal pedicle isthmus width is always greater than the transverse pedicle isthmus width, which is the limiting factor in choosing the diameter of the pedicle screws. Use of a larger size screw will lead to the violation of the medial or lateral cortex of the pedicle and may lead to neurologic deficit.

The mean PCL in this study was found to have an oscillatory pattern, an increase was noted at L2, then decrease at L3 and increase at L4 and L5 on the right and left sides of the measured vertebral pedicles, and significant difference was noted at all lumbar level for PCL measurements of males and females. This pattern is consistent with that obtained from CT scan images of lower thoracic and lumbosacral spines of patients from Indian subcontinent by (Chadha *et al*., 2003) in which they reported the mean PCL ranged from 47.49 mm at L1 to 49.45 mm at L5, With a transient increase seen at L2, then decrease at L3 and finally increase at L4 and L5 segments. The present data are quite comparable to those obtained by (Kim *et al*., 1994) who recorded mean PCL values for both male and female Koreans by direct caliper measurements of dry specimen of lumbar vertebrae at L1 40.90 mm and 50.1 mm at L5 levels. Kim observed that the PCL was longest at the L3 level (54.4 mm) and shortest the L1 level. However, the values obtained in our study were less than those obtained in other series, which may not be unconnected with the childhood prevalence of malnutrition and vitamin deficiencies in our environment thus affecting the normal bone development of the black Nigerian population.

Our study reports a significant level-dependent difference in the mean pedicle width of subjects across all vertebral levels from L1-L5 on the right and left sides

(P<0.001). this variation was more pronounced at L4 and L5 segments. This is in concordance with the work of (Alam *et al*., 2014) that observed statistically significant differences between pedicles at some levels. Similarly (Gulek *et al*., 2007) had previously observed the same level-dependent variations among adult human vertebrae in Turkey using CT scan measurements of L3-L5 pedicles., thus suggesting similarity in trend of lumbar vertebral pedicle variations from imaging measurements.

The current study showed insignificant difference in the mean PW of different ethnic groups/tribes, however Igbo tribe showed the largest dimensions of pedicles, followed by Fulani and Hausa tribes, while Yoruba group had the least values for PWs (P>0.05). this pattern was also observed by (Masharawi *et al*., 2010) on dry thoraco-lumbar vertebrae specimens in an American population they noted that neither ethnicity nor age was found to have any significant effect on the calculated vertebral parameters. The above findings suggest there is a uniformity of configuration and dimensions of the lumbar pedicle width, which transcends ethnicity and age.

The dimensions and parameters obtained from our study gives an understanding of the morphological relevance of the lumbar vertebrae to clinical diagnosis of low back pain for clinicians and could as well trigger forensic relevance due to population specific variations in body dimensions.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. SUMMARY

This study determined the Morphometric dimensions of lumbar vertebrae pedicles of adult human subjects in Kano-Nigeria using their Computed Tomography (CT) Scan images of 110 study subjects with a view to establish the normative values of the pedicle dimensions, variations across vertebral levels and explore the relationship of these dimensions with demographic factors like age, sex and ethnicity of adult Nigerians.

The Pedicle width (PW), Sagittal Pedicle Height (SPH) and the Pedicle chord length (PCL) of individual pedicle were determined from L1 to L5 on both right and left sides with vertebral pedicle measurements done in transverse and sagittal planes. The Mean PW generally increased in size craniocaudally along the lumbar spine from L1 (7.49 ±1.52 mm) to L5 (14.31 ±1.93 mm). A gradual decrease in Mean SPH from L1 (14.53 ±1.32 mm) to L5 (11.73 ±1.38 mm) was noted. While mean PCL showed an irregular 'U' pattern with the smallest size at L4 (44.63 ±3.42 mm) and highest at L2 (46.80 ± 3.85 mm). All measured dimensions were significantly higher in the right pedicles and among male subjects ($p<0.05$). But Age and ethnicity did not consistently affect pedicle dimensions in a statistically significant manner using correlation and regression analysis.

This study observed right pedicle dimensions and male subjects as having significantly larger pedicle diameters, with no significant ethnic differences in PW and SPH values among study subjects across all vertebral levels. However, pedicle dimensions among adult Nigerians were noticed to be larger than Asian and Arab pedicles when compared with previous study in different regions of the world.

5.2. CONCLUSION

The present study accurately describes the morphometric dimensions of the lumbar vertebral pedicles and has provided baseline normative data for the Northern Nigerian population. This study of 1,100 lumbar pedicels of adult Nigerians has characterized the relationship between pedicle dimensions and some demographic factors. Sex consistently influenced pedicle dimensions in a statistically significant manner, with male individuals having larger pedicles. However, the difference in pedicle dimensions with respect to age and ethnicity did not consistently reach statistical significance.

5.3. RECOMMENDATIONS

1. Feature studies should cover other vertebrae types (cervical, thoracic and sacral) in this environment to establish baseline normative values as well.
2. We recommend further studies that would relate morphometric dimensions to change in physical activity levels and explore the possibility of remodelling of lumbar vertebrae to withstand changing mechanical stresses and compressive forces in certain group of individuals.
3. Further studies with larger sample sizes and possibly inclusive of higher number of multi-ethnic individuals from other regions of the country in other to get a wider population-specific dimensions.
4. Future studies should compare pedicle dimensions with other anthropometric parameters like height, weight and body mass index of individuals is recommended.

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APPENDIX I

DATA COLLECTION TOOL/SHEET

(RIGHT & LEFT PEDICLES MEASUREMENTS)

				RIGHT PEDICLE (mm)									LEFT PEDICLE (mm)								
S/N	Age(Yrs)	Sex	Ethnicity	PW			SPH			PCL			PW			SPH			PCL		

***KEY*:**
S/N = Serial Number;
PW = Transverse pedicle width;
SPH = Sagittal pedicel height;
PCL = Pedicle Chord length.

APPENDIX II

AMINU KANO TEACHING HOSPITAL

P. M. B. 3452, ZARIA ROAD, KANO.
(☎:07068297399)www.akth.info/www.akth.gov.ng, E-mail: enquiries@akth.info/akthkano@yahoo.com

NHREC/21/08/2008/AKTH/EC/2319

AKTH/MAC/SUB/12A/P-3/VI/2419 **5th September, 2018**

Recd.
13/9/2018

Dr. Yusuf Lawal
Department of Radiology
AKTH, Kano.

Ufs:

The Head of Department
Radiology
AKTH, Kano.

Noted with Congrats.
13/9/2018

ETHICS APPROVAL

Further to your application in respect of your research proposal titled "Morphometric Study of Lumbar Vertebral Pedicles Using Computed Tomography among Normal Adults in Kano, Nigeria", The Committee reviewed the proposal and noted same as a prospective study.

In view of the above, Ethics approval is hereby granted to conduct the research.

However, the approval is subject to periodic reporting of the progress of the study and its completion to the Research Ethics Committee.

Regards,

Abubakar S. Mahmud
Secretary, Research Ethics Committee
For: Chairman

APPENDIX III

INFORMED CONSENT FORM

My name is Dr. YUSUF LAWAL, a Postgraduate student in the Department of Anatomy, Bayero University, Kano (BUK) and I am conducting a study on **MORPHOMETRIC STUDY OF LUMBAR VERTEBRAL PEDICLES USING COMPUTED TOMOGRAPHY AMONG NORMAL ADULTS IN KANO, NIGERIA,** and would like you to participate in the Research.

This study will involve you being asked some questions (age, ethnicity and address) and also physical recordings of your height and weight with measurements of some dimensions on the electronic CT-Scan images of your lumbar vertebrae (Lower Backbone/spine) obtained from raw data of your Abdominopelvic CT Scan medical examination.

Please note that all information and findings shall be treated and kept with outmost confidentiality. In the event that this study is reported in scientific literature or gathering, your anonymity will be maintained. Also all costs incurred outside the standard cost of care will be borne by me.

The final outcome of the study will provide a reference baseline for assessing the normal dimensions of lumbar vertebral pedicles among adults in this environment.

Though CT scan uses Ionizing radiation **but** in a controlled environment, it's a non-invasive and relatively safe imaging method as indicated by your clinical condition.

Your participation in the study is **voluntary**, and you are free to decline consent or willingness to participate at any stage in the study, with no negative consequences to the care you receive. For further enquiries about this study please contact:

Dr. YUSUF Lawal,

Department of Anatomy, BUK, Kano-Nigeria.

I have understood the study as directly explained to me and I am willing to participate.

Investigator's Sign……………………………

Participant's Sign/Thumb print……………….

Participant's Contact Phone.............................

Witness's sign……………………………….....

Witness Contact Phone......................................