Sudan University of Science and Technology

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Study Of Lumbar Vertebrae Morphology Using Multi-Detector Computed Tomography

دراسة شكل الفقرات القطنية باستخدام الأشعة المقطعية المحوسبة متعددة الكواشف

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By: Saeed Taha Mohamed Ali

Supervisor:

Professor: Caroline Edward Ayad Khilla

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الأية

قال تعالى:

﴿قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ﴾

صدق الله العظيم

(البقرة الآية32)

Dedication

Dedicated to: My Mother for her love and unconditional support, to spirit of my father and sisters, to my small family wife for her warm encouragement and kids, to my brothers, sisters and colleagues.

Acknowledgments

Iam thankful to Almighty (Allah) for His blissful granting that gave me strength for carrying out this work.

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And above all ,to my wife and kids: in their unconditional support .

I am also thankful to all who helped me during this study.

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List of Abbreviations

Abbreviations	Meaning
ANOVA	Analysis of Variance
AP	Anteroposterior
BMI	Body Mass Index
BMP	Uncompressed Bitmap
C/B	Canal to Body ratio
C1	First Cervical Vertebra
C7	Seven Cervical Vertebra
CNS	Central Nervous System
Co-Cr-Mo	Cobalt-Chrome and Molybdenum
CT	Computerized tomography
CT/MR	Computed Tomography/Magnetic Resonance
DICOM	Digital Communication in Medicine
GE	General Electric Company
HU	Hounsfield Unit
IPD	Interpedicular Distant
JPEG	Joint Photographic Expert Group
KFCH	King Fahad Central Hospital (Jazan)
KSA	Kingdom Saudi Arabia
Kv	Kilovolt
mAs	Milliamper
MDCT	Multi Detector Computed Tomography
MG	Mammography
MPR	Multi Planar Reconstruction
MRI	Magnetic Resonance Imaging
PACS	Picture Archiving And Communication System
Pc	Pearson correlation
PDAL	Pedicle Axial Length

PDH	Pedicle Height
PDW	Pedicle Width
PET-CT	Positron Emission Tomography –Computed Tomography
PI	Pedicle Index
SCD	Spinal Canal Depth
SCW	Spinal Canal Width
SD	Standard Deviation
SPA	Sagittal Pedicle Angle
SPSS	Statistical Package for the Social Sciences
T1	T1 Weighted Image
T2	T2 Weighted Image
Ti-6Al-4V	Mixture of Titanium, Aluminum and Vanadium Alloy
TPA	Transverse Pedicle Angle
US	Ultrasonography
USA	United States Of America
USB	Universal Serial Bus
VBD	Vertebral Body Depth
VBH	Vertebral Body Height
VBL	Vertebral Body Length
VBW	Vertebral Body Width
VCH	Vertebral Canal Height
VCW	Vertebral Canal Width
WMV	Windows Media Video
%	Percentage
3D	Three dimension

Abstract

The objectives of this descriptive analytical study are to study the normal morphometric measurements of the lumbar spine, as well as to establish a reference values for adult individuals of both genders relevant to the Jazan population (KSA). However, it includes the pedicle dimensions ,vertebral body , spinal canal, vertebral corpus , chord length as well as pedicle angles from the levels of first lumber vertebra (L1) to fifth lumbar vertebra (L5) using Multi detector Computed Tomography (MDCT).

The study sample included 200 Jazan adult participants (100 were males and 100 were females). The participants' lumbar vertebrae, pedicles body and canal from (L1 to L5) were evaluated .The selected sample were those who underwent CT lumbar spine and abdominal CT scans done for various reasons, at governmental hospitals Jazan region, pathological cases were excluded. The participants age ranged from 19-75 years old (with the mean of 41.77 years), during the period from March 2016 to July 2020. The two thousand pedicles, one thousand normal lumbar vertebrae (L1 to L5) were analyzed using DICOM viewer for their width, height and length of the pedicles dimensions as well as pedicle axis length. Pedicle angles were also been measured including transverse and sagittal angles. Vertebral body width, depth and height were measured in addition to spinal canal width and spinal canal depth as well as pedicle index, pedicle ratio (CT ratio) and spinal canal ratio.

The mean values of pedicle width of the right and left was found to be gradually increased from L1 to L5 level in both genders. The mean pedicle width in males was (8.39 ± 1.23) mm and in females was 8.47 ± 1.17 mm , the measurement demonstrated that there was significant different between males and females participant($p \leq 0.05$) for L3. Results also demonstrated that Pedicle width measurements at L5 was significantly larger in older age than in younger age with no significant differences were found between the mean pedicle width for older and younger ages .
Results conceived that there was no statistical significant difference found between the gender regarding pedicle height and spinal canal width and chord length. Regarding age the study demonstrated statistically significant relation between older and younger ages at L1,L2 and L3 for the transverse pedicle angle(TPA). The angle of inclination showed that the lumbar vertebrae increased gradually from L1 to L5 in both genders . The largest (TPA) was located at female L5 ((30.70 ^{o}) and the smallest (TPA) was located at female L1 (18.49 ^{o}) and the mean (TPA) in the older age was larger than the mean (TPA) in the younger age with highly significant differences at ($p \leq 0.05$) being depicted at all vertebral levels L1to L5. The largest sagittal pedicle angles (SPA) was found in both genders at L5 (18.01^{o}) and L5 (17.45 ^{o}) respectively, and the lowest (SPA) was found in males and females at L1 (14.09 ^{o}) and L1 (13.97 ^{o}) respectively.
The study reveals that there is no significant difference between gender regarding sagittal pedicle angles (SPA). The largest mean value in (mm) for the variable vertebral body width (VBW) was seen at vertebral level L5 in both males (43.97±3.09) and females (43.57±2.51) and the least was at vertebral level L1 in both males (33.29±2.80) and females (32.90±2.54) with statistically significant difference between genders at L3 and L4. Nevertheless, the results suggest that the average mean values for the **v**ertebral body depth (VBD) was higher in males than in females with highly significant difference between gender at all vertebral levels with exception of L5.
There is no statically significant difference between genders regarding the spinal canal depth (SCD) at each vertebral levels.

The pedicle index (PI ratio) demonstrated that there was gradually increasing from L1 to L5 and the results among genders conceived that pedicle index ratio were greater in females than males at each lumbar level with exception of L1, which was greater in males. The pedicle index curve is similar to both the PDH curve and the PDW curve, especially at lumbar levels of L1–L3. PDW curve demonstrated positive linear relationship with Pedicle index and PDH curve demonstrated negative linear relationship with Pedicle index, whereas in the measurements of pedicle ratio were gradually increased from L1 to L5; however, that pedicle ratio were greater in females than males at each lumbar level except for L1 which was greater in males. The pedicle ratio curve was similar to the PDW curve than the VBW curve, especially at lumbar levels of L1–L2, and the PDW curve depicted highly positive linear relationship with Pedicle ratio and VBW curve demonstrated negative linear relationship with Pedicle ratio. Regarding the spinal canal ratio, it demonstrated that the ratio between the width of spinal canal and lumbar vertebral body was 0.6 at L1, L2 and L3 but it becomes 0.5 at L4 and 0.4 at L5. The ratio of the spinal canal demonstrated that there it was gradually decreasing from L1 to L5. This ratio has also demonstrated that the spinal canal ratio was similar to the SCW curve than the VBW curve, along lumbar vertebral levels of L1–L5, SCW curve demonstrated a positive linear relationship with spinal canal ratio and VBW curve depicted no linear relationship with spinal canal ratio.

A Local reference values of lumbar vertebral measurements was established for Saudi-Jazan population. These data might be helpful for the orthopedic surgeons dealing with lumbar vertebral surgery particularly the transpedicular fixation in choosing the suitable threaded screw that can be safely accommodated by the pedicle as orthopedic surgeons should therefore be aware of racial disparities on pedicular parameters.

المستخلص

الغرض من هذا البحث التحليلي الوصفي هو دراسة القياسات الشكلية الطبيعية للعمود الفقري القطني، وكذلك إنشاء قاعدة بيانات ذات قيمة مرجعية بين الأفراد البالغين من كلا الجنسين من سكان منطقه جازان (المملكة العربية السعودية). شملت الدراسة أبعاد العنيقة،والجسم الفقري، القناة الشوكية، وجسم الفقرة، وطول الحبل، وكذلك زوايا العنيقة ابتداءً من مستوى الفقرة القطنية الأولى (L1) إلى الفقرة القطنية الخامسة (L5) باستخدام التصوير المقطعي المحوسب متعدد الكاشفات.(MDCT)

اشتملت عينة الدراسة على 200 مشارك بالغ من جازان (100 من الذكور و100 من الإناث). تم تقييم الفقرات القطنية للمشاركين وجسم العنيقات والقنوات من (L1) إلى(L5) ، شملت العينة المختارة أولئك الذين خضعوا للتصوير المقطعي المحوسب للعمود الفقري القطني والتصوير المقطعي المحوسب للبطن لأسباب مختلفة، بما في ذلك: الاصابات، وآلام الظهر المزمنة، والأورام المشتبه بها والانزلاق الفقاري في المستشفيات الحكومية بمنطقة جازان ولقد تم استبعاد الحالات المرضية. تراوحت أعمار المشاركين من 19-75 سنة (بمتوسط 41.77 سنة)، خلال الفترة من مارس 2016 إلى يوليو 2020. تم تحليل ألف فقرة قطنية طبيعية من(L1)إلى (L5) باستخدام عارض DICOM لـقياس عرضهم وارتفاعهم وطولهم وكذلك طول محور العنيقات. وايضاً تم قياس زوايا العنيقات بما في ذلك الزوايا المستعرضة والزوايا السهمية. تم قياس عرض وعمق وارتفاع الجسم الفقري بالإضافة إلى عرض القناة الشوكية وعمقها وكذلك مؤشر ونسبة العنيقة (CT)ونسبة القناة الشوكية.

وجد أن القيم المتوسطة لعرض العنيقة من اليمين واليسار تزداد تدريجياً من المستوى L1 إلى المستوى L5 في كل من الذكور والإناث. كان متوسط عرض العنيقة عند الذكور (8.39 ± 1.23) ملم والإناث (8.47 ± 1.17)ملم، أظهر القياس وجود اختلاف كبير بين الذكور والإناث المشاركين بالنسبة لـ L3(p≤ 0.05). أظهرت النتائج أيضًا أن قياسات عرض العنيقة في L5 كانت أكبر بشكل ملحوظ في الأشخاص الأكبر سناً بالمقارنة مع الأصغر سناً مع عدم وجود فروق ذات دلالة إحصائية بين متوسط عرض العنيقة لجميع الفئات العمرية تحت الدراسة.توصلت النتائج إلى عدم وجود فروق ذات دلالة إحصائية بين الجنسين فيما يتعلق بارتفاع العنيقة وعرض القناة الشوكية وطول الحبل. فيما يتعلق بالعمر، أظهرت الدراسة علاقة ذات دلالة إحصائية بين الأعمار الأكبر والأصغر سنا في L1و2L و3L لزاوية العنيقة المستعرضة (TPA). أظهرت زاوية الميل أن الفقرات القطنية زادت تدريجياً من L1 إلى L5 في كل من الذكور والإناث (TPA). كان أكبر (TPA) حدث في L5 عند الإناث (30.70^{o}) وأصغر (TPA) كان في L1 عند الإناث (18.49^{o}) وكان متوسط (TPA) في العمر الأكبر أكبر من متوسط (TPA) في السن الأصغر مع وجود فروق ذات دلالة إحصائية عند (p 0.05) تم رصدها في جميع مستويات العمود الفقري L1 إلى L5. تم رصد أكبر حجملزوايا العنيق السهمية (SPA) في كل من الذكور والإناث عند L5 (18.01 درجة) و5L (17.45 درجة مئوية) على التوالي، وأقلها (SPA) وجدت عند الذكور والإناث عند L1 (14.09)و1L (13.97) درجة على التوالي. كشفت الدراسة أنه لا يوجد فرق كبير بين الجنسين فيما يتعلق بزوايا العنيقة السهمية (SPA). سجلت أكبر قيمة متوسطة بـ (مم) لعرض الجسم الفقري المتغير (VBW) عند المستوى الفقري L5 في كل من الذكور (43.97 ± 3.09) والإناث (43.57 ± 2.51) وكان الأقل عند المستوى الفقري L1 في كلا الذكور (33.29 ± 2.80) والإناث (32.90 ± 2.54) مع وجود فروق ذات دلالة إحصائية بين الذكور والإناث عند L3و4L. تشير النتائج إلى أن متوسط القيم المتوسطة لعمق

الجسم الفقري (VBD) كان أعلى في الذكور منه في الإناث مع وجود فرق كبير بين الجنسين على جميع مستويات العمود الفقري باستثناء L5. لا توجد فروق ذات دلالة إحصائية بين الجنسين فيما يتعلق بعمق القناة الشوكية (SCD) في كل مستوى من مستويات العمود الفقري. أظهر مؤشر العنيقة (ratioPI) أن هناك زيادة تدريجية من L1 إلى L5 أظهرت النتائج بين الجنسين أن نسبة مؤشر العنيقة كانت أعلى في الإناث منها عند الذكور في كل مستوى قطني باستثناء L1، والتي كانت أكبر عند الذكور. يتشابه منحنى مؤشر العنيق مع منحنى PDH ومنحنى PDW، خاصة عند المستويات القطنية من L1 إلى L3. أظهر منحنى PDW علاقة خطية إيجابية مع مؤشر العنيقة وأظهر منحنى PDH علاقة خطية سلبية مع مؤشر العنيقة، بينما تم زيادتها تدريجياً في قياسات نسبة العنيقة من L1 إلى L5؛ ومع ذلك، كانت هذه النسبة أكبر في الإناث من الذكور في كل مستوى قطني باستثناء L1 الذي كان أكبر عند الذكور. كان منحنى نسبة العنيق مشابهًا لمنحنى PDW من منحنى VBW، خاصة عند المستويات القطنية من L1 إلى L2، وقد أظهر منحنى PDW علاقة خطية إيجابية للغاية مع نسبة العنيقة، وأظهر منحنى VBW علاقة خطية سلبية مع نسبة العنيقة. فيما يتعلق بنسبة القناة الشوكية، أوضحت الدراسة أن النسبة بين عرض القناة الشوكية والجسم الفقري القطني كانت 0.6 عند L1و2L و3L ولكنها أصبحت 0.5 عند L4و0.4 عندL5. أظهرت نسبة القناة الشوكية أن هناك تناقصًا تدريجيًا من L1 إلى L5. أظهرت هذه النسبة أيضًا أن نسبة القناة الشوكية كانت مشابهة لمنحنى SCW من منحنى VBW، على طول مستويات العمود الفقري القطني من L1 – L5، وأظهر منحنى SCW علاقة خطية موجبة مع نسبة القناة الشوكية ولم يوضح منحنى VBW أي علاقة خطية مع نسبة القناة الشوكية.

تم وضع قيم مرجعية محلية للقياسات الفقرية القطنية لسكان منطقة جازان السعودية. قد تكون هذه البيانات مفيدة لجراحي العظام الذين يتعاملون مع جراحة العمود الفقري القطني وخاصة التثبيت عبر العظمة في اختيار المسمار الملولب المناسب الذي يمكن أن يتكيف بأمان مع العنيقة حيث يجب أن يكون جراحو العظام على دراية بالفوارق العرقيةفي معايير العنيقات.

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Chapter One

Introduction

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Introduction

1.1 Prelude:

In 2003, spinal fusion became the nineteenth most performed surgical procedure in the United States, and it increased from 22 to 51procedures performed per 100,000 inhabitants (Santoni et al.2008). As of 2008 spinal fusion ranks number 16 in total number of discharges amongst all inpatient procedures, with approximately 413,000 spinal fusions performed annually in the US, Looking back to 1998, where it was ranked in position 37, it becomes clear that the practice of spinal fusion has grown at a significantly higher rate in comparison to that of other notable procedures in the US(Rajaee,S.2012),whereas according to iData research report there are more than 1 million instrumented spinal procedures performed in the U.S. annually (Wohns,2019).

Several studies have been conducted to determine morphometry of lumbar vertebra (Vivek et al.2021) and (Li Dachuan et al.2022) as knowledge of high precision of human lumbar vertebra anatomy is necessary *not only* for the understanding of biomechanical and functional feature of lumbar spine but also for various interventions such as; safe placement of screws in pedicle fracture, correction of deformities or degenerative changes, vertebroplasty, pediculoplasties,discography,discectomy,vertebral biopsy as well as pre surgical planning and designing surgical instruments (Gailloud et al.2002).

Spinal anomalies caused by fracture, deformity or degenerative disease is corrected with surgical procedures by using transpedicular screw fixation, this instrumentation has been popular for lumbar vertebrae and its use in the thoracic spine remains restricted due to the technical and anatomical pitfall, specific to the lumbar spine(Ashwini et al.2013). The use of pedicle screw in the thoracic spine is unacceptable in screw position because the thoracic pedicles are too small in size and variable when compared to the standard lumbar pedicle (Ashwini et al.2013). Transpedicle screw is increasingly used worldwide ,these screws enable various devices (plates, rods or wires) to be applied to the spine for the purpose of immobilization or fixation (Dhaval K.and Pritha.S. 2014). Transpedicular fixation has become the most frequently used technique in lumbar spine arthrodesis due to its biomechanical superiority and the observed clinical improvement compared with other available vertebral fusion systems (Chan, Jimmy et al.2019)

Most anatomical studies on morphology of lumber pedicle have been reported in white population, Asian patients, American and African with a few report in Arab zone in spite of these anatomical constraints in the lumbar spine. Accurate anatomical descriptions of the shape and orientation of lumbar is also important to distinguish differences in morphometry of vertebrae in men and women and to understand changes in the elderly (Abu-Leil S, et al. 2021) as incorrect placement of instruments and devices may have serious complications. Most of studies have been carried out using fresh cadaver or osteological collections with the help of Vernier caliper (Can H, et al.2020).Computerized tomographic (CT) images have been employed more recently to study lumbar vertebrae and its used in morphometric analysis of lumbar spine measurements in this study(Güleç A, et al.2017)

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 screw angulation at the moment of introduction (Alfonso Olmos et al. 2002). Knowledge of these features is important for the surgeon to avoid pedicle cortex, meningeal, nerve root, facet joint, viscera or adjacent vascular structure lesions due to poor placement or improper screw orientation (Okutan et al. 2004) and (Rosello et al. 2009).

Multi-detector computed tomography (MDCT) systems may prove to be as revolutionary a development for clinical diagnostic imaging today. Many of the advantages of MDCT from a clinical standpoint arise from the speed and increased spatial resolution of the scanners, which in turn can improve the overall image quality. Imaging of the, lumbar vertebrae are effectively achieved with CT imaging These techniques have proved their diagnostic usefulness in assessing the anatomical and pathological with helical CT, can creating high-quality three-dimensional (3D) reconstruction, so advantages of helical technology include rapid scanning, decreased motion artifact, and minimization of misregistration artifacts.

The present study is to investigate and analyze the radiologic parameters of the adult lumbar vertebrae morphometrically measurements from L1 to L5 using MDCT scan. The study took place on patients with the stable lumbar spine. With the permission taken from the head of the medical imaging departments at Jazan region[KSA]. The researchers measure the transverse diameter [inner and outer diameters of the pedicle], transverse angles of the pedicles, interpedicular distance, sagittal pedicle angle , chord length of the pedicle and pedicle angles from the level of L1 to L5 vertebrae. There are no studies on the morphometric characteristics of the lumbar vertebrae related to Jazan population[Saudi Arabia], and according to (Mohammed Hasen et al.2016) even there are no existed reports about the vertebrae in Saudi population before they published their own paper, they have been measured the morphometry of vertebrae in Saudi population and compared their results with other population, they found a remarkable difference and characteristic pattern important to be addressed in safe placement of screws,pre-surgical planning and designing surgical instruments. The researchers believe that the first time that such a paper has been carried out in pedicle morphometry of Saudi population that found by (Amonoo- kuofi HS.1995) with this being of great importance for the proper planning, execution, and outcome of transpedicular lumbar spinal fusion.

1.2. Study problem:

Intensive information of anatomic depiction and measurements of lumbar vertebrae is essential for an exact clinical and surgical administration of different spinal disorders.
The current study would solve the problem of finding a workspace for several spinal procedures and can acting as a robot designed to guide the surgeon during those procedures using the results of normal anatomy of the lumbar spine. With an increasing frequency for fixation in spinal fractures and degenerative spinal disorders. Hence the need for adequate anatomical knowledge of vertebrae is imperative.
The study concentrated at measuring the various dimensions of lumbar vertebrae in MPR and 3D CT images.

The accurate identification and characterization of lumber vertebral imaging by using MDCT has important therapeutic and prognostic significance in surgical fixation.

1.3. Objectives:

1.3.1 General objectives:

The general aim of this thesis is to study of lumbar vertebrae morphology using multi-detector computed tomography to develop a lumbar vertebral morphometrical data directly relevant to population of Jazan region(KSA).

Objectives of the present study were to specify morphometrical data particularly the dimension of pedicles , vertebral body and spinal canal support for successful surgery of spinal fusion, pedicle screw fixation and also to analyze the quantification of spinal stenosis by determining the mean values of normal lumber [L1toL5] diameter in Saudi Arabian population [Jazan region]. These results of the dimension of lumbar pedicles, vertebral body and canal had been done to find out an index for the Jazan population, and compare the results with those of similar studies of other population in literature by other methods, to deduce safety parameters for surgical procedures placements in lumber areas. comparison between these parameters results according to age and sex.

1.3.2 Specific objectives: Objectives of the present study were to specify morphometrical data particularly the dimension of pedicles , vertebral body and spinal canal support for successful surgery of spinal fusion, pedicle screw fixation and also to analyze the quantification of spinal stenosis by determining the mean values of normal lumber [L1toL5] diameter in Saudi Arabian population [Jazan region].dimension to deduce safety parameters for surgical procedures placements in lumber areas. comparison between these parameters results according to age and sex. Lumbar pedicles dimension parameters measured in this study included pedicle width ,pedicle height, transverse pedicle angle ,sagittal pedicle angle and pedicle axis length or chord length (screw path length) as well as pedicle ratios that indicate pedicle index (width of the pedicle/height of the pedicle) and CT ratio (pedicle width/vertebral body width).

Lumbar vertebral body dimension parameters included vertebral body width, vertebral body depth and vertebral body height, whereas Lumbar spinal canal parameters indicated by spinal canal width, spinal canal depth in addition to the measurement of spinal canal to vertebral body ratio.

1.4. Study significance:

The study shows the highlight of [MDCT] in morphometric measurements of the lumber vertebral anatomy. It provides morphometrically data support for successful fixation in the lumbar spine operation if needed such as; fracture and degenerative changes this service may acting as database for the student and researcher. Better understanding of normal structural in the lumbar spine which lead to helpful in predicting vertebral anomalies if happened. The study act as standard method for measured population in cases of spinal stenosis are related to the anatomical variant with varying degree of reduction of vertebral foramen, especially in sagittal diameter to which are added degenerative lesions of vertebral arches, facet joint and flaval ligaments. The study also is important to distinguish differences in morphometry of lumbar vertebrae in men and women and to understand changes in the elderly.

Chapter Two

Literature review and Theoretical background

Chapter Two

Literature review and Theoretical background

2.1. Historical background regarding area of interest:

Actually the first study regarding measurements of lumbar pedicles among Saudi population have been detected, done by (Amonoo-Kuofi.1995) he has studied horizontal and vertical diameters of pedicles on radiographs of 270 males and 270 females. He has observed variations in different age groups and at different levels of lumbar spine. Amonoo-Kuofi's readings of 40-49.9 years age group reveals that the width of pedicles in males & females is maximum at L5 with 14.2mm and 12.5mm respectively and similarly. The study also reflected that the height of pedicles in males and females are maximum at L5 with 20.7mm & 17.5mm respectively, so he showed that there was a cephalocaudal gradient of increase (from L1-L5) of the horizontal diameters (width) of male and female pedicles in all age groups except the males of the 5th decade. He has also shown that there was a cephalocaudal increase of the vertical diameters (height) of pedicles from L1-L5 in males and females of all age group except the (20-29.9) years female age group.

The contrast between this study and Amonoo-Kuofi is the difference in methods adopted by Amonoo-Kuofi and the present study. He studied the plain radiographs of lumbar spine whereas the present study based on measurement of lumbar pedicles by means of CT scan, also another feature for this contrast that of racial variation. He had studied different population of particular race in Saudi Arabia; whereas the present study was conducted on Jazan population of Jazan region [KSA].

The first study that indicating not only the pedicle morphometry but also the whole vertebral morphometry among Saudi population have taken place by (Mohamed Hasen et.al.2016),the study found a remarkable difference and characteristic pattern important to be addressed in safe placement of screws, pre-surgical planning and designing surgical instruments, but for unfortunately there are no enough information about their paper details.

2.1.2. Literature Review:

(Irshad, F., et al 2022) among Pakistani Punjab population confirmed that all parameters were significantly larger in the males as compared to the females. Significant difference was found in the anterior height of the intervertebral discs at L1-2 to L4-5 while it was insignificant at L5-S1. Posterior height of discs was significantly larger in the male group at L1-2 to L3-4. Wedge index (WI) for discs was relatively larger in the female group.

(Khatiwada, et al (2021) in their “Morphometric study of lumbar vertebral pedicles” among Nepal population confirmed that the mean width of the pedicles of left and the right sides gradually increased as we moved down the vertebrae however, the mean height of the pedicles alternatively decreased and increased down the vertebrae for both the sides. The mean interpedicular distance gradually increased craniocaudally.

(Khan, M., and Zvikomborero, B. D.2020). A Cadaveric morphometric study of lumbar vertebrae in Zimbabwean adult males their results showed, there was an insignificant difference between pedicle dimensions of the right and left sides ($P > .05$),pedicle transverse diameter with gradually increased from vertebral level L1 to L5 and the chord length increased from a minimum at L1 to reach a maximum at L3 and then again decreased to L5 level. A screw length of 40-45 mm should be used for lumbar transpedicular screw fixation with minimal risk of implant failure in Zimbabwean population.

(Kumar, V. and Mittal, M. 2020) Among Indians had found that there is always an increase in the width of lumbar pedicles proceeding from L1 to L5 levels and the width maximum at L5 level to enable in weight transmission. Further, in this study, there was a significant correlation between the height of typical and atypical vertebrae ($p<0.05$)and also between the height and interpedicular distance of male and female vertebrae ($p<0.05$).

(Banik, Suranjana and Rajkumari, Ajita. 2019). In morphometric analysis of lumbar vertebrae and its applied clinical importance found that their study showed increase in all the diameters from L1 to L5 and their data forms a baseline of adult lumbar vertebral morphology and is useful source of information to surgeons, physicians and anatomists. It is also helpful for the screw and implant manufacturers.

Among the Sudanese population by means of MRI modality (Yasir Elhassan et.al.2016) [Sagittal diameter of the lumbosacral spinal canal in normal adult Sudanese population] found that the longest mean AP diameter was at L1 (17.5±2.0mm) in male while (18.1±2.7) in female. The shortest mean AP diameter was at S1 (15.9±3.2mm) in male and (15.4±3.2) in female. The AP diameter gradually decreased from L1 to S1, there is no significant difference between both sexes. There is significant difference between people live in different zones. There is association between age, height and weight and the AP canal diameter.

(Esra Bakri et.al..2015) had noticed that in their study [Measurement of Normal Dimension Range of Lumbar Spinal Canal in Sudanese Population by CT among Sudanese population] that the mean value of anterior-posterior measurement in the axial cut (2.498±0.3711 cm), and the mean value of transverse measurement in the axial cut (1.458±0.2500cm) this study showed that relationship between the patient age, height, weight and BMI measurement in the axial cut was found to be indirect relationship.

(Torres Castellanos,et.al.2015) in spinal canal measurements among Mexican Population, had declared, the measures obtained were mean interpedicular distance of 22.80 in L3, range of 16.34/28.72. In L4, mean of 23.83, range of 17.62/27.92. In L5, mean of 25.28, range of 21.88/31.29.

(Alam et al.2014) in their study of the [Lumbar Morphometry: A Study of Lumbar Vertebrae from a Pakistani Population Using Computed Tomography Scans] found that there was significant differences in various dimensions of lumbar vertebrae between females and males. Moreover, there was a statistically significant difference among pedicle dimensions in a Pakistani population and other populations. These differences have critical implications for spinal surgeons to perform a safe operation on patients of South-Asian background.

(Ashwini et al.2103) in radiological assessment using computerized tomographic (CT) scan. Data in that study convinced that [Screw length of 26 to28] mm appeared to be safe at upper and lower thoracic level. Even 4mm diameter screw used with care in mid thoracic region .The inter pedicular distance in his study was larger than the other study. Hence to allow the pedicular fixation at adjacent level the plate devices should be chosen carefully.

(Chawla et al 2013) in their paper [Importance of transverse pedicle angle & chord length of lumbar pedicle in screw placement: a CT scan study on North West Indian population] found the transverse pedicle angle increased from L1 to L5 in both males and females. The chord length in males was maximum at L5 (51.3 mm) and minimum at L1 (48.1 mm). In female chord length was maximum at L2 (51.1 mm) and minimum at L4 (47.6) on right side and on left side it was maximum at L3 (50.9 mm) and minimum at L1 (46.7 mm) and according to that result he summarized that for north west Indian population [Steffee pedicle screws of 5.5 mm] diameter can be safely used in lumbar vertebrae, as the diameter of the pedicular screw is decided by the minimum diameter of the pedicle which in that study was across the width (8.7 mm).The study also found that screws of [40mm length] appeared to be safe at all lumbar levels as the minimum mean chord length was 46.1 mm.[Image 1and 2 in appendix1]. At the lower lumbar levels, higher lateral inclination of the pedicle should be kept in mind, as it may lead to the breach of the medial cortex of the pedicle with resultant risk to the neural tissues.

(Cheung et.al 2013) in their retrospective study that aimed to determine the intra- and inter-reader reliability of MRI measurements of the lumbar spine and the reliability of measurements usingT1- and

T2 weighted MRI films. Measurements in axial scan included midline anteroposterior (AP) vertebral body diameter, mid-vertebral body width, midline AP spinal canal diameter, midline AP dural sac diameter, spinal canal width/interpedicular distance, pedicle width (right and left), and lamina angle. Measurements in the sagittal scan included midline AP body diameter, mid-vertebral body height, and AP spinal canal diameter. Cronbach alpha was used to characterize intra- and inter-reader reliability for qualitative rating data. Similarly, T1 and T2 comparison also was performed in the same manner. His study resulted in; good to excellent intra- and inter observer reliability was obtained for all measurements.

(Upendra et al.2010) mentioned that the pedicle anatomy in scoliosis patients shows very high individual variations and a careful study of preoperative CT scans is essential for planning proper pedicle screw placement.

(Maaly et al.2010) in [Morphological measurements of lumbar pedicles in Egyptian population using computerized tomography and cadaver direct caliber measurements] found that the angle of inclination of the lumbar pedicle axis on the midline are more obtuse than the known western measurements and becoming more obtuse from L1-L5. Their study also clarified that the pedicle width becomes progressively thicker from L1-L5 and the endosteal thickness follows the pedicle breadth becoming thicker at L5 than L1.They also found that CT pedicle measurements are accurate indicators for the actual pedicle morphometry.

(Decker et.al 2010) aimed to evaluate agreement and repeatability of vertebral column measurements using computed tomography (CT) and magnetic resonance imaging (MRI). Dogs (n=18) with disc associated wobbler syndrome; Dog cadavers (n=3). Five measurements of the 5th cervical vertebra were performed: vertebral body length (VBL), vertebral canal height (VCH), vertebral body height (VBH), vertebral canal width (VCW), and vertebral body width (VBW). Measurements were performed independently twice by 2 observers. Bland-Altman plots were created to evaluate agreement. Cadaveric vertebrae with soft tissue. Removed had the same variables and actual dimensions measured. The largest discrepancy between CT and MRI measurement was for VBL (mean difference+/-SD=1.262 mm+/-1.245; P<0.001), with the difference for all the other variables being acceptable. The first measurement was significantly higher than the second only for VBL using CT (mean difference=0.476 mm+/-1.120; P=.009),with all other variables having acceptable differences. Mean difference for all measurements between 2 observers was small, except for VBL using CT (mean difference=0.762 mm+/-1.042; P<.001). Only the difference for VBL between CT and cadaver specimens was statistically significant. Their results suggest high repeatability and good agreement for most vertebral measurements of interest. VBL measurement using CT was considered problematic. Provided limitations are understood, linear measurements of vertebral dimensions from CT and MRI images can be used clinically.

According to (Urrutia et al.2009) in [Morphometry of Pedicle and Vertebral Body in a Mexican Population by CT and Fluoroscopy] they convinced [in a Mexican population the mean narrower pedicular width (7.81mm) was at L1-L2 levels. The dimensions (widths) of the L1 and L2 pedicles measured by CT are enough to insert pedicles screws. Use of a [5.5 to 6.5 screw] should be safer in Mexican population. [A lumbar pedicle with a diameter of 7.81mm will easily accommodate a 4.5 mm screw], especially if the pediculation is performed with a Jamshidi-cannula followed by guide-wire insertion and subsequent insertion of a cannulated screw.When [Urrutia et al.2009] Compared their results of the pedicle width with other studies, there were differences with the reports of Mitra et al. in Indians, Kim et al. in Koreans and Olsewski et al. in Americans. The pedicular width were wider in Indians, Koreans, and Americans than in Mexicans. There some important differences in L1, L2, L5 between races, but in L3 and L4 there is no such wide variation. This suggests that variations occur more often in transitional vertebra (upper and lower). However, they found some similarity in the report of Christodoulou et al. in Greeks & Hou et al. in Chinese population.

(Urrutia et al.2009) found that CT scanning evaluation is the gold standard in determining the feasibility of pedicle screw insertion, and fluoroscopy is used only to obtain the proper entry points and angulations for screw insertion intraoperatively. The magnification observed in pedicle size by fluoroscopy is not important for the choice of the appropriate implant.

(Kim et al.2009) among Korean observed no significant difference between males and females in case of pedicle angle and chord length whereas in their study among Indian population there were statically significant gender difference observed for both chord length and transverse pedicle angle. Some of the differences may be due to factors such as race, stature, build and in CT scans due to observer’s bias, slice thickness, and scan diameter, calibration standards, and orientation of the scanning plane relative to the anatomic structure of interest.

(Tarek et al .2006)in their study about among adult Egyptians showed that there is a cephalocaudal gradient of increase (from L1-L5) of the horizontal diameter (width) of pedicles of lumbar vertebrae. Also, cephalocaudal gradient of decrease (from L1-L5) of the vertical diameter (height)and anteroposterior diameter (length) of the pedicles were observed. The later study authors mentioned that variation in dimensions of pedicles throughout the lumbar vertebrae could reflect both the morphological and functional adaptation of the vertebral column at the lumbar region regarding body weight transmission.

(Inceoglu et al.2005) had found that the pedicle is the strongest part of the lumbar vertebra that is made up of entirely cortical bone with a small core of cancellous bone. He also mentioned that lumbar region, being the mobile part of vertebral column, is subjected to instability following trauma particularly related to road traffic accidents, use of heavy mechanical devices and adventure sports besides surgical laminectomies, degenerative conditions, congenital defects and metastasizing malignant tumors of the prostate and other pelvic organs.

(Soyuncu et al.2005) found that the mismatched size of pedicle and screw could result in loosening of the screw, fracture of the pedicle, tearing of dura, leakage of CSF and nerve-root injuries

[Image 4 in appendix1]

(Goel et al.2005) mentioned that the use of pedicle screws ensure dramatic clinical improvements for management of various spinal disorders including traumatic vertebral fractures, scoliosis and spondylolisthesis.

(Li et.al.2004) described that morphometric characteristics of the pedicle should be obtained at the level of the "pedicle isthmus", which is defined as the narrowest portion of the pedicle, and therefore its dimensions represent the minimum diameter that the screw must have for adequate pedicle fixation, thereby establishing this area as the most important of the pedicle.

According to (Tacar et .al.2003) in their study about [Morphology of the lumbar spinal canal in normal adult Turks.].they had found that ; At all levels (L1 - L5) the transverse diameters of the lumbar spinal canal were approximately 1 - 1.5 mm][higher in males than in females. The intersegmental differences increased proximodistally, in both sexes. The ratio of the transverse diameter canal to the width of the vertebra ranged from 0.55 to 0.60 mm in both sexes. The distribution of the different lumbar canal types were 47% A, 42% B, 11% C. Additionally, subtypes were determined and classified.

(Wolf.et al 2001) in the Morphometric Study of the Human Lumbar Spine for Operation–Workspace Specifications, among Israeli population found that the workspace of surgical tools during insertion was divided into angular and displacement regions. It has been shown that for percutaneous surgical procedures such as vertebral body biopsy and discectomy, the mean value of the puncture point is 70.4mm from the midline, with a minimum value of 45.9 mm in L1 and a maximum value of 108.6 mm in L5. In this case, the entry angle has a mean value of 24 degrees, with a minimum of 20.7 degrees in

L1 and a maximum of 27.3 degrees in L5. For open surgery cases, the mean value of the puncture point is 70.3 mm from the midline, with a minimum value of 49.8 mm in L2 and a maximum value of 97.7 mm in L4. In this case, the entry angle has a mean value of 35.4 degrees, with a minimum of 29.2 degrees in L3 and a maximum of 38.8 degrees in L5. For the pedicle entry point in percutaneous cases, a mean value of 34.2 mm from the midline was found, with a minimum value of 14.6 mm in L1 and a maximum value of 72 mm in L5. For open surgery cases, a mean value of 28.5 mm from the midline was found, with a minimum value of 14.1 mm in L1 and a maximum value of 53.1 mm in L5. In both cases, the average entry angle is 13.7 degrees, with a minimum value of 10.5 degrees and a maximum value of 22.5 degrees. This angle is dictated by the anatomy of the pedicle [Image 3 in appendix1]

(Zhou et.al 2000) stated that the precise dimensions of the lumbar vertebrae and discs are critical for the production of appropriate spinal implants. The results from this study indicated that the depth and width of the vertebral endplate increased from the third to the fifth lumbar vertebra. Anterior vertebral height remained the same from the third to the fifth vertebra, but the posterior vertebral height decreased. Mean disc height in the lower lumbar segments was 11.6 ± 1.8 mm for the L3/4 disc, 11.3 ± 2.1 mm for the L4/5, and 10.7 ± 2.1 mm for the L5/S1 level. The average circumference of the lower endplate of the fourth lumbar vertebra was 141 mm and the average surface area was 1492 mm2. An increasing pedicle width from a mean of 9.6 ± 2.2 mm at L3 through to 16.2 ± 2.8 mm at L5 was noted.

The lumbar pedicle has been the object of many morphometric studies in different populations around the world to determine their true dimensions using direct measurement in cadavers spines using Vernier calipers and goniometers such as; (Chaynes et al.2001) (Christodoulou et al.2005) (Islam et al. 1996) (Lien et al.2007) (Nojiri et al .2005) (Berry et al.1987) (Penjabi et al.1992) (Hou et al. 1993)(Kim et al.1994) (Ebraheim et al.1996) (Mitra et al. 2004) (Shiu-Bii Lien et al. 2007) (Dhaval et al .2014) (Seema et al.2016) the measurement of dry vertebrae such as; [Singel et al.2004) (Tan et al.2004) (Dhaval et al.2014) (Ebraheim et al.1996) Plain radiography such as; (Zindrick et al.1987) Fluoroscopy e.g. some studies have been carried out regarding the morphometric characteristics of lumbar pedicles using fluoroscopy and CT in Mexico by (Urrutia et al. 2009). 3D reconstruction, magnetic resonance imaging and computed tomography (CT) such as;(Olsewski et al. 1993) (Wolf et al.2001) (Singel et al. 2004) (Nojiri et al. 2005) (Lien et al.2007) (Acharya et al. 2010) (Maaly et al. 2010) and (Kang et al. 2011). As well as some studies have been carried out regarding the morphometric characteristics of lumbar pedicles using conventional computed tomography by (Urrutia et al., 2009).The mentioned studies demonstrate that significant differences exist between different ethnicities, genders, age groups, vertebral levels, and the proportions of lumbar pedicle elements (cortical and cancellous bone),as well as (Nojiri, Kenya et al.2005) (Robertson and Stewart.2000) whom they assessed these measurements in various lumbar spine degenerative diseases.

In several studies it had found that the mean horizontal diameter (pedicle width) increase from L1to L5 level, whereas mean vertical diameter were maximum at L2 and minimum at L5 [Marasini ,Amonoo-Kuofi in Saudi Arabia, Oleski et al, on cadaver Americans ,Kadioglu et al on Anatolian ,Lien et al on Taiwanese and Zindric et al on Indians] predicted gradual increase in horizontal (width) diameter while vertical diameter showed gradual decrease as we go down, these variation are attributed to racial, ethnic or regional variation]

(According to (Zindrick,1991) Lumbar pedicle screw fixation is considered one of the most stable and versatile methods for stabilization of lumbosacral spine.

Various pedicle screw systems involve insertion of screw through the pedicle into the vertebral body from the posterior aspect for vertebral immobilization. The success of the transpedicular screw fixation technique depends on the size of the pedicle and the quality of the vertebral body (Esses and Bednar,1989).

Lumbar vertebral pedicle is used as an access port for procedures performed inside the vertebral body including biopsies, vertebroplasty and kyphoplasty (Scoles et al.1988) Furthermore it 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 of (Pal and Routal,1987).

Various devices like rods, plates or wires can be fixed to the spinal column by the screws for immobilization (Amonoo-Kuofi, 1995) The factors to achieve stability using implants include accurate screw for fixation and the good quality of bone for the proper screw path (Zindrick et al.1986).

In the recent past, transpedicular screw implantation techniques have gained popularity over anterior instrumentation and hook-rod devices as the mean of spinal fixation (Zindrick et al.1987). The unique anatomy of the pedicles provides an excellent implantation site for screw fixation in reconstructive spinal surgeries to maintain and restore stability in such patients (Roy-Camille et al.1986).

The morphology of vertebral pedicle and angular alignment is difficult to estimate by plain x-ray or at surgery. A mismatched size of pedicle and screw may result in loosening of the screw and fracture of the pedicle, tearing of duramater, leakage of CSF and nerve-root injuries (Matsuzaki et al.1990) (Masferrer et al.1998) (Ofiram et al.2007).The horizontal diameter of pedicle decides the screw diameter. The transverse (width) and vertical (height) parameters of pedicle decide the screw path.

The vertebral pedicles are used for placement of screws through them for the management of the unstable lumbar spine and offer potential advantages over anterior instrumentation and hook rod devices (Matsuzaki et al. 1990) and with the help of screws, various devices such as rods, plates or wires can be applied to spine for immobilization or fixation (Amonoo-Kuofi .1995).

Regarding measurements of the normal adult lumbar spinal canal of Pakistan population (Janjua MZ,et al.1989)The canal showed gradual decrease in measurement from L1 to L5 vertebral levels in both sexes but relative width of the canal was more in the females than in the males of the same age group. The normal values of the canal to vertebral body ratio (C/B) varies between 1:2.0 and 1:5.0. The ratio 1:2.0 indicates a wider canal whereas any ratio beyond 1:5.0 would be conclusive of stenosis of the lumbar vertebral canal.

2.2. Theoretical background:

2.3. Anatomy of the Human Vertebrae:

In a human's vertebral column there are normally thirty-three vertebrae the upper twenty-four are articulating and separated from each other by intervertebral discs, and the lower nine are fused in adults, five in the sacrum [5 (fused) vertebrae (S1–S5)] and four in the coccyx [4(fused) vertebrae] or tailbone. The articulating vertebrae are named according to their region of the spine. There are seven cervical vertebrae(C1-C7), twelve thoracic vertebrae(T1-T12) and five lumbar vertebrae(L1-L5). The number of vertebrae in a region can vary but overall the number remains the same. The number of those in the cervical region however is only rarely changed. There are ligaments extending the length of the column at the front and the back, and in between the vertebrae joining the spinous processes, the transverse processes and the vertebral laminae (Darke et al.2005). [Image 5 in appendix1]

The complex anatomy of the lumber spine is a remarkable combination of these strong vertebrae, multiple bony elements linked by joint capsules, and flexible ligaments/tendons, large muscles, and highly sensitive nerves. it also has a complicated innervation and vascular supply (Drake et al.2009).

A typical vertebra consists of two parts: the vertebral body and the vertebral arch. The vertebral arch is posterior, meaning it faces the back of a person. Together, these enclose the vertebral foramen, which contains the spinal cord. Because the spinal cord ends in the lumbar spine, and the sacrum and coccyx are fused, they do not contain a central foramen. The vertebral arch is formed by a pair of pedicles and a pair of laminae, and supports seven processes, four articular, two transverse, and one spinous, the latter also being known as the neural spine. Two transverse processes and one spinous process are posterior to (behind) the vertebral body. The spinous process comes out the back, one transverse process comes out the left, and one on the right. The spinous processes of the cervical and lumbar regions can be felt through the skin**.** Above and below each vertebra are joints called facet joints. These restrict the range of movement possible, and are joined by a thin portion of the neural arch called the pars interarticularis. In between each pair of vertebrae are two small holes called intervertebral foramina. The spinal nerves leave the spinal cord through these holes (Saladin, K. S 2012,p201). [Image6 and 7 appendix1]

2.3.1 Functional movement and Functional spinal unit of the human spine

The human spine is like a mechanical structure that consists of vertebrae and other related structures such as facets, intervertebral discs, ligaments and muscles. The lever in the mechanics is the vertebrae; the pivots are the facet joints and the intervertebral disc whereas the activators are the muscles and the ligaments (White and Panjabi 1990,p 177). These structures give human spine its three fundamental biomechanical functions: (1) to allow sufficient mobility between head, trunk and pelvis; (2) to transfer weight of the head to the pelvis and (3) to offer protection to the spinal cord.

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

2.3.2 Vertebrae

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

2.3.3. Intervertebral disc:

An intervertebral disc lies between adjacent vertebrae in the vertebral column. Each disc forms a fibrocartilaginous joint (a symphysis), to allow slight movement of the vertebrae, to act as a ligament to hold the vertebrae together, and to function as a shock absorber for the spine**.**

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

2.3.4. Facet joints

The facet joints,(or zygapophysial joints, zygapophyseal, apophyseal,or Z-joints) are a set of synovial, plane joints between the articular processes of two adjacent vertebrae. There are two facet joints in each spinal motion segment and each facet joint is innervated by the recurrent meningeal nerves.These are the synovial joints of the spine between the superior articular processes and inferior articular processes (Bogduk and Long.1979). The joints have a fibrous capsule, articular cartilage and synovial lining (Bogduk, 2005). The joints play an important role in axial load bearing during extension and their orientation differs from one region of the spine to the other. In the cervical region, the joints adopted a coronal orientation and therefore allow for all possible range of movements such as flexion, extension, lateral flexion and rotation (Kowalski et al. 2005). In the lumbar region, the joints lie in sagittal plane which allows flexion but no rotation movements (Gray.2008). The joints in the thoracic region assumed an intermediate position between coronally oriented cervical and sagittally oriented lumbar regions. This allows for lateral flexion and rotation but no flexion or extension movements (Kowalski et al. 2005).

2.3.5 Cervical vertebrae:

These are smallest vertebrae and characterized by the presence of a foramen in their transverse processes, the foramen transversarium, which transmit the vertebral artery and veins (Grey.2008). The atlas is the first cervical vertebra with no vertebral body and spinous process.

It consists of two lateral masses which are joined by a short anterior and a long posterior arch (Kramer and Allan, 2005). The axis is the second cervical vertebra and bears an upward projection from its body called the odontoid process. The odontoid process articulates with the anterior arch of the atlas above (Netter, 2014). From the third to the sixth vertebrae, these are typical cervical vertebrae; characterized by the presence of a short, bifid spinous processes and each transverse process bears a foramen transversarium

(Kramer and Allan, 2005). The seventh cervical vertebra is atypical and consists of a small foramen transversarium and a very large spinous process which is not bifid.

2.3.6. Thoracic vertebrae:

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

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

2.3.7. Lumbar vertebrae:

The lumbar vertebrae are, in human anatomy, the five vertebrae between the rib cage and the pelvis. They are the largest segments of the vertebral column and are characterized by the absence of the foramen transversarium within the transverse process (as it is only found in the cervical region), and by the absence of facets on the sides of the body (as only found in the thoracic region). They are designated L1 to L5, starting at the top. The lumbar vertebrae help support the weight of the body, and permit movement.As with other vertebrae, each lumbar vertebra consists of a vertebral body and a vertebral arch. The vertebral arch, consisting of a pair of pedicles and a pair of laminae, encloses the vertebral foramen (opening) and supports seven processes. The complex anatomy of the lumber spine is a remarkable combination of these strong vertebrae, multiple bony elements linked by joint capsules, and flexible ligaments/tendons, large muscles, and highly sensitive nerves. it also has a complicated innervation and vascular supply (Drake et al.2009).

The lumbar spine is designed to be incredibly strong, protecting the highly sensitive spinal cord and spinal nerve roots, At the same time, it is highly flexible, providing for mobility in many different planes including flexion, extension, side bending, and rotation (Kirkaldy et al.1999). [Image 5 and 6 appendix1].

2.3.7.1 Features of lumbar vertebrae:

Vertebral body is large and wider transversely and deeper in front. On the anterior aspect its vertical extent is more than on the posterior aspect. This accounts for the ventral convexity of the lumbar part of vertebral column. Vertebral foramen is triangular, larger than that of thoracic vertebra but smaller than that of cervical vertebra. Laminae are broad and short but do not overlap as much as they do in the thoracic region. Spinous process is almost horizontal, quadrangular in shape and thickened along its posterior and inferior borders. The superior articular processes bear vertical concave articular facets facing posteromedially, with a rough mamillary process on their posterior borders. Inferior articular processes have vertical convex articular facets facing anterolaterally. Transverse processes are thin and long except in the more substantial fifth pair. (Williams PL.1989). A small accessory process marks the postero-inferior aspect of the root of each transverse process. [Image6-7 and 8 appendix1]

2.3.8. Sacrum:

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

The superior surface of the body of the first sacral bone which forms the base of the sacrum has a prominent anterior lip called the sacral promontory, which serves as an important obstetric landmark (Bogduk, 2005). The lateral, wing-like parts of the base form the alae of the sacrum. Each ala consists anteriorly of the costal element, and posteriorly of the transverse process (Kramer and Allan. 2005). Both components are fused to the side of S1 body and its pedicle forming the lateral boundary of the sacral canal (Moore.2013). The anterior or pelvic surface of the sacrum is relatively smooth. Its central portion has four transverse ridges which indicate the regions of fusion between the bodies of the five sacral vertebrae (Grey, 2008). Lateral to these ridges are anterior sacral foramina through which the anterior rami of S1 to S4 spinal nerves enter the pelvis on each side (Drake et al. 2005).The posterior surface is slightly convex and very irregular. There are five prominent longitudinal ridges on this surface (Bogduk.2005). The lateral surface is rough and triangular in shape. It articulates with the ilium forming the sacro-iliac joint (Moore.2013). [Image 8 and9 appendix1].

2.3.9. Coccyx:

This is a small triangular bone, formed by the fusion of four coccygeal vertebrae (Kramer and Allan.2005). Their number is variable and may be one less or more in some people. They are concave anteriorly,thus continuing the curve of the sacrum. There are traces of a vertebral arch and processes but the vertebral bodies are absent and there is no vertebral canal (Moore. 2013). The most obvious features of these vertebrae are the tubercles which represent remnants of the transverse or articular processes (Kramer and Allan. 2005). [Image 8 in appendix1]

2.3.10. Lumbar vertebral Body:

The lumber vertebrae, numbered L1-L5, have a vertical height that is less than their horizontal diameter. They are composed of the following 3 functional parts: The vertebral body, designed to bear weight, the vertebral (neural) arch, designed to protect neural elements and the bony processes (spinous and transverse), which function to Increase the efficiency of muscle action. The lumber vertebral bodies (vertebrae) are the heaviest components, connected together by the intervertebral discs. The size of the vertebral body increase from L1 to L5, indicative of the increasing loads that each lower lumber vertebra absorbs. Of note, the L5 vertebra has the heaviest body, smallest spinous process, and thickest transverse process. The inter vertebral disc surface of an adult vertebra contains a ring of cortical bone peripherally termed the epiphyseal ring. This ring acts as a growth zone in the young while anchoring the attachment of the annular fibers in adults. A hyaline cartilage plate lies within the confines of this epiphyseal ring.

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

2.3.11 Lumbar Vertebral arch:

Each vertebral arch is composed of 2 pedicles, 2laminae, and 7 different bony processes, joined together by facet joints and ligament, the pedicle, strong and directed posteriorly, joins the arch to the postero-lateral body. It is anchored to the cephalic portion of the body and function as protective cover for the cauda equine contents. The concavities in the cephalic and caudal surfaces of the pedicle are termed vertebral notches. The pedicles are very strong, directed backward from the upper part of the vertebral body; consequently, the inferior vertebral notches are of considerable depth. The pedicles change in morphology from the upper lumbar to the lower lumbar. They increase in sagittal width from 9 mm to up to 18 mm at L5. They increase in angulation in the axial plane from 10 degrees to 20 degrees by L5. The pedicle is sometimes used as a portal of entrance into the vertebral body for fixation with pedicle screws or for placement of bone cement as with kyphoplasty or vertebroplasty. Beneath each lumbar vertebra , a pair of inter vertebral foramina with the same number designations can be found, such that the L1 neural foramina are located just below the L1 vertebra .Each foramina is bounded superiorly and inferiorly by the pedicle ,anteriorly by the inter vertebral disc and vertebral body ,and posteriorly by facet joints .The same numbered spinal nerve root, recurrent meningeal nerves , and radicular blood vessels pass through each foramen .five lumbar spinal nerve roots are found on each side.

The laminae are broad, short, and strong. They form the posterior portion of the vertebral arch. In the upper lumbar region the lamina are taller than wide but in the lower lumbar vertebra the lamina are wider than tall. The lamina connects the spinous process to the pedicles. The vertebral foramen within the arch is triangular, larger than the thoracic vertebrae, but smaller than in the cervical vertebrae. The broad and strong laminae are the plates that extend posteromedial from the pedicel .The oblong shaped spinous processes are directed posteriorly from the union of the laminae. The two superior and inferior articular processes ,labeled SAP and IAP,respectively,extend cranially and caudally from the point where the pedicles and lamina join. The facet or zygapophyseal joints are in parasagittal plane. When viewed in an oblique projection, the outline of the facets and the pars inter articularis appear like the neck of a Scottie dog (Rosse C and GaddumP1997,p67).Between the superior and inferior articular processes , 2transverse processes are projected laterally that are long ,slender ,and strong .they have an upper tubercle at the junction with the superior articular process and an inferior tubercle at the base of the process .These bony protuberances are sites of attachment of deep back muscles(Pansky B.1996). [Images 8and9 in appendix1]

2.3.12 Anatomy of pedicle:

The pedicle of lumbar vertebra is a very strong, cylindrical, anatomic bridge between the dorsal spinal elements and the vertebral body. It is composed of a strong shell of cortical bone and a core of cancellous bone and presents superior and inferior vertebral notches which form the intervertebral foramina. Pedicles serve as the load transmitting struts between the neural arch and the vertebral body.(Benzel

EC.2005).Pedicles are closely related to important structures on all sides. These structures help the surgeon to avoid penetrating pedicle during surgery. They are:1- Medial to pedicles lie the epidural space, nerve root and dural sac. 2-Caudally lies the exiting nerve root from the same level. 3- Laterally and cranially, nerve root from the level above lies closely.[Image10 in appendix1]

2.3.13 Morphometry of pedicles:

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

2.3.14.Vertebral canal

The tubular vertebral canal contains the spinal cord, its meninges, spinal nerve roots, and blood vessels supplying the cord,meninges,vertebrae, joints, muscles, and ligaments. Both potential and real spaces intervene between the spinal cord, meanings, and Osseo ligamentous canal walls. The canal is enclosed within its column and formed by the juxtaposition of the vertebral foramen, lined up with one another in series .The vertebral bodies and discs make up the anterior wall, whereas the laminae and ligamentum flavum border the canal posteriorly. Laterally, spinal nerves and vessels travel through the intervertebral foramen (PanskyB.1996). [Image 7 in appendix1].

2.3.15. Spinal cord

Other than the brain, the spinal cord is one of the two anatomic components of the central nervous system (CNS). It is the major reflex center and conduction pathway between the brain and the body, As noted earlier, the spinal cord normally terminates as the conus medullaris within the lumbar spinal canal at the lower margin of the L2 vertebra, although variability of the most caudal extension exists (Pansky B. 1996). In a cadaveric study of 129 cadaveric specimens, the spinal cord terminated at L2 in 60%, L1 in 30%, and

L3 in 10% of specimens. Differential growth rates in the spinal cord and the vertebral canal are the cause of these disparities. Exceptions also include patient with congenital spinal deformities known as spina bifida ,in such patient, the conus medullaris can be displace downward to the middle or lower lumbar spine

(Lippincott W and Wilkins) (2007).

2.4 Physiology of the Spine:

The spinal column protects the delicate nerve tissue of spinal cord. The spinal cord is a highly organized and complex part of the central nervous system. Its complexity is due to the role it plays in the 3 most important functions of the individual: sensation, autonomic and motor control. If it was to simply report to the brain the information that it receives from the large number and variety of afferent inputs and relay back to the moto-neurons and pre ganglionic neurons the outcome of processing performed by the supra spinal centres the situation would be more straight forward. However, as is well established, this is not the case and the spinal cord has, in addition to relaying information from the rest of the body to the brain and receiving efferent commands from varied portions of the brain the ability to integrate and modify both afferent signals from the periphery, and efferent signals from segmental afferents and supra spinal centres. Thus there is a complicated network of neurons that normally operates in conjunction with the rest of the CNS to allow perfect control of sensory, autonomic and motor functions. This complex circuitry is critically dependent on its connections with the brain and it cannot function appropriately when it is either completely or even partially disconnected from it. It is rather regrettable, that we understand so little of the potential of the complex intrinsic circuitry of the spinal cord that when it loses connection with the brain we are unable to exploit its' potential function and restore deficits caused by spinal cord lesions. In spite of the fact that the physiology of the spinal cord has been intensively investigated for at least a century it keeps revealing new surprising phenomena.(M.Y.Sukkar et.al 2000).

2.4.1.Sensory Processing:

In an oversimplified manner it can be stated that the somatic afferent functions that are processed in the spinal cord constitute the following: (a) pain and temperature, (b) touch, and (c) proprioception. Different sense organs in the peripheral structures initiate these sensory modalities, but the processing of them is usually carried out by a network of neurons in the spinal cord that are common to several of these different modalities of sensation (M.Y. Sukkar et.al 2000).

2.5. Surgical instrumentation of the pedicle

The use of pedicle screws in spinal surgery is broad and encompasses the treatment of deformity, trauma, cancer and degenerative disorders, including degenerative lumbar spine disease (Gaines. 2000).Degenerative lumbar disease causing nerve compression is a common problem, and it responds well to surgery. The frequency of this disease is increasing due to an aging demographic. A common form of treatment is fusion and decompression of the lumbar spine with use of pedicle screws as the primary mode of stabilization [Image 2:appendix 1] .Although multiple forms and types of spinal instrumentation exist, the pedicle screw is the most commonly utilized (Benzel,.1995).These screws are inserted from posterior to anterior (i.e.from the back to the front of the vertebral body).Screws in adjacent bodies are rigidly connected via rods to one another to achieve fusion or stabilization of adjacent vertebra [Image 2:appendix 1].Lumbar spine fusion is used to eliminate motion and provide stability across degenerative or unstable motion segments. This lateral x-ray of the lumbar spine shows pedicle screw instrumentation of the L4 vertebra and L5 vertebra. An intervertebral cage is also used to re-establish lost vertebral disk height and to promote bony fusion.

In regards to the possible length of instrumentation used in the pedicle, morphometric studies have demonstrated an average distance of 40mm from the posterior aspect of the pedicle to the anterior aspect of vertebral body in the thoracic spine and on average 50mm in the lumbar spine (as measured from the posterior aspect of the pedicle going through the pedicle along its long axis towards the anterior vertebral body. For the current commercially available pedicle screw systems, the ideal length of screw depth insertion is utilized to allow for maximum strength with minimum complications. Biomechanical studies show that approximately 60% of the screw strength is within the pedicle, while the remaining 40% is divided equally between the cancellous screw purchase in the vertebral body and the anterior vertebral cortex; for a screw which penetrates the anterior wall of the vertebral body (Benzel,.1995). In other words, a screw that penetrates the anterior vertebral body will be 20% stronger than a screw which remains in the body. However, perforation of the anterior vertebral cortex is associated with potential injury to the major anterior vasculature including the aorta. Thus, the risk associated with breaching the anterior cortex is thought to exceed the benefits gained from additional strength (Weinstein.,1992) .Although this rule applies to the entire thoracic and lumbar spine, the values are reversed in the sacrum. The sacrum has a strong anterior weight bearing column of bone that contributes to 60% of the screw strength and therefore consideration for anterior wall penetration in this region should be made (Weinstein.,1992).

2.5.1. History of vertebral screw and pedicle screw fixation:

The first described treatment of spinal disease with surgical instrumentation was published by Hadra in 1891, during which time, he utilized a wiring technique to stabilize a pathologic cervical spine fracture-dislocation secondary to Pott's disease (Hadra, B.E.,1891) (Schlicke, L.H. and D.J. Schulak,1981) ,whereas the use of bone screws to obtain internal spinal fixation at the time of fusion was first described by (Toumey.1943) and (King.1944),their techniques involved passing a screw from medial to lateral across the facet joint. The screws were short and designed only to cross the facet joint but the method was faulty and it led to higher rates of pseudo arthrosis. (Boucher 1959) modified the technique by using a longer (one and a half to two inches) stainless steel screws placed through the inferior facets into the pedicle and vertebral body below. This led to the reduction of pseudo arthrosis rates to approximately 14% to 17% (Andrea et al., 2005). (Magerl 1984) introduced another form of facet screws in which a screw was passed from one side of the spinous process into the opposite lamina across the facet joint to the base of the transverse process. The disadvantage of this technique was that it required intact lamina.

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

2.5.2 Transpedicular screw fixation development:

The major advancement in lumbar spine care in the recent past has been the development of pedicle screw internal fixation systems. (Ramamurthi B, Tandon PN.1986).

In 1980's, Steffee and others (Steffee AD.et al.1986) (Lin PM, Gill K. 1989) and associates and (Luque ER.1986) used slotted plates in an attempt to alleviate the problem of screw breakage in screw and plate systems. Arthur D. Steffee in 1982 found that, the pedicles are the strongest part of the spine to fix from posterior to anterior and developed the variable screw. Steffee's variable screw placement system provided rigid fixation and excellent fusion rates, but screw breakage continued to be a problem. (Whitecloud TS.et al.1989).

In 1986 Krag et al, using CT scan data, measured the lower thoracic and lumbar spine (Krag MH.et.al.1986). In 1987, Berry et al, using direct specimen measurement technique, looked at select pedicles in the spine (Berry JL.1987). In 1988, Roy Camille et al, reported that 10% of pedicle screws were placed incorrectly (Boachie–Adjei.et al.O.2000), (Gertzbein SD.et al.1990) (Roy-Camille.1.et al.986).

In the same year Weinstein et al reported an overall failure rate of 21% from cadaveric studies (Weinstein JN.et al.1988).

(Olsewski J. M. et al1990) studied the morphometry of lumbar spine and anatomical perspectives related to transpedicular fixation (Olsewski JM.1990). In 1992, a detailed description of the lower thoracic and lumbar pedicle and relative landmarks on the posterior surface of the spine have been reported by (Zindrick et al.1987,1992). In the same year (1992), Thomas N. Bernard and Charles E. Seibert MD studied the average pedicle diameter and reported that the pedicles of L4, L5 and S1 can safely accept pedicle screws with **7** mm outer diameter (Bernard TN.et al.1992). In 1993, Scott W. Atlas described markedly thinned pedicles as a normal variant in the entire lumbar spine, as seen on routine films, as well as CT scan (Atlas SW. et al.1993).

In the year 1994, Kim N H et al had studied the different dimensions of the lumbar vertebral pedicle in Korean population and compared it with that of Westerners and stressed its relevance in transpedicular screw fixation which is indicated in unstable spine compression like traumatic listhesis, wedge compression fracture, primary and secondary tumors, infections like brucellosis and tuberculosis (Kim N H et al.1994)

In 1995, Srdjan R. Mirkovic investigated intervertebral foraminal anatomy of L2–S1 by the anatomic dissection of 96 foraminal levels in 12 human cadaveric spines and concluded that either a 7.5 mm cannula placed in line with the medial one third of the pedicle or a 6.3 mm cannula located in the midline of the pedicle appears safe (Mirkovic SR, et al.1995).

In 1996, Nabil A. Ebraheim studied 250 lumbar vertebrae and reported that the average distance from the projection point of the lumbar pedicle axis to the midline of the transverse process consistently varied at different levels (Ebraheim NA.et al.1996). In 2002, James J.Y.et al, studied the treatment of upper, middle and lower thoracic and lumbar spine injuries with transpedicular instrumentation and concluded that pedicle screw fixation of thoracic and lumbar spinal injuries is a reliable and safe method of posterior spinal stabilization (James JY. et al.2002).

In the year 2007, Yu Hailong et al studied the computer analysis of the safety of using three different pedicular screw insertion points in the lumbar spine in the Chinese population and reported that pedicle breakthrough occurs more easily in the medial and lateral walls if the entry point is far away from the axial line of the pedicle (Hailong Y.et al.2007).

2.5.3. Screw design:

The screw can be divided into 4 basic components: head, core, thread and tip. Alterations to any of these components will change the mechanical properties of the screw, as well as its interface with bone. Screws are commonly utilized in surgical procedures involving bone, and different screw attributes and designs have been well studies and optimized to allow for the best possible fixation strength to be achieved. The head of spinal pedicle screws is often referred to as a 'tulip'. Generally a screw head functions to resist the translational force created by the rotation of the screw once the screw is fully tightened with its head abutting against the surface into which the screw is placed. However, for modern pedicle screws, the head must play two roles: resist the translation force and act as the anchor point for fixation to a rod which connects the other screws along the screw-rod construct. This mechanism has been well studied and well designed and is very rarely the point of failure. As such the screw design modifications suggested in this thesis do not attempt to alter the tulip designs.

A pedicle screw consists of a head, neck and body [Image.2.1 in appendix1]. It has a major (outer) and minor (inner) diameter (Cho et al.2010). The outside diameter of the screw ranges from 4.5 to 7mm. Screw length ranges from 30 to 55mm and is measured from the tip to the base of the screw head (Andrea et al., 2005). The main function of the screw head is to provide the anchoring site to a rod or plate which connects the other screws along the screw-rod construct (Parham.2013). The inner diameter of the screw is the determining factor for resistance of screw to bending or fracture.

The strength of the screws increases exponentially as the inner diameter is increased (Petersilge et al. 1996).The thread depth, pitch and type are three most important design element of the screw. Thread depth is the difference between the outer and inner diameters (Parham, 2013). Larger thread depth result in better bone securing and stronger screw pull-out in soft cancellous bone but reduces fracture strength of the screw (Parham, 2013). Thread pitch is the distance between two adjacent threads or may be defined as the number of threads per inch (Parham, 2013). Thread type refer to the shape of the thread, of which there are many options, the design utilized most often in surgical implants include "V" shaped threads, buttress shaped thread and square shaped threads (Parham, 2013).

2.5.4. Techniques for screw insertion:

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

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

2.6.Pathology:

2.6.1.Complications of screw fixation:

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

The complications reported are due to misplaced screw or coupling failure, nerve root injuries, fracture of the screw and non-union or screw loosening. The rate of screw misplacement ranges from 0-25% (Barr et al.1997; Liljenqvist et al.1997) in patients with scoliosis and about 4.2% in patients with degenerative diseases (Blumenthal and Gill.1993).Coupling failures of the device occur due to inadequate nut tightening, resulting in disengagement of the screw from the clamp elements of the rod (Pihlajamäki et al.1997). Nerve-root and/or cauda equine injuries are associated with pain and sensory deficit. Screws that are placed medially and inferiorly are the ones that place the nerve at the risk of injury. showed that 36% screws had fatigue failure. In other studies, the frequency of screw breakage ranged from 0.5-11.2% of the inserted screws (Pihlajamäki et al. (1997).

(Lonstein et al.1999) associated screw breakage to three factors: design of the screw, presence of pseudo arthrosis and their use in burst fracture. Loosening of the pedicle screw has been commonly seen in patients with low bone mineral density (BMD) and osteoporosis and it indicates micro movement at the region of the screw and rod (Pihlajamäki et al.1997). Loosening of the pedicle screws was most commonly seen in patients with multilevel instrumentation and in patients with screw fixation in the sacral vertebra (Pihlajamäki et al.1997). Other complications include bending of screws, infection and injury to the blood vessels.

2.6.2 Indications of pedicle screws in spinal disorders:

The indications for the application of a pedicle screw system differ from one spinal pathology to another (Boos and Webb.1997).

According to Chandan. N the pedicle screw instrumentation is broadly used in the following conditions:

1 .Stabilization following a decompressive laminectomy in Spondylolisthesis (degenerative).

2 .Stabilization of spine following trauma which led to unstable burst fractures.

3 .Primary or metastatic tumors of the spine needing aggressive resection or decompression which will be needing stabilization.

4 .In treating Isthmic spondylolisthesis which require reduction and stabilization .

5 .Fusion in symptomatic pseudarthrosis

6 .Deformity corrections as in scoliosis

7 .Certain disease conditions causing nerve root irritation due to rotational instability.

2.6.3. Osteomyelitis:

It is a disease of childhood and adolescence occurring in the undernourished. Lumbar and lower thoracic vertebrae are known to be affected more frequently by osteomyelitis. In the year1979, Goldman AB et al noted that the incidence of osteomyelitis of spine is 2-4 % (Goldman AB et al.1979). This type of vertebral osteomyelitis is more commonly seen in adults between the age group of 20 to 60 years(Ratcliffe JF.1982). The infection of spine is typified by pyogenic and tuberculous osteomyelitis of the spine and the deformity may be either scoliosis or kyphosis both giving rise to pain (Melzack W.1984).

2.6.4 Spondylosis:

It refers to defect in the pars interarticularis and is more commonly seen in the fifth lumbar vertebra, but may occur at other lumbar levels (Eisenstein S. 1978). It is more commonly observed in whites (Roche MB.et.al.1952). The most frequent occurrence is reported in the Eskimo skeletons.

2.6.5.Osteoporosis:

It is a most common degenerative condition affecting the ageing lumbar spine(Nicholas JA.et.al.1963).It involves a loss of bone substance and may occur as a consequence of disease (Dent and Watson.1966).In the year 1947, Sarpyener described congenital stenosis of vertebral canal associated with spina bifida as well as congenital stenosis without any other developmental anomalies (Sarpyener MA.1947).The narrowing of bony vertebral canal as a cause of compression of spinal cord or of cauda equina may be the result of bone disease, such as chondrodystrophia foetalis or any developmental anomaly(Vogi and Osborne.1949) and (Spillane.1952).

In the year 1954, Verbiest reported some patients who developed signs of compression of caudal nerve roots due to abnormal developmental narrowness of bony vertebral canal (Verbiest H. A.1954). In the year 1955, Simril N. A. et al felt that abnormal widening of one or more interpedicular spaces is strongly suggestive of an intraspinal mass even though the absolute measurements were within the normal limits, (Simril N.A.et al.1955). In the year 1962, Epstein described based on plain radiographic study, that anteroposteior diameter less than 18 mm is suggestive of stenosis of the canal (Epstein JA.et.al.1962).

In the year 1966, Hinek et al did the morphometrical study of interpedicular distances in children and adult, based on roentgenograms of lumbar region of white American subjects and reported a steady increase in interpedicular distances from L1 to L5 (Hinck VC.et.al.1966). According to Taveras and Wood (1976) said, “a change in the normal oval contour of the pedicles or in the interpedicular distances, as shown in the frontal film may indicate the presence of an expanding lesion within the vertebral canal”. In the year 1977, Eisenstein measured the anteroposterior and transverse diameters of the canal and body with Vernier calipers on adult skeletons belonging to South African Sotho Nigroids and White Caucasoids. In the year 1982, Amonoo Koufi H.S. et al had compared the Nigerian and South African vertebral canals on the basis of radiographic observations. They reported that there is a steady increase of interpedicular distance from first to fifth lumbar vertebrae (Amonoo Koufi H.S.et al. 1982).The interpedicular distance may narrow progressively from first to fifth lumbar vertebrae in achondroplasia

2.6.6.Tuberculosis:

Tuberculosis of the spine i.e. Pott's disease forms 50 - 60% of total incidence of skeletal tuberculosis and is most commonly seen in thoracic spine of children and thoracolumbar spine of adults. About 2% of patients with spinal tuberculosis have an absence of pedicle (Bell D and Cockshott WP.1971)**.**

2.6.7. Spinal stenosis syndrome:

It consists of low back pain, usually in an adult approaching middle age, accompanied by claudication in the lower limbs. Classically, the patient complains of pain, weakness and numbness in the lower limbs on walking and relief cannot be achieved merely by standing and resting; the patient finds it necessary to undo his lumbar lordosis by bending or crouching. There may be objective neurological signs such as loss of tendon jerk or changes in sensibility. These features are even more suggestive if the peripheral circulation is normal.

Narrowing of the spinal canal may be developmental, or it may be the consequence of degenerative changes, injury or disease or after spinal operations. Lumbar canal stenosis can be present at birth as a congenital malformation in disorders like achondroplasia (Goldman AB.et.al.1979).

2.6.8.Scoliosis:

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

2.6.9. Spinal fracture:

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

2.6.10 Tumors:

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

2.6.11 Spondylolisthesis:

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

2.7 MDCT:

Computed tomography (CT) is a non-invasive imaging modality which has been used extensively in human to perform in vivo morphometric analysis of the spine (Olsewski JM,et al.1990 and Krag MH,et al.1988) and describe the normal variation in size and shape of the human vertebrae at various spinal levels (Abuzayed et al.2010; Wolf et al.2001).Measurement accuracy represents the core of morphometric studies. Therefore, the factors affecting the accuracy should be addressed. The accuracy of the measurements based on CT images is affected by scanning parameters (Way TW, et al. 2008) and viewer control setting (Beers GJ,et al.1985).

2.7.1.CT lumbar technique:

patient position : supine position and both arms elevated
tube voltage120 (140) kVp
tube current :as suggested by the automated current adjustment mode for (128slices) 100 mAs.
Scout :diaphragm to hip
scan extent: might vary with regard to the clinical question, should include thoracic 12 and Sacrum 1
scan direction: craniocaudal
scan geometry: field of view (FOV): 120-200 mm (should be adjusted to increase in-plane resolution)
slice thickness: ≤0.625 mm, interval: ≤0.5 mm. Reconstruction algorithm: bone, soft tissue
contrast injection considerations:
usually non-contrast, optionally with contrast. Contrast volume: 70-100ml (0.1 mL/kg) at 2-3 mL/s
scan delay: 65-80 seconds.
multiplanar reconstructions/reformats
sagittal images: sagittal aligned through the center of the vertebral bodies and spinal processes
coronal images: coronal aligned to the transverse processes
axial images: perpendicular to the lumbar spine with a separate reconstruction of several blocks
curved reformats might be helpful
slice thickness: bone ≤2 mm, soft tissue ≤3 mm, overlap 50%
https://radiopaedia.org/articles/ct-lumbar-spine-protocol-1?lang=us

Chapter Three

Materials and Methods

Chapter Three

Materials and Methods

3.1 Materials:

3.1.1.Study design:

The study was an observational, prospective, descriptive and comparative morphometric study based on a review of CT images by measuring the dimension of the lumbar spine. The mean value and variance of each dimension were taken and data distribution was found. The participants underwent CT lumbar spine or even abdominal CT scans for various reasons, including trauma, chronic backache, suspected tumors and spondylolisthesis, at governmental hospitals Jazan region.

3.1.2 Participants:

Participants older than seventy-five years of age or younger than nineteen years. The comparative analyzed two hundred Saudi national participants, Jazan region population were enrolled in the study(hundred males and hundred females)

3.1.3. Study duration:

The study was carried out during the period of March 2016 to July 2020.

3.1.4. Study population:

This study was conducted on Jazan population, Saudi Arabia.

3.1.5 Study area:

The study was conducted at Jazan region, the region is one of the administrative regions of the Kingdom of Saudi Arabia, located in the southwest of the Kingdom and overlooks the Red sea. It contains the port of Jizan, the third port of the Kingdom on the Red Sea coast in terms of capacity. The capital of the administrative region is the city of Jizan, and the region includes a number of governorates and its administrative centers distributed in its eastern departments in the mountainous and western coastal highlands, as it is distinguished by its environmental and climatic diversity. The region composed of fourteen provinces. Total population 1,603,659million (census 2017), they are living in Geographical area of approximately 16000 km^2 . (Table 3.1).

Table 3.1: Information about the study region.

Capital	Jazan
Area	16000 Sq. Km (0,6% of KSA total surface area)
Population Census 2017	1,603,659 million
Population density	117.97/km2
(HOT & Humid)	
Average temp.	25°C -35°C
Average relative humidity	60 - 90%

3.1.6. Study sample: Data collection tools:

The study sample analyzed more than two thousand pedicles, one thousand morphometrical normal lumbar vertebral body and canal from (L1to L5) of two hundred patients (hundred male and hundred female). The age, race and sex of the study sample were known.

Data were collected from MDCT units of governmental hospitals after permission from head of the medical imaging departments in the region in a form of lumbar CT or abdominal CT images using USB flash or CD-ROM. Data were then analyzed however some cases were independently measured and analyzed in the PACS rooms in some hospitals in the region, by radiologists to rule out scans that showed symptomatic i.e. the medical history of the patients was reviewed to exclude those with previous surgery of the lumbar spine, growth disorders, systemic bone disease, chronic renal disease, congenital deformity, infection, trauma, tuberculosis or tumors (primary or secondary) of the spine because these conditions can alter the size or composition of the vertebral pedicle.

3.1.7. Samples analyzer:

The PACS DICOM viewer [RadiAnt DICOM Viewer 4.6.9 (64-bit) reviewed April 14, 2019] had used as a software program to measure and analyze collected CT scans lumbar samples, this viewer was selected because all the necessary tools close at hand and it easily provides the following basic tools for the manipulation and measurement of images:

- Fluid zooming and panning.
- Brightness and contrast adjustments, negative mode.
- Preset window settings for Computed Tomography (lung, bone, soft tissue)
- Ability to rotate (90, 180 degrees) or flip (horizontal and vertical) images Segment length.
- Mean, minimum and maximum parameter values (e.g. density in Hounsfield Units in Computed Tomography) within circle/ellipse and its area.
- Angle value (normal and Cobb angle).
- Export DICOM files to images and movies: RadiAnt DICOM Viewer can export DICOM files to JPEG (compressed) or BMP (uncompressed bitmap) images and WMV (Windows Media Video) movies.

- Multiplanar reconstructions provider: The MPR tool provided within RadiAnt DICOM Viewer can be used to reconstruct images in orthogonal planes (coronal, sagittal, axial or oblique)
- Compare different series or studies
- 3D volume rendering lets us visualize large volumes of data generated by modern CT/MR scanners in three-dimensional space.
- Supports multiple DICOM file types i.e. has capability to open and display studies obtained from different digital imaging modalities such as; CT, MRI, (CR, DX), Mammography (MG), Positron Emission Tomography PET-CT (PT) and Ultrasonography (US).

3.1.8 Exclusion and Inclusion criteria:

Many patients CT scanner images met the exclusion criteria, due to pathological condition such as: fractures, metastasis, retrolisthesis, previous spinal surgery, and other pathologies were excluded from the study.

3.2 Methods:

3.2.1.Test of repeatability:

To measure the intra observer error, the first, third and fifth lumbar vertebrae of 8 specimens (4 females and 4 males) were measured, and were repeated on different occasions. The Lin's concordance correlation coefficient of repeatability was used to assess the intra observer error and the value obtained is shown in (Table 3.2).

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

Parameters	PDW	PDAL	PDH	TPA	SPA	VBW	VBD	VBH	SCW	SCD
Pc values	0.98946	0.98564	0.97778	0.99794	0.99659	0.88855	0.99884	0.97994	0.99883	0.98632

Pc values range from 0 to 1 and a value close to 1 indicate a high degree of repeatability. Except for vertebral body width(VBW) (0.88855), all Pc values obtained were greater than 0.9, which shows that the correlation between the repeated measurements was high and thus, the intra observer error was minimal.

3.2.2. Statistical data analysis:

CT images are analyzed and interpreted by senior radiologists; All data were collected first into available software spreadsheet used for statistical analysis (Microsoft Excel 2010, Microsoft Deutschland GmbH, Unterschleissheim, Germany) and data validation and cleaning was conducted. Data then exported to Statistical Package for Social Science (SPSS version 19,SPSS Inc., Chicago,USA).All data collected were presented as mean±SD values by using of the (SPSS) For descriptive analysis, the categorical variables of gender and age were described as frequencies and percentages.

Student’s T-test was used to compare the means Mean, SD of pedicle width, pedicle height, transverse angle, sagittal angle, chord length, the inter-pedicular distance,spinal canal depth, vertebral body width,height and width between: (right and left) sides, (males and females) .

Paired-samples T- teste was used to compare the means of the (right and left) sides of the pedicle width and pedicle height, whereas Independent-samples T teste used to analyze for differences between mean of the (males and females).The mean values ,SD , range, maximum and minimum of all variables of lumbar vertebrae (L1 - L5) were provided by using descriptive statistical analysis.

Differences in means with the threshold of p-value<0.01&0.05 were considered statistically significant.

Graph Pad prism 8 (Version 8.4,3(686) GraphPad Software, USA) was used in a form of Bar charts to provide the results of all variables regarding differences in means and SD of (right and left) sides of the pedicle width and height, (males and females) and in comparison the mean values of the lumbar vertebrae(L1-L5).Excel software was used in a form of linear graphs to compare the results of the study with different populations.

3.2.3. Ethical issues :

There was official permission to Jazan governmental hospitals to take the data. No patient data were published also the data was kept in personal computer with personal password.

3.2.4.MDCT contributed in the evaluation:

Lumbar vertebral [L1-L5]cases used in the study were collected from CT scanners that belong to the General Directorate of Health Affairs Jazan region (KSA) governmental hospitals, the table below show more information about them, including their governmental Health institution, manufacturers, CT scanner Model, Slices acquisitions per rotation(number of slices) and country of manufacturer, the mentioned scanners are with advance clinical application software, higher acquisition of slices and most of them were installed or replaced old CT scanners and most of hospitals indicating PACS system.(Table 3.3)

Table 3.3: MDCT scanners which were used as evaluation method in the region.

Health institution	Manufacturer	Scanner Model	Slices acquisitions per rotation	Country of Manufacturer
KFCH	GE	Optima CT 540	128	USA
KFCH	GE	Optima CT 540	128	USA
KFCH	Siemens	Somatom definition As	64	Germany
Sabia G. hospital	Toshiba	Prime aquilion	16	Japan
Abu Arish. hospital	GE	Optima CT540	16	USA
Samtah G. hospital	Toshiba	Aquilion prime	16	Japan
Eldarb G. hospital	Siemens	Somatom emotion	6	Germany
Prince M. bin Naser. H	GE	Revolution	128	USA
Prince M. bin Naser. H	Siemens	Somatom definition As	16	Germany
Baish G. hospital	GE	Optima CT 540	16	USA
Ahad almsaraha	GE	Optima CT 540	16	USA

3.2.5.Used CT protocols:

lumbar vertebral examination that contributed in the study were performed on CT scanner mentioned, with participants positioned supine in the gantry, most of them were placed the arms over the head other participants that couldn’t kept the arms crossed high over the chest, (AP) and lateral digital radiographs were used for localization. The CT examinations of the lumbar spine Scan started for most cases with the lowest scans first. The maximum gantry angle was used, parallel to each disc space and covering the whole intervertebral foramen.

All Lumbar spine examinations were performed with: AP and lateral radiographs

3.2.5.1.Scan projection CT lumbar spine:

Length, 30–40 cm, for lumbar spine.

100kV(16-64-128slices)-120Kv(6slices)

10 mAs(6slices) -– (16-64-128slices) 100 mAs.

3.2.5.2.Axial scans (helical) lumbar spine:

helical slice thickness: of 2.5mmto 5 mm

Table pitch: 0.75: 1.5

Reconstruction Algorithm: standard *or* high resolution.

speed (mm/rot) of 3.75

(0-10) degree gantry angulation.

Kilovoltage 100-120 kV for (16-64-128slices)-120KV for (6slices)

mAs per slice 160–320 mAs for (6 slices) --320–380 mAs for (16-64-128slices)

Scan field of view 35–48 cm

Display field of view: supine dimension16- 18 cm

Window width: 1000–3000 HU (bone window)

Window level: 200-400 HU (bone window)

Post process into 3 mm increments

Data that sets were transferred to a workstation for reconstruction. For the MPRs, images with a slice thickness of 2mm and an increment of 2mm were reconstructed using a *bone window* setting. Slices were taken parallel to the upper margin of each vertebral body.

The slice at the middle of the pedicle was selected to measure pedicle width, pedicle axis length, transverse pedicle angle, interpedicular distance, vertebral body width, vertebral body depth, spinal canal width and spinal canal depth. Pedicle height and vertebral body height were measured on 3D reconstructed algorithm whereas sagittal pedicle angle was measured using sagittal reformatted images passing through the midpoint of the pedicle in MPR reconstructed algorithm.

All patients in abdominal CT were positioned head first supine in the gantry, with the arms elevated above the head, if possible, a continuous scan was performed with a thickness of 5mm to 10 mm with the same interval from the diaphragmatic dome to the symphysis pubis as a standard protocol for image acquirement of the abdomen. Subsequently, a reconstruction of the field of view focused on the lumbar spine from T12/L1 to L5/S1 was made with a thickness of 2.5mm to 5 mm using the "Bone Plus" algorithm as below the criterion:

3.2.5.3.Scan projection Abdominal CT:

Length, 30–40 cm, for lumbar spine.

100kV(16-64-128slices)-120Kv(6slices)

100 mAs (16-64-128slices)-10 mAs(6slices).

3.2.5.4.Axial scans (helical) Abdominal CT:

helical slice thickness: of 5mm to 10 mm (reconstructed 5mm) 3–5 mm to specific organs, the thinnest value possible to improve spatial resolution, with the maximum mA value possible to minimize noise

Table pitch: 1–2

if the distance to be covered by the scan is 25 cm and the patient can hold their breath for 25 seconds the table speed is 10 mm/second. Thus, the slice thickness could be 10 mm with a pitch of 1 or, for better spatial resolution, a 5 mm slice with a pitch of 2, assuming a 1 second scan time. (Suzanne Henwood,1999)

Reconstruction Algorithm: standard

Scan time ranges between 0.75 and 2 seconds per rotation

speed (mm/rot) of 3.75

0-degree gantry angulation.

Kilovoltage 100-120 kv for (16-64-128slices)-120KV for (6slices)

mAs per slice 160–320 mAs for (6 slices) --320–380 mAs for (16-64-128slices)

Scan field of view 40–50 cm

Display field of view: supine dimension25–30 cm

Window width: 1000–3000 HU (bone window)

Window level: 200-400 HU (bone window)

The collected images by the USB flash and CD player were stored in the computer and measured using the mentioned DICOM viewer that allowed enhancement, magnification, and rotation and had a measuring tool. To measure the distance between two points, a cursor is positioned using the mouse over an initial reference point, the cursor is then moved to the second reference point by dragging the mouse. When the mouse button is released, the distance between the two points is displayed in the information box, reflecting a measurement from the CT image and the actual size of the lumbar spinal measured portion in the plane of the slice. Each measurement was obtained twice by the same observer and was recorded in a database.

3.2.6. Variables parameters measurements:

For each lumbar vertebral level (L1-L5),nine parameters were measured from the transverse (axial) MPR images including [pedicle width(Rt and Lt),inter pedicular distant, transverse pedicle angle(chord angle), chord length(Screw path length),vertebral body width, vertebral body depth, spinal canal width, spinal canal depth],whereas only the[sagittal pedicle angle] parameter from the sagittal MPR images and three parameters were measured from the 3D reconstruction images[Pedicle height (Rt and Lt) and Vertebral body height].Lengths were measured in millimeters whereas angles in degrees.

The following lumbar vertebral parameters were taken with the help of DICOM viewer.

3.2.6.1.Pedicles parameters:

3.2.6.1.1.Pedicle width (PDW):

Was measured using the superior approach in the transverse plane, 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, also known as (isthmus), transverse or axial width. As proposed by (Zindrick et al.1987), the pedicle axis was defined as a line perpendicular to and bisecting the narrowest diameter of the pedicle. Both right and left pedicles width were measured.(Figure.3.1).

3.2.6.1.2.Pedicle Height (PDH):

Was measured from the 3D reconstruction images using the lateral approach in the sagittal plane. This is the maximum diameter of the pedicle It is the vertical distance between superior and inferior border of pedicle at its midpoint isthmus. Both right and left pedicles height were measured. (Figure.3.2 and Figure.3.3)

3.2.6.1.3.Interpedicular distance (IPD)or spinal canal width(SCW)

Using the axial plane, the maximum distance between the medial surfaces of the right and left isthmuses of the pedicles of the vertebra was measured and *also recorded as the transverse diameter of the vertebral canal* as *described* and measured by (Jones, Thomson,.1968) (Figure.3.4).

3.2.6.1.4.Pedicle axis length (PDAL):

The pedicle axis length known as; (Chord length) or (screw path length) was measured 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 on the axial plane, as described or reported by (Olszewski et al. 1990). (Figure.3.5)

3.2.6.1.5.Transverse pedicle angle (TPA):

Transverse pedicle angle or pedicle axis angle measured between a line passing through the pedicle axis and a line parallel to the vertebral midline in the transverse plane, It's the angle between (PAL) and the vertebral sagittal midline. (Berry et al.,1987) described it as the angle between the mid-sagittal plane of vertebral body and the plane bisecting the pedicle. (Figure. 3.6).

3.2.6.1.6.Sagittal pedicle angle (SPA):

The sagittal pedicle angle was measured between a line passing through the pedicle axis and superior vertebral body border in the sagittal plane described by (Dhaval and Bhuiyan ,2014), measured from the sagittal MPR images. (Figure.3.7)

3.2.6.2.Vertebral body parameters:

3.2.6.2.1.Vertebral body width (VBW):

Was measured using the superior approach in the transverse plane, vertebral body width measurements, include the distance between the lateral borders of the vertebral body in the transverse plane of the cranial endplate, i.e. it’s the widest distance between the lateral borders of the vertebral body. The Transverse diameter of the vertebral body, measured from the external cortex of the right border to the external cortex of the left border**.** (Urrutia et al.,2009). (Figure.3.8)

3.2.6.2.2.Vertebral body depth (VBD):

Vertebral body depth was measured using the superior approach in the axial plane, It's the distance between the dorsal and ventral borders of the vertebral body described by (Dhaval and Bhuiyan,2014). Anteroposterior diameter of the vertebral body or the length measured on the midline of the vertebral body from the external cortex of the anterior border to the external cortex of the posterior border (Urrutia et al.2009). (Figure.3.8)

3.2.6.2.3.Vertebral body height (VBH):

Vertebral body height was measured from the 3D reconstruction images using the lateral approach in the sagittal plane, It's the vertical distance between the superior and inferior borders of the vertebral body, in the midline. Described by (Dhaval and Bhuiyan,2014). (Figure.3.9)

3.2.6. 3.Spinal canal parameters:

3.2.6. 3.1 Spinal canal width (SCW):

(interpedicular diameter) using the axial plane, the maximum distance between the medial surfaces of the right and left isthmuses of the vertebral pedicles**,** was measured and *also recorded as the transverse diameter of the vertebral foramen width* as *described* and measured by (Jones, Thomson,.1968). Transverse diameter of the spinal canal. The distance that exists between the external cortex of the medial border of both pedicles according to (Urrutia et al.2009). (Figure.3.10)

3.2.6.3.2 Spinal canal depth (SCD):

Vertebral foramen depth (anteroposterior diameter) was defined as the distance from the dorsal border of the vertebral body to the laminae at the midline (upper aspect of the root of the spine) (Jones, Thomson,.1968), whereas (Urrutia et al.,2009) reported spinal canal depth as the AP diameter of the spinal canal or the length that exists between the external cortex of the posterior border of the vertebral body to the external cortex of the union of the vertebral lamina. (Figure.3.11)

All of the collected data results from the measurements of pedicles parameters, vertebral body parameters and spinal canal parameters were analyzed and compared with previous studies.

3.2.7. Pedicle index:

The pedicle index for the study population, was measured and analyzed, pedicle index was described and reported in many previous studies as; the ratio of the pedicle width to the pedicle height at each lumbar vertebral level, that is to say

Pedicle index = Pedicle width (PDW) /Pedicle height (PDH)

3.2.8. The (CT ratio):

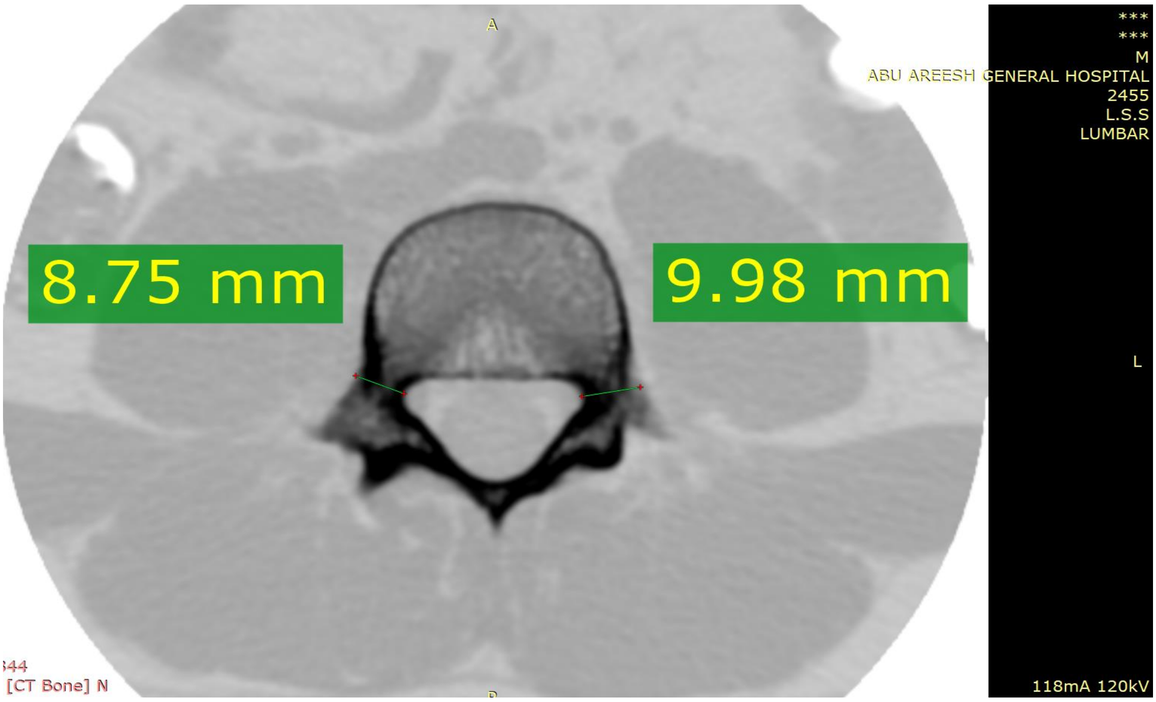
The (CT ratio) or pedicle ratio, which take the ratio of pedicle width (PDW) to the vertebral body width (VBW) was measured at each lumbar level using the superior approach in the axial plane according to (Ki Ser Kang.2010) method.

Pedicle ratio (CT ratio) = Pedicle width (PDW)/Vertebral body width (VBW)

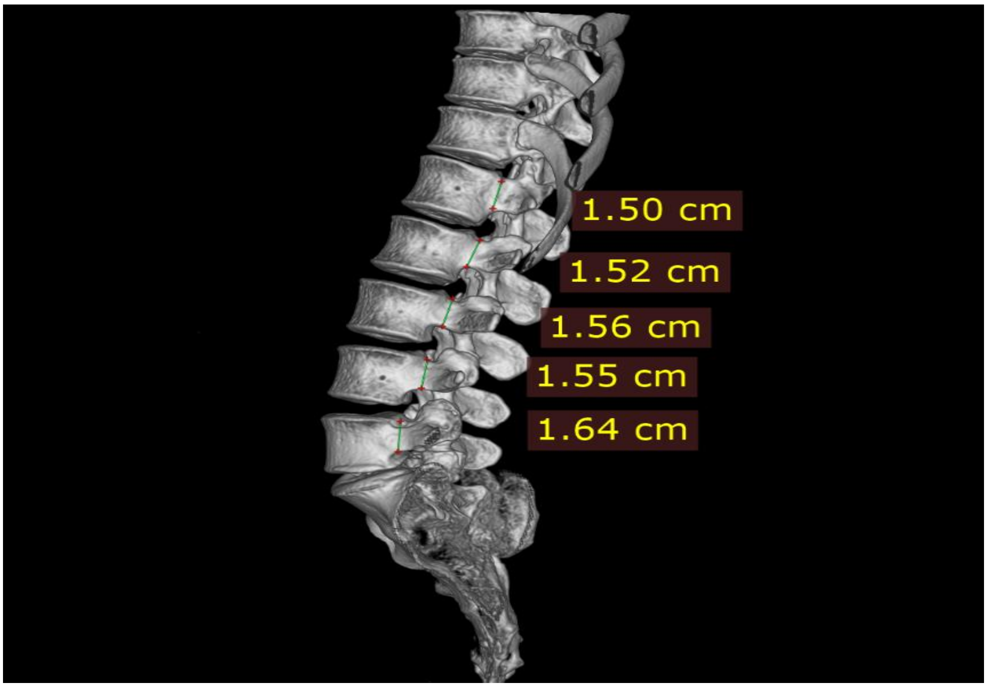
3.2.9. Spinal canal ratio:

Spinal canal ratio method reported and measured by [(Jones and Thomson,1968)(Janjua and Muhammad,1989)(El-Rakhawy et al,2010)]was measured at each level of the lumbar vertebral by assessing the correlation between spinal canal width and vertebral body width, SCW/VBW ratio as follows:

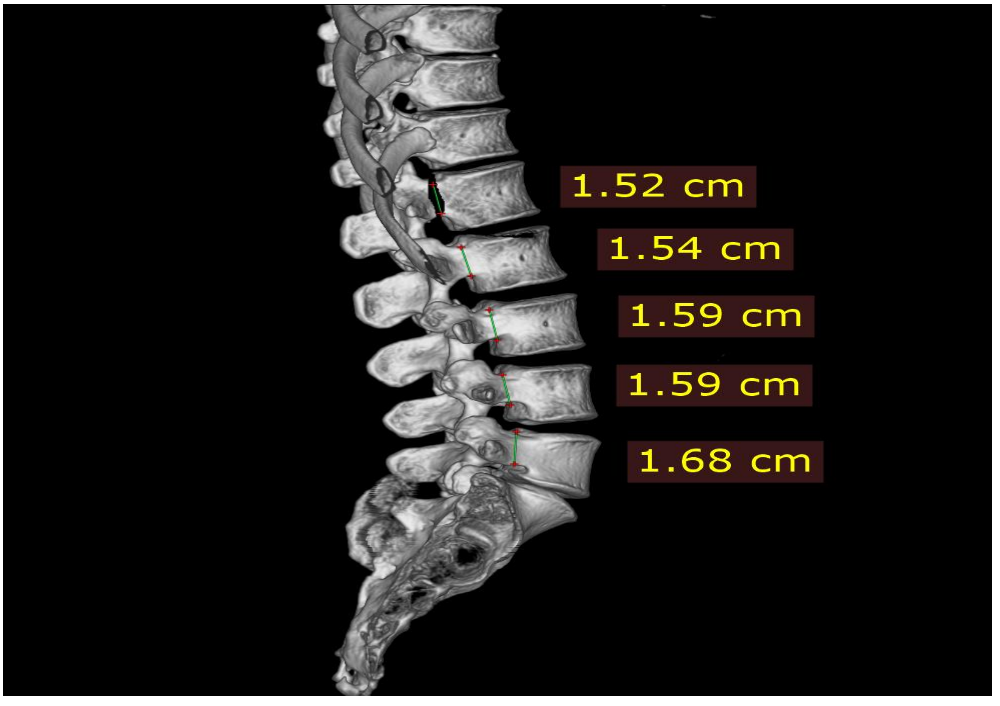
Spinal canal ratio SCW/VBW=Mean spinal canal width/Mean vertebral body width



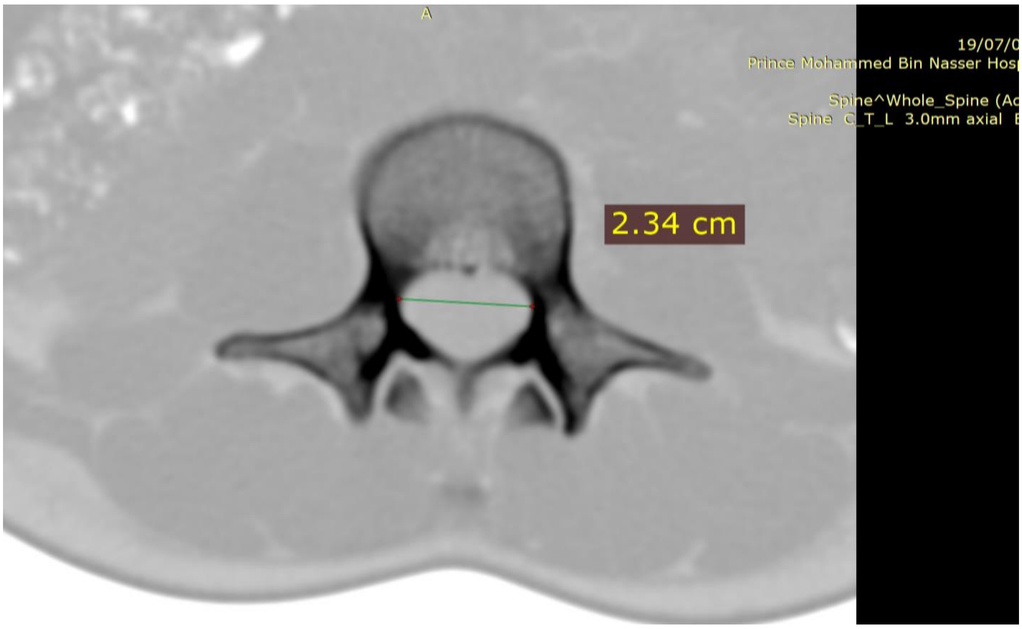
(Figure.3.1): Demonstrated measurements of the right and left pedicles of the Pedicle Width (PDW) using axial MPR images at the level of (L4).



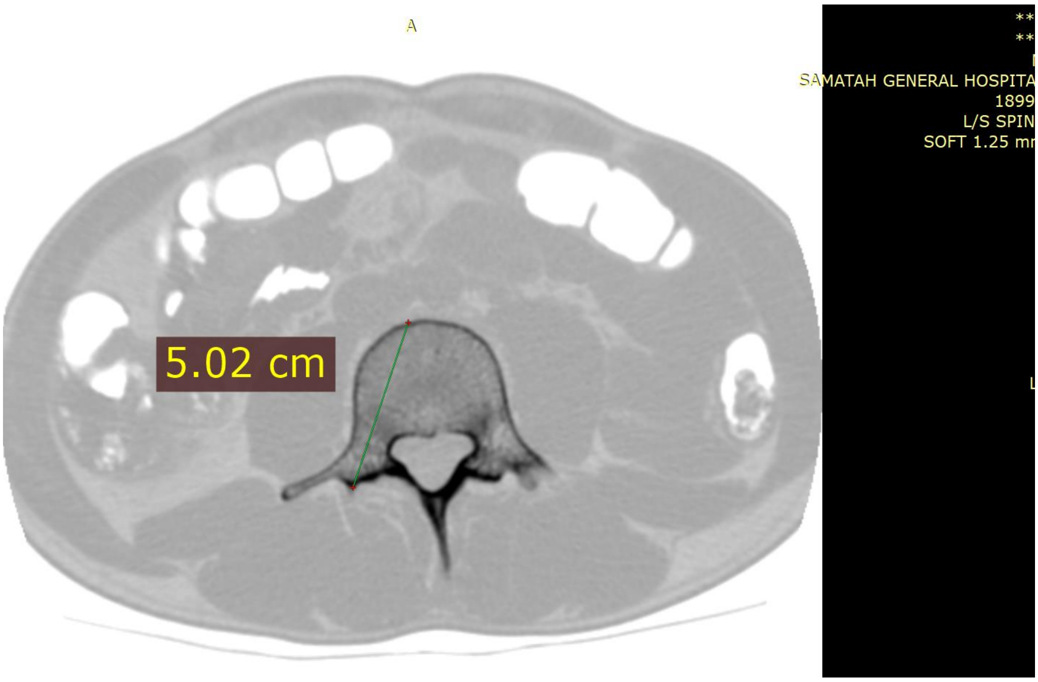
(Figure.3.2): demonstrated measurement of the *left* Pedicle Height (PDH): using 3D reconstruction images.



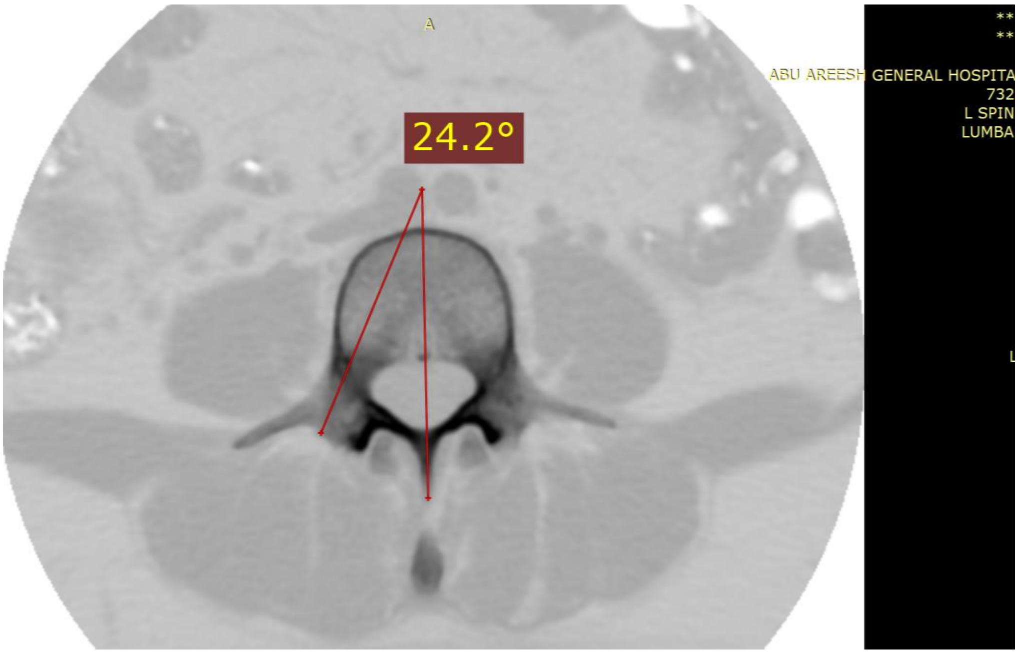
(Figure.3.3): Demonstrated measurement of the *right* Pedicle Height (PDH): using 3D reconstruction image.



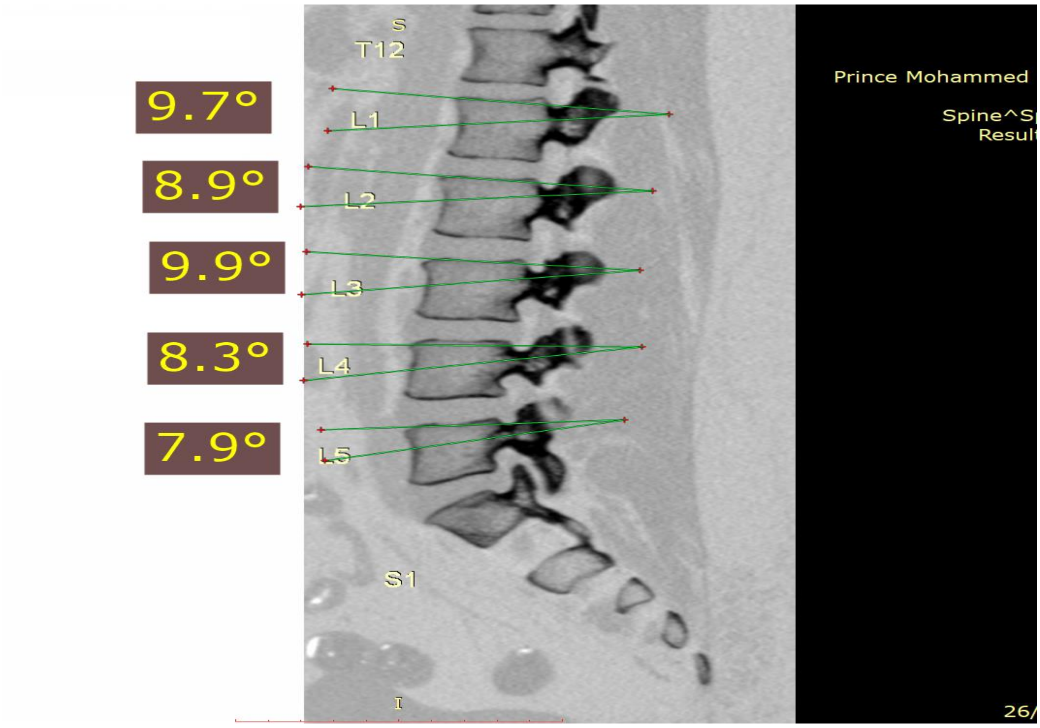
(Figure.3.4): demonstrated measurement of the (L4) Interpedicular Distance (IPD) or the transverse diameter of the vertebral canal using axial MPR images at the level of (L4).



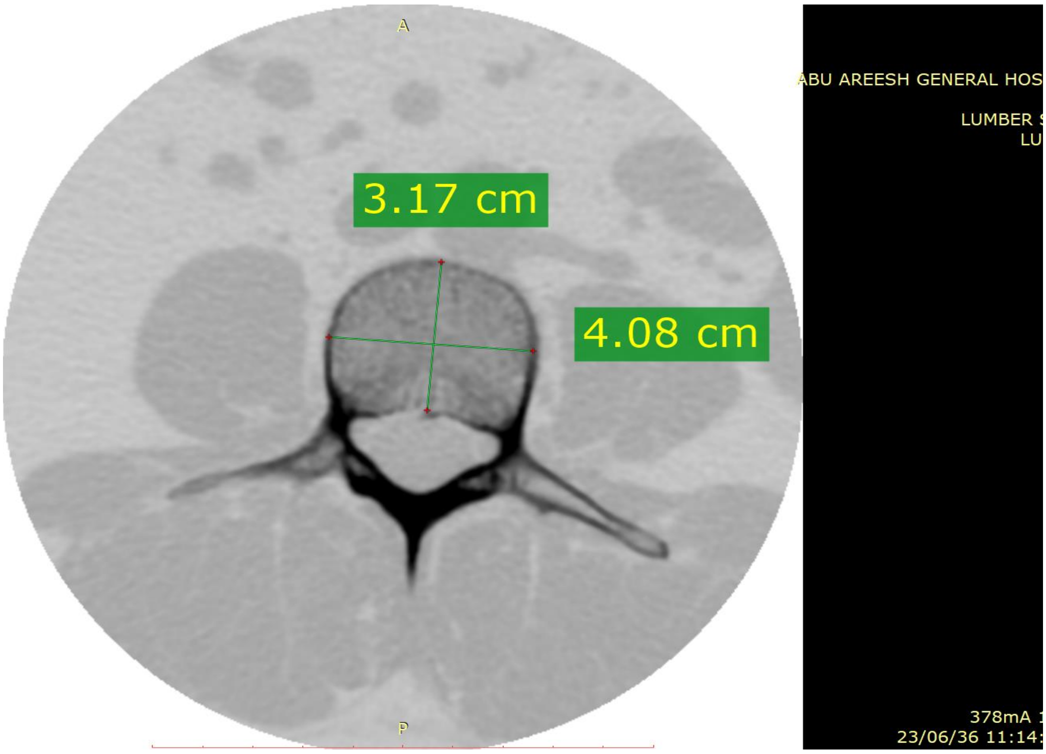
(Figure.3.5):Demonstrated measurement of the Pedicle Axis Length (PDAL) (Chord length) or (Screw Path Length) using axial MPR images at the level of (L4).



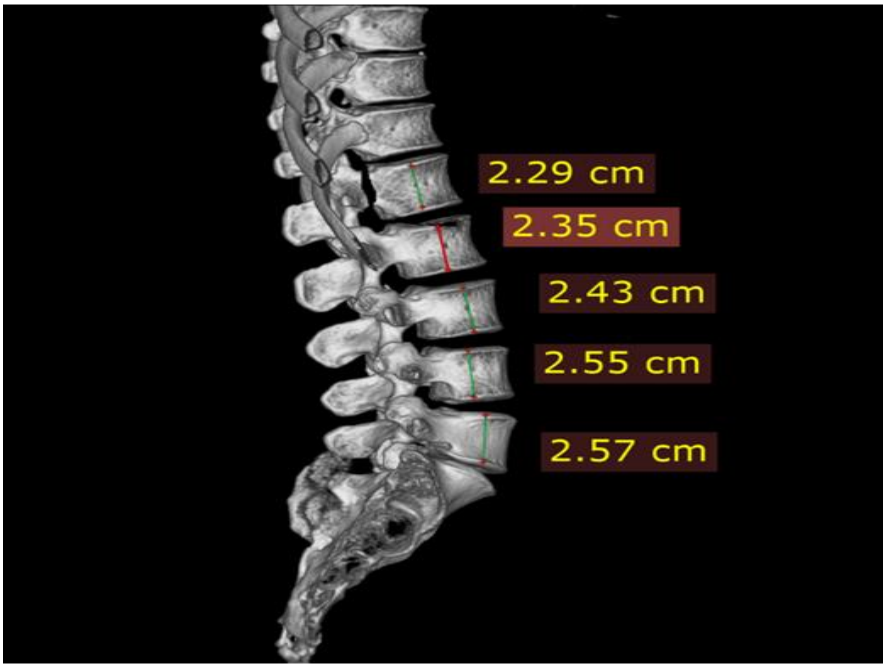
(Figure.3.6): Demonstrated measurement of the Transverse Pedicle Angle (TPA) or the Pedicle Axis Angle using axial MPR images at the level of (L4).



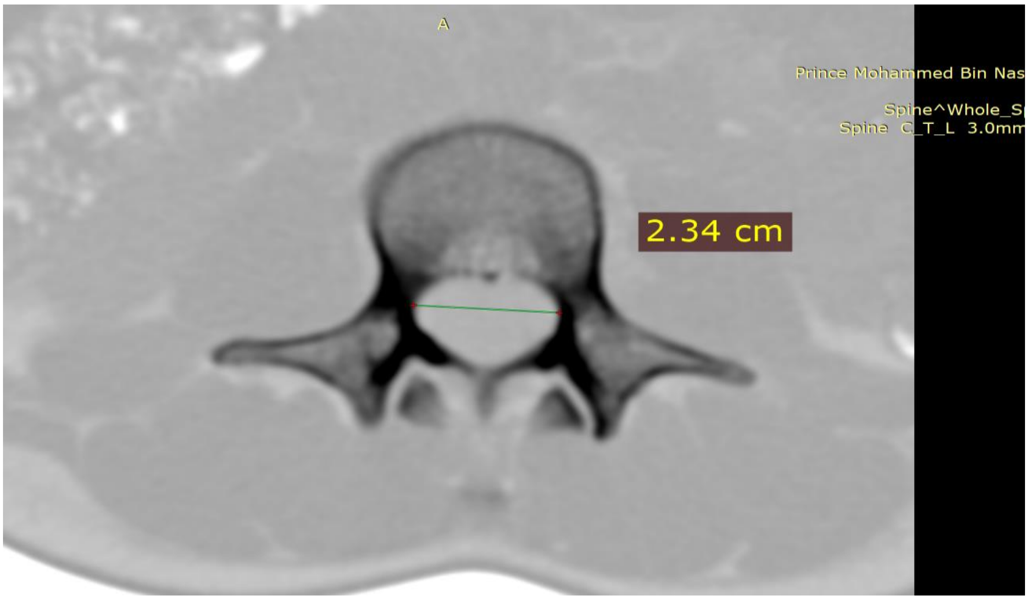
(Figure.3.7): Demonstrated measurement of the Sagittal Pedicle Angle (SPA) using the sagittal MPR images (L1 to L5) .



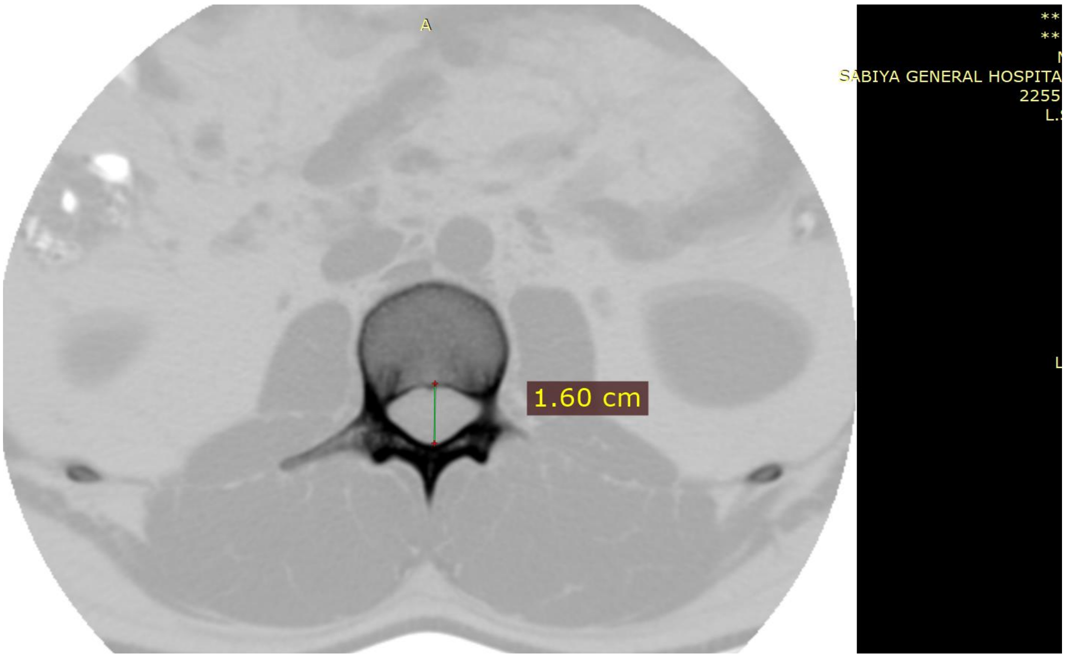
(Figure.3.8): Demonstrated measurement of both the Vertebral Body Width (VBW) and the Vertebral Body Depth (VBD) using axial MPR images at the level of (L3.



(Figure.3.9): Demonstrated measurement of the Vertebral Body Height (VBH) using the 3D reconstruction images (L1-L3).



(Figure.3.10): demonstrated measurement of the Spinal Canal Width (SCW) or (interpedicular diameter) using axial MPR images at the level of (L3) .



(Figure.3.11): Demonstrated measurement of the Spinal Canal Depth (SCD) or Vertebral foramen depth using axial MPR images at the level of (L3) .

Chapter Four

The Results

Chapter Four

The Results

4.1.Gender:

This study analyzing 200 participants, lumbar vertebral level (L1 to L5) (1000 vertebrae,2000 pedicles) ,with the mean age of the 100 male was 41.36 years(range between20–75years) and the mean age of the 100 female patients was 40.17 years (range between19–75years),So the mean age of the total participants was 40.77 years (range between nineteen and seventy-five years).

4.2.Age categories:

The participants that ranged in age from 19-75 years,were subdivided into categories and found their percentage as 9% are below 25yearrs of age, followed by 36% between 26-35yrs of age, 18.50% falling in 36-45yearrs age group, 22.00% in 46-55years age group and 14.50% above 55years. (Table.4.1) (Figure 4.1)(Figure 4.2)

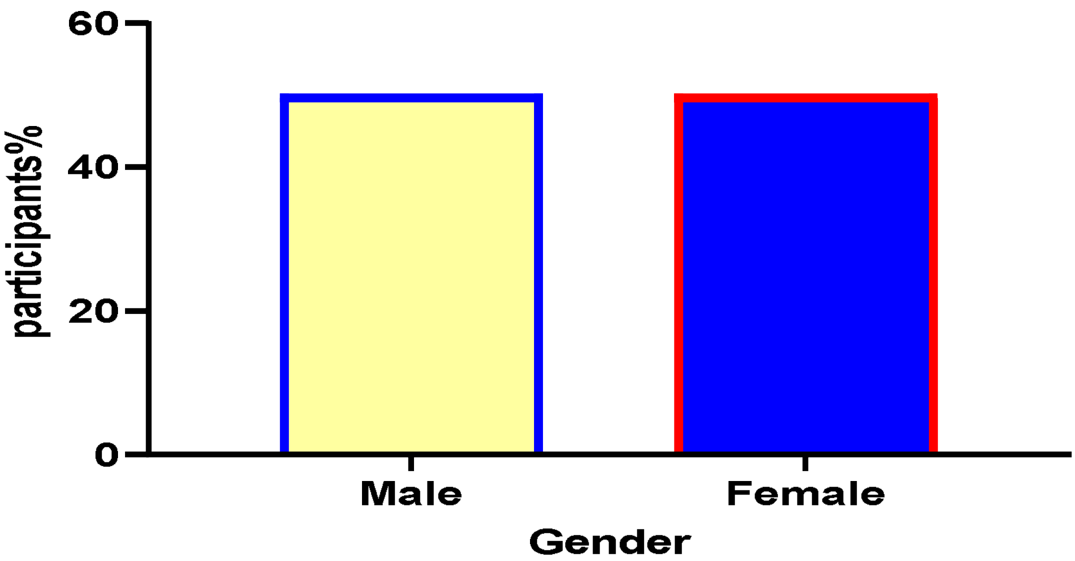


Figure 4.1: demonstrated the percentage of the gender distribution

Table 4.1: demonstrated comparison between gender percentage in relation to participants age categories mm=millimeter , SD= standard deviation.

Gender	Age categories (years)	Mean(mm)	SD	Number	Percentage
Male	< 25	23.13	1.88	8	8
	26 - 35	31.18	2.55	34	34
	36-45	40.27	3.25	22	22
	46-55	50.29	2.59	21	21
	> 55	63.27	7.56	15	15
	Total	41.36	12.90	100	100
Female	<25	23.00	2.40	10	10
	26 - 35	30.84	2.46	38	38
	36-45	41.47	2.87	15	15
	46-55	49.96	2.26	23	23
	> 55	60.29	6.64	14	14
	Total	40.17	12.40	100	100
Total	<25	23.06	2.13	18	9.00
	26 - 35	31.00	2.49	72	36.00
	36-45	40.76	3.122	37	18.50
	46-55	50.11	2.40	44	22.00
	> 55	61.83	7.17	29	14.50
	Total	40.77	12.64	200	100

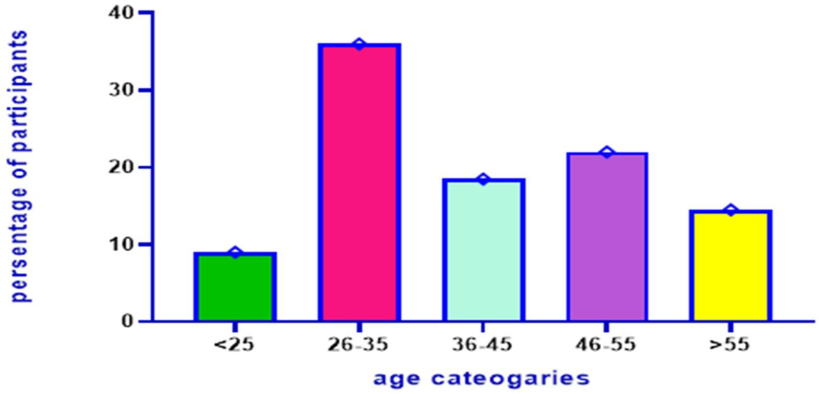


Figure 4.2: Demonstrated Bar chart of the percentage of the age categories among participants

Table 4.2: Depicted Pearson's correlation coefficient (r) of participants age with lumbar variables measurement.

Levels	Age & PDW	Age & PAL	Age & PDH	Age &TPA	Age &SPA	Age & VBW	Age & VBD	Age & VBH	Age &SCW	Age &SCD
L1	-.222**	1	1	1	.139*	.548**	.256**	-.064	.117	-.232**
L2	.168*	.682**	.431**	.614**	.159*	.274**	-.137	-.505**	.352**	-.506**
L3	.009	.438**	.389**	.635**	.204**	.162*	-.303**	-.325**	.036	-.469**
L4	.024	.266**	.259**	-.034	-.240**	-.486**	-.280**	-.620**	-.196**	-.417**
L5	.447**	.010	.264**	.186**	-.136	-.486**	-.251**	-.610**	.259**	.011

Pearson's correlation coefficient (r) * Statistical significance was considered at ***P<0.05;** all measurements are in (mm) except TPA&SPA in (degrees).First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) and Fifth Lumbar Vertebra (L5).

Table 4.3: Demonstrated comparison between right (Rt) and left (Lt) pedicle width (PDW) from (L1 to L5) among Jazan population using Paired sample t-test.

		(Rt) pedicle width(mm)	(Lt) pedicle width(mm)	t-value	Significance
L1	Mean	5.46	5.49	-.62	.54
	SD	.90	.88		
	Maximum	9.23	9.87		
	Minimum	4.00	4.00		
L2	Mean	6.01	6.01	-.14	.88
	SD	.81	.79		
	Maximum	9.06	9.06		
	Minimum	4.80	4.90		
L3	Mean	7.81	7.75	1.32	.19
	SD	.76	.80		
	Maximum	9.80	9.70		
	Minimum	5.00	5.00		
L4	Mean	9.83	9.90	-1.58	.12
	SD	1.11	1.08		
	Maximum	12.90	12.90		
	Minimum	8.00	8.00		
L5	Mean	13.00	13.01	-.29	.77
	SD	1.20	1.23		
	Maximum	15.70	15.50		
	Minimum	10.00	9.00		

First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)Third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) Fifth Lumbar Vertebra (L5) , SD=standard deviation, results are expressed in mm

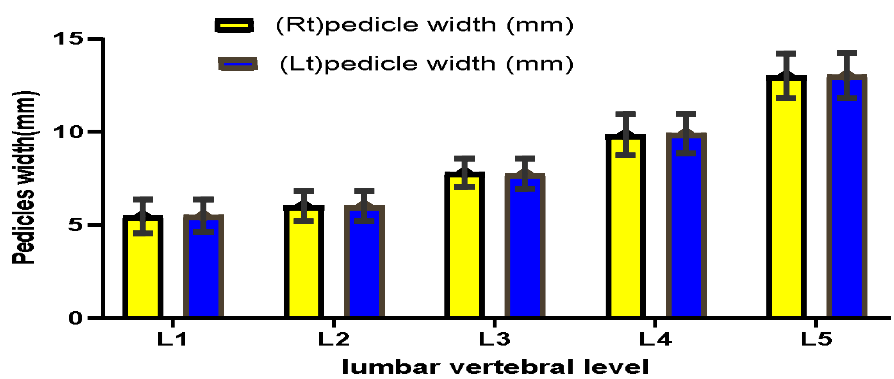


Figure 4.3:Bar chart demonstrated comparison between the mean values and SD of the right and left pedicles width at each lumbar vertebral level

Table 4.4: Demonstrated comparison of pedicle width(PDW) of lumbar vertebrae (L1 -L5) between gender using independent sample t-test ,the results are expressed in mm.

		Male	Female	T-values	Significance
L1	Mean	5.56	5.39	1.49	0.13
	SD	.95	.68		
	Maximum	9.44	9.07		
	Minimum	4.34	4.25		
L2	Mean	5.98	6.04	-.62	0.53
	SD	.65	.83		
	Maximum	8.00	9.03		
	Minimum	4.85	5.00		
L3	Mean	7.67	7.89	-2.15	.032*
	SD	.74	.65		
	Maximum	9.35	9.50		
	Minimum	5.17	6.05		
L4	Mean	9.73	9.99	-1.76	.08
	SD	.900	1.17		
	Maximum	11.85	8.15		
	Minimum	8.25	12.90		
L5	Mean	12.99	13.02	-.18	.85
	SD	1.29	1.05		
	Maximum	15.60	15.25		
	Minimum	9.50	10.95		

First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)Third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) Fifth Lumbar Vertebra (L5) ,SD=standard deviation,.* **P<0.05** between female and male at the lumbar level

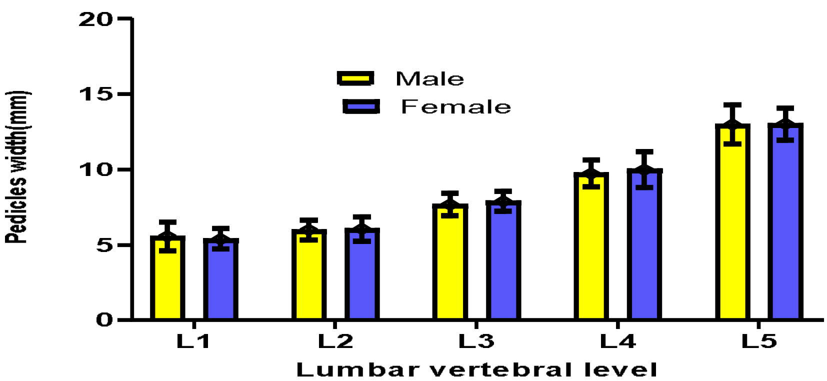


Figure 4.4: Bar chart depicted the mean values of the pedicle width at each level among gender inJazan population.

Table 4.5: Comparison of pedicle width between younger (26-35 yrs.) and older (> than 55 yrs.) age categories using (ANOVA) table among Jazan population.

Vertebral Levels	26-35 yrs. Mean ±SD (mm)	More than 55 yrs. Mean ±SD(mm)	P-value
PDWL1	5.56 ± .815	5.13 ± .532	.013*
PDWL2	5.871 ± .586	6.31 ± .882	.077
PDWL3	7.814 ± .5630	7.91 ± .46	.007*
PDWL4	9.76 ± 1.015	9.93 ± 1.30	.240
PDWL5	12.46 ± 1.039	13.96 ± .946	.000*

*P<0.05 statistically significant differences

Table 4.6: Pair wise (post hoc Bonferroni) comparison of the mean pedicle width between younger and older categories in Jazan population.

Vertebral Levels	26-35years Vs > 55years (p- value)
L1	.160
L2	.075
L3	1.000
L4	1.000
L5	0.000*

*Statistically significant values

Table 4.7: Demonstrated correlation coefficient between the Pedicle width and age:

	Unstandardized Coefficients		Standardized Coefficients		
Age	B	Std. Error	Beta	T	Sig
(Constant)	.015 8.576	.003 .118	.349	5.240 72.456	.000 .000

Established equation to predict the pedicles width for Saudi –Jazan region population of known age. Correlation is significant at ($p \leq 0.05$) ,**R^2 =.122.**

Pedicle width(PDW) =8.58+0.015*age.

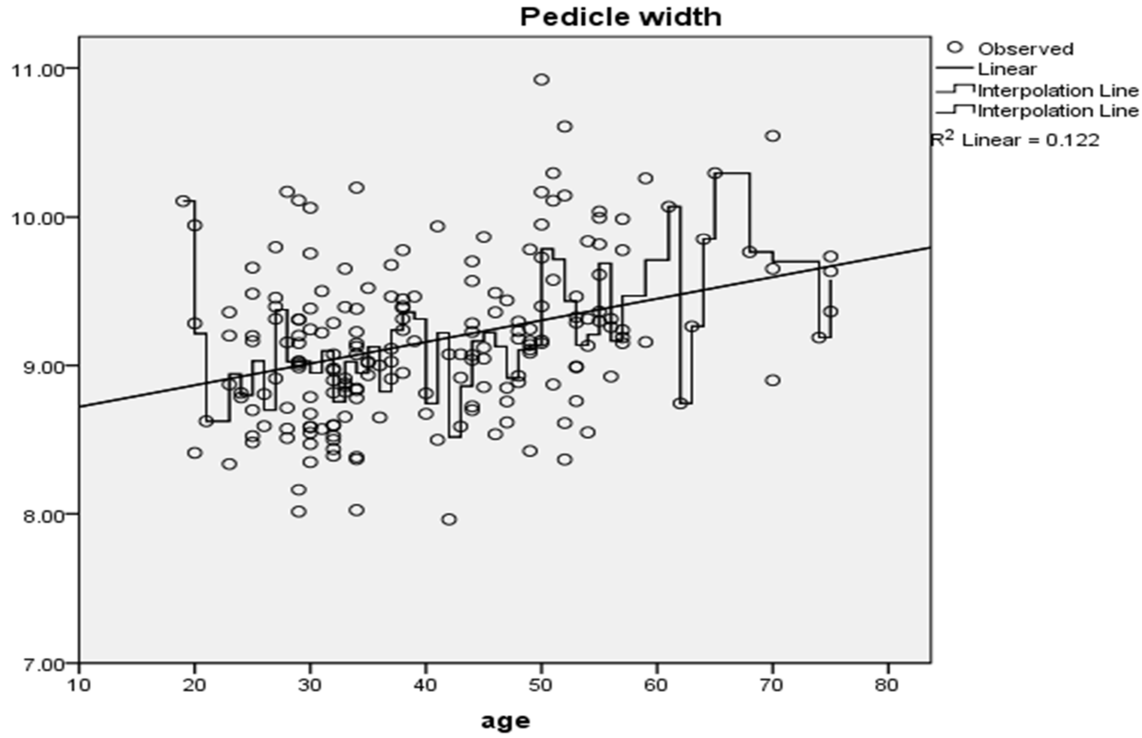


Figure 4.5: A scatter plot diagram demonstrated the positive linear relationship between the pedicle width and age among Jazan population.

Table 4.8: Demonstrated the mean values ,SD and range of pedicles width(PDW) of lumbar vertebrae using descriptive Statistics analysis,the results are expressed in mm

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Pedicle width L1	200	5.19	4.25	9.44	5.4770	.82784
Pedicle width L2	200	4.18	4.85	9.03	6.0115	.74422
Pedicle width L3	200	4.33	5.18	9.50	7.7796	.70631
Pedicle width L4	200	4.75	8.15	12.90	9.8654	1.04882
Pedicle width L5	200	6.10	9.50	15.60	13.0082	1.17559

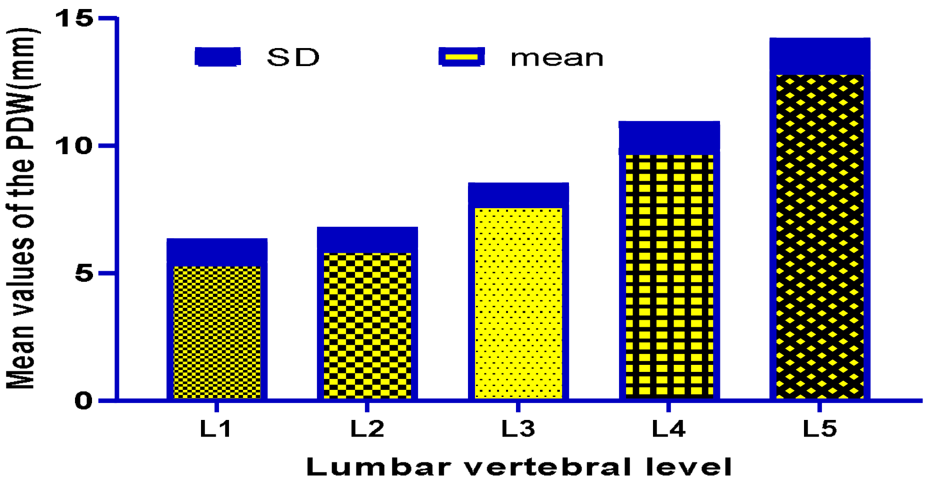


Figure 4.6: Bar chart demonstrated the mean values (mm) and SD of the (PDW) at each lumbar vertebral level among participants.

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Table 4.9: Depicted comparison of pedicle width (L1 to L5) obtained from previous studies performed with different world populations. Results are expressed in (mm) ± SD.

Author	Population	Year	Method	L1	L2	L3	L4	L5	Mean
(Líen, Liou and Wu	Chinese	2007	Direct	6.4±1.6	7.4 ±1.7	9.3 ±1.9	11.6 ±2.1	17.5 ±2.6	10.44
(Li Jiang, Fu et al.)	Chinese	2004	CT	7.9 ± 1.4	8.7 ± 1.2	10.2 ± 1.7	11.5 ± 1.2	13.7 ± 2.3	10.4
(Olmos, Villas et.al)	Spanish	2002	CT	------	------	8.7 ± 2.2	11.5 ± 2.1	16.3 ±2.5	12.17
(Kadioglu, et.al)	Turkish	2003	Direct	6.4 ± 2.0	6.6 ± 2.3	8.6 ± 3.8	10.8 ± 3.3	12.4 ± 2.4	8.96
(Castro Reyes,et.al)	Mexicans	2015	Direct	7.4 ± 1.6	7.8 ± 1.7	9.1 ± 2.1	10.7 ± 2.4	14.7 ± 3.7	9.94
(UrrutiaVega, Elizondo- et.al)	Mexicans	2009	CT	7.8 ±1.3	8.2 ±1.4	9.5± 1.0	10.7 ±0.6	14.3 ±1.8	10.1
(Nojiri,Matsumoto, Chiba et al.)	Japanese	2005	Direct	7.4 ±2.0	7.8 ±1.7	9.1 ± 1.7	10.1 ±1.7	11.1 ±1.7	9.1
Dhaval K. et.al.	Indians	2014	Direct	7.4 ± 1.6	7.8 ± 1.7	9.1 ± 2.1	10.7 ± 2.4	14.7 ± 3.7	9.94
(Acharya,Dorje and Srivastava)	Indians	2010	Direct	7.2 ±0.93	7.6 ±0.84	8.9 ± 1.1	11.1 ±1.0	13.9 ± 1.1	9.74
(Kang,Song, Lee et al.)	Koreans	2011	CT	8.1 ±1.7	8.5 ± 1.5	10.0 ±1.7	11.5 ±2.0	16.5 ±2.4	10.92
(Amonoo Kuofi)	Saudi Arabian	1995	X-ray	8.7	9.0	10.5	11.1	12.5	10.36
(Singel, and Gohil)	Indians	2004	Direct	8.2 ±6.7	8.5 ±6.5	10.4 ±7.0	13.5 ±7.0	18.2 ±9.7	11.76
(Olsewski, Gurpide et al.)	Americans	1990	Direct	7.7 ±1.9	7.9 ± 1.9	9.6 ± 2.4	12.5 ± 2.3	18.4 ± 3.6	11.22
(Wolf, Shoham, Michael et al.)	Israelites	2001	CT	5.6 ±1.3	7.7 ± 1.5	8.9 ± 1.9	11.4 ± 1.8	13.7 ± 2.2	9.46
(Maaly and Houlel)	Egyptians	2010	CT	6.8 ±1.9	8.8 ± 1.4	10.1 ± 1.6	12.9 ± 1.8	18.9 ± 2.1	11.5
Current study	Saudi Arabians	2020	CT	5.5 ±.83	6.0 ±.74	7.8 ±.75	9.9 ±1.05	13.0 ±1.8	8.43

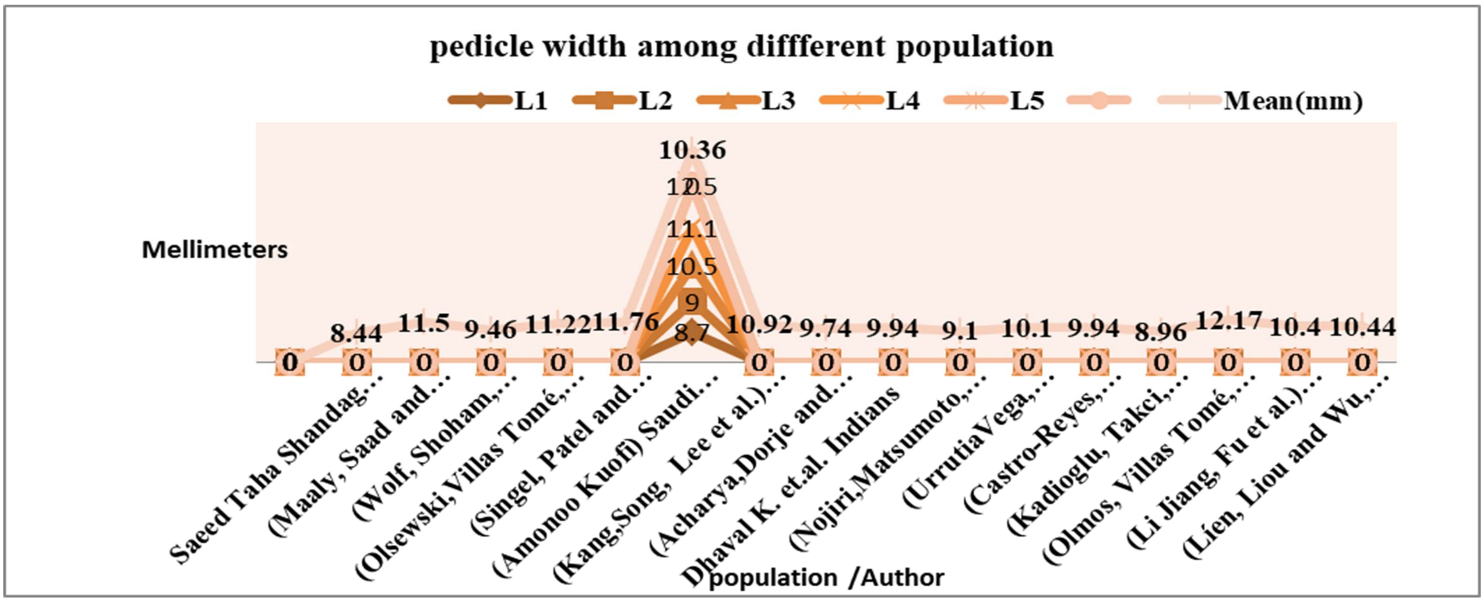

Figure 4.7: Pedicle width of lumbar vertebra pedicles obtained in studies performed in different populations.

Table 4.10:Demonstrated comparison between the right (Rt)and the left (Lt) pedicle height(PDH) from (L1 to L5) in Jazan population using Paired sample t-test ,results are expressed in mm.

		(Rt) pedicle Height(mm)	(Lt) pedicle Height(mm)	T-values	Significance
L1	Mean	13.25	13.30	-1.040	.300
	SD	1.85	1.92		
	Maximum	17.9	17.9		
	Minimum	10.9	10.9		
L2	Mean	14.06	14.08	-.667	.505
	SD	1.93	1.94		
	Maximum	17.9	17.9		
	Minimum	11	11		
L3	Mean	13.99	13.98	.196	.845
	SD	1.32	1.25		
	Maximum	17.9	17.9		
	Minimum	11.9	11.9		
L4	Mean	14.51	14.49	.298	.766
	SD	1.61	1.57		
	Maximum	17.7	17.7		
	Minimum	11.5	11.5		
L5	Mean	16.17	16.15	.390	.697
	SD	1.48	1.51		
	Maximum	19.5	19.5		
	Minimum	12.8	12.8		

Rt= right, Lt=left, SD=standard deviation, mm=millimeter.

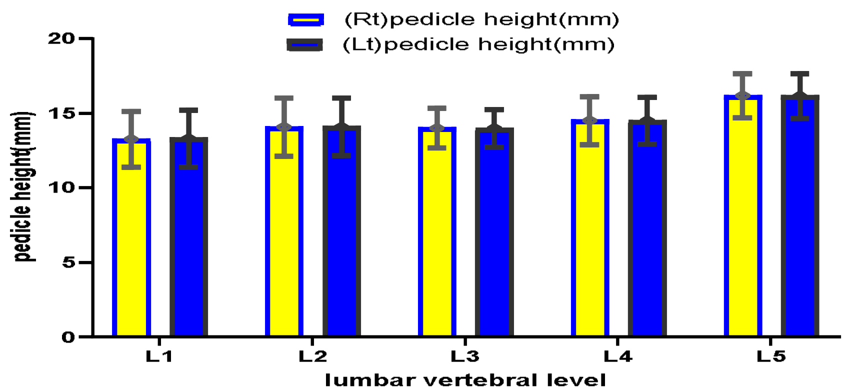

Figure.4.8: Bar chart demonstrated the comparison between the mean values of the right and left pedicles height at each level.

Table 4.11:Depicted comparison of pedicles height(PDH) of lumbar vertebrae (L1 toL5) between gender using independent sample t-test ,the results are in (mm).

		Male	Female	T-values	Significance
L1	Mean	13.36	13.19	0.627	0.531
	SD	1.83	1.86		
	Maximum	17.90	17.00		
	Minimum	10.95	11.00		
L2	Mean	14.04	14.10	-0.232	0.817
	SD	1.91	1.92		
	Maximum	17.90	18		
	Minimum	11	11.40		
L3	Mean	13.98	13.98	-0.018	0.986
	SD	1.25	1.20		
	Maximum	17.90	17.88		
	Minimum	11.90	11.50		
L4	Mean	14.57	14.44	0.569	0.570
	SD	1.64	1.50		
	Maximum	17.70	17.50		
	Minimum	11.75	11.50		
L5	Mean	16.19	16.12	0.347	0.729
	SD	1.41	1.52		
	Maximum	19.25	19.00		
	Minimum	12.80	12.70		

First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)Third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) Fifth Lumbar Vertebra (L5) ,SD=standard deviation**,. P>0.05** statistically insignificant between female and male at the lumbar level

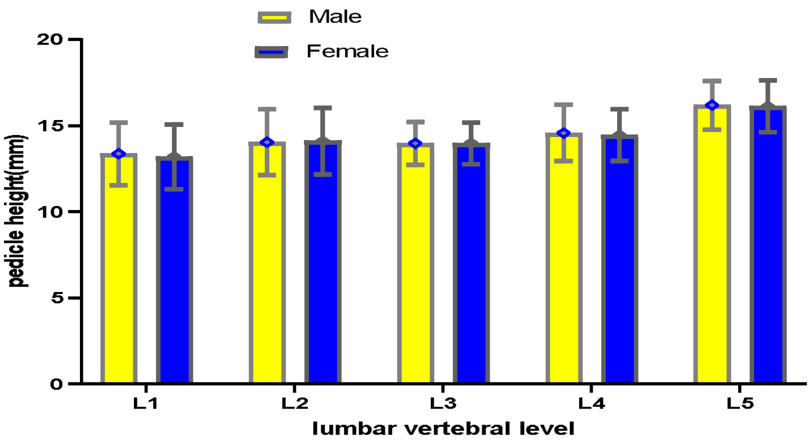

Figure 4.9: Bar chart demonstrated the mean values of the pedicle height at each level and the gender among Jazan population.

Table 4.12: Demonstrated the mean values and SD and range of pedicles height(PDH) vertebrae(L1-L5)using descriptive statistics analysis, results are in (mm)

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Pedicle height L1	200	6.95	10.95	17.90	13.2743	1.84689
pedicle height L2	200	6.85	11.00	17.85	14.0705	1.91333
pedicle height L3	200	6.00	11.90	17.90	13.9811	1.22665
pedicle height L4	200	5.95	11.75	17.70	14.5027	1.57098
pedicle height L5	200	6.45	12.80	19.25	16.1601	1.46476

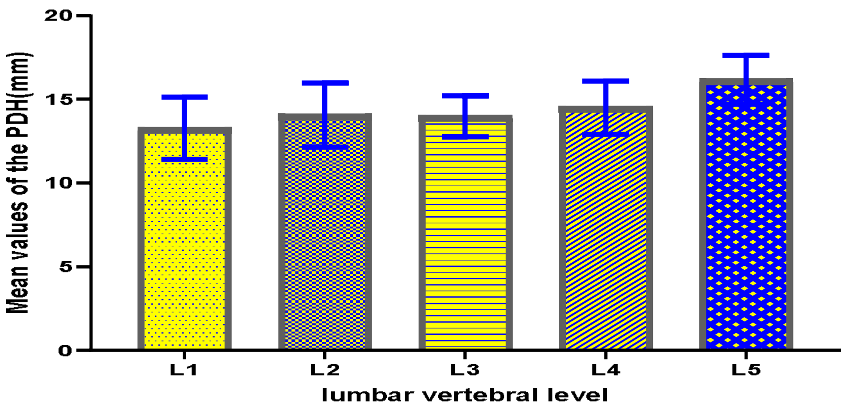

Figure.4.9: Bar chart demonstrated dimension of PDH mean values (mm) and SD among participants. at each lumbar vertebral level.

Table 4.13: Demonstrated comparison of mean pedicle height of the study with other previous studies performed with different world populations.

Author	Year	Population	Method	Mean (mm)
¶ Amonoo Kuofi	1995	Saudi Arabia	Plain X-ray	17.93
Ebraheim et al	1996	USA	Dry bones	13.68
Alon Wolf et al	2001	Israel	CT scans	14.8
K. Zafer Yuksel et al	2013	Turkey	CT scans	13.84
Singel TC et al	2004	India	Dry bones	14.65
Tan et al	2004	Singapore	Dry bones	12.92
Shiu-Bii Lien et al	2007	Taiwan	Dry bones, cadaveric	13.59
Tarek M. Mostafa et al	2006	Egypt	Dry bones	14.55
Dhaval K et.al.	2014	India	Dry bones	13.93
This current study	2020	Saudi Arabia	CT scans	14.40

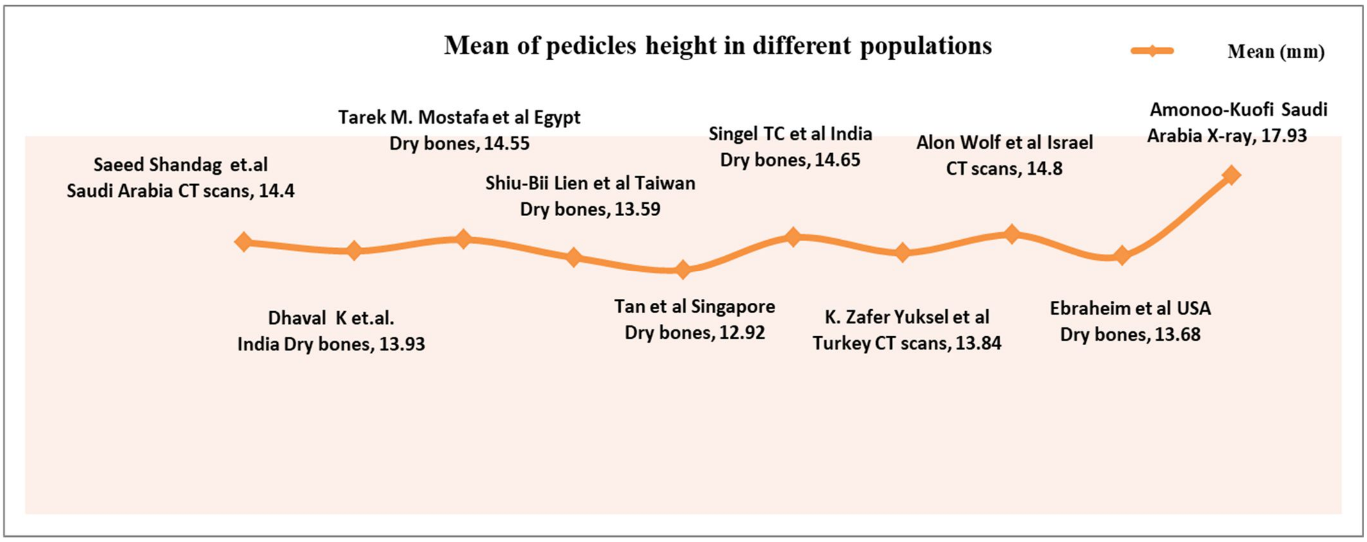

Figure 4.10:Pedicle Height of lumbar vertebra pedicles obtained in studies performed in different populations(results expressed in mm).

Table 4.14: Demonstrated comparison of mean values of (PDH) and (PDW) of our study with other previous studies in different world populations in relation to findings

	Author	Findings	Present Study
1	Kim N H et al in 1994 (T1 to L5)	PDH widest at T12, narrowest at T1 ,PDW maximum at L5 and minimum at T4	PDH was increased from L1 mean (13.27± 1.85) to L5 (mean: 16.16±1.46) though it reduced a little bit in L3(mean: 13.98±1.23). PDW increased gradually from L1 (mean:5.48±.83) to L5 (mean:13.07±1.18mm)
2	H S Amonoo- Kuofi (1995)	PDH in female maximum at L5 (18. 2 mm), in male at L5 (20. 7 mm) and minimum in female at L2 (14. 2mm) in male at L3 (14.8mm). PDW maximum mean at L5 (13.6 mm) in females and in male at L5 (14.2mm), minimum at L1 (7.4mm) in female and in male at L1 (7.5mm).	
3	P. Chaynes et. al (2000)	PDH increased from T1 to L5.	
4	Abdullah MiLCAN et. al 2001 T11 to L2)	PDW widest in females at T12 (5.9+1.2 mm) and minimum at T11 (5.6±1.4 mm) , in males maximum at L2 (6.5±1.6 mm) and minimum (6.1+2 mm)	
5	Singel TC 2004 (L1 to L5)	PDH in male maximum at L2 (15mm) PDW in males maximum at L5 mean (18.2mm) and minimum at L1 mean (8.2mm), in female maximum at L5 mean (19.25mm) , minimum at L1mean (8.5mm)	
6	Christodoulou AG 2005 (T1 to L5)Greek	PDH maximum at T11 mean: 17.02 mm (range: 14.84-19.57 mm), and the narrowest at T1 mean of 8.90 mm (range: 7.18-11.37 mm). PDW max at L5 mean (13.61 mm) and (range: 10.29-16.20 mm) and minimum at T5 mean (5.09 mm) and (range: 4.10-6.88 mm)	
7	Arora L, et. al 2006 (L1 to L5)	PDW increased from L1 to L5 range (815 mm) in male and (7-14mm) in females	
8	Shiu-Bii Lien et. al 2007 T1 to L5	PDH largest at T11 (mean: 15.3 ± 1.3) and smallest at T1 (mean: 8.6±1.1) PDW widest at L5 (17.7±2.7) and narrowest at T4 (3.4±0.6) check it	
9	Prakash et. al 2007 (L1 to L5)	PDH maximum at L5(mean: 17.4+0.39mm) and minimum at L1 (14.6+0. 39mm) PDW maximum at L5 (16.2 +0.39) and minimum at L1 (mean 8.2+0.43) both side.	
10	Karkhyle Md. Layeeque1,et.al 2015	PDH was decreased from L1 mean (15.2±1.7) to L5 (mean: 18.4 ±2.2mm) PDW increase from L1 (mean: 8.2±2.4) TOL5 (mean: 18.4 ±2.2mm).	

Table.4.15: Demonstrated comparison of (IPD) or (SCW) of lumbar vertebrae (L1 toL5) between gender using independent sample t-test ,the results are expressed in (mm).

		Male	Female	T-values	Significance
L1	Mean	21.36	21.14	1.34	0.18
	SD	1.24	1.11		
	Maximum	26	26		
	Minimum	19	19		
L2	Mean	21.21	20.78	1.48	0.14
	SD	2.00	2.14		
	Maximum	24.30	24.30		
	Minimum	16.20	16		
L3	Mean	22.04	21.45	1.63	0.11
	SD	2.90	2.15		
	Maximum	29.90	29.90		
	Minimum	18	14		
L4	Mean	21.65	20.96		0.08
	SD	2.99	2.372	1.79	
	Maximum	29.40	29.40		
	Minimum	17	17		
L5	Mean	20.85	20.45		0.30
	SD	2.89	2.55	1.05	
	Maximum	29	29		
	Minimum	15	17		

First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)Third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) Fifth Lumbar Vertebra (L5) ,SD=standard deviation,. P>0.05 statistically insignificant between female and male at the lumbar level.

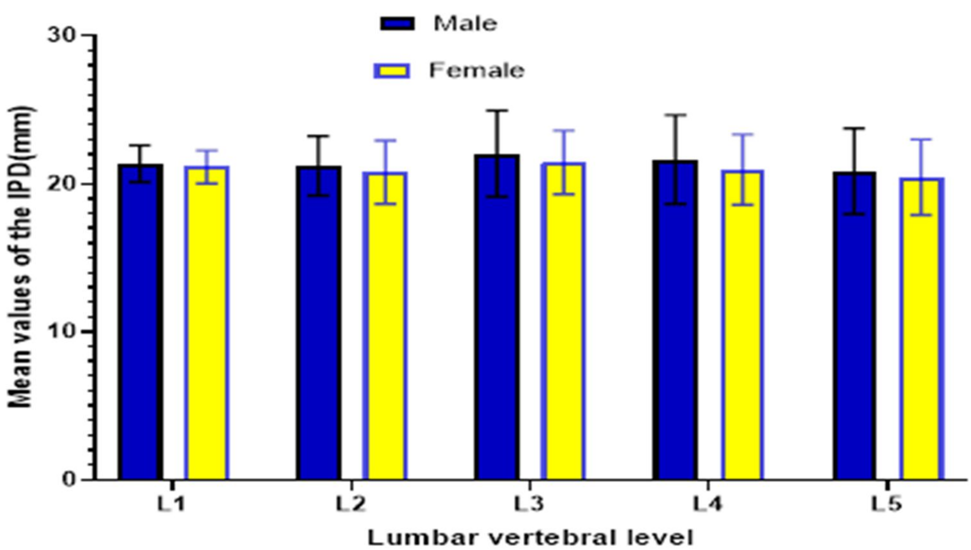

Figure.4.11: Bar chart demonstrated the mean values of the (IPD) at each level and the gender among Jazan population

Table 4.16: Show the mean values, SD and range of Interpedicular distant (IPD) or (SCW) of lumbar vertebrae(L1-L5)using descriptive statistics analysis, results are expressed in (mm).

	N	Range	Minimum	Maximum	Mean	Std. Deviation
IPD L1	200	7.00	19.00	26.00	21.2470	1.18100
IPD L2	200	8.30	16.00	24.30	20.9970	2.07512
IPD L3	200	15.90	14.00	29.90	21.8190	2.28529
IPD L4	200	12.40	17.00	29.40	21.3055	2.71682
IPD L5	200	14.00	15.00	29.00	20.6520	2.72916

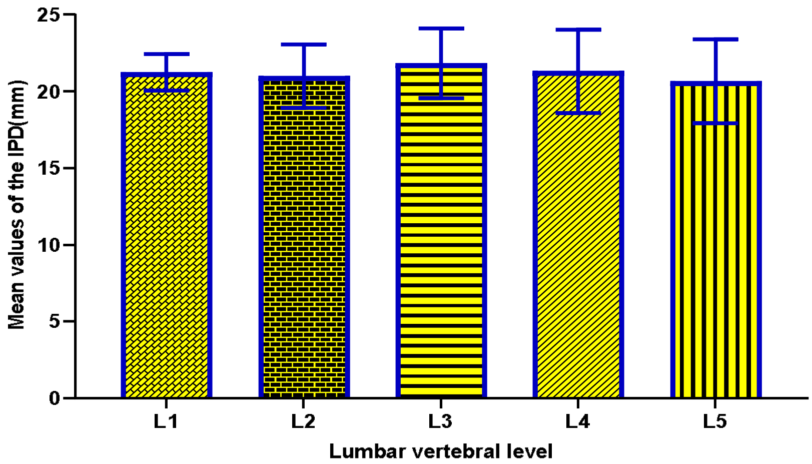

Figure.4.12: Bar chart demnstrated dimension of IPD mean values (mm) and SD in sample at each lumbar vertebral level among participant

Table 4.17: Comparison of mean (IPD) of the study with other previous studies performed with different world populations .Results are expressed in (mm).

Author	Year	Population	Method	Mean (in mm)
A.S. Jadhav et. al	2011	Indians	Cadavers	27.68
Tarek aly et.al	2013	Egyptians	CT scans	26.52
Roxana Torres Castellanos.et.al	2016	Mexicans	CT scans	23.97
AZU, O. O.et.al	2016	South Africans	Human cadavers	21.68
Piera et al.	1988	Spanish	CT scans	30.83
Amonoo Kuofi HS.	1982	Nigerians	Plain X-ray	26.12
Rudra Prasad Marasini	2011	Nepalese	CT scans	26
Mohammed El-Rakhawy	2010	Egyptians	Cadavers & plain X-ray	22.62
Current Study.	2020	Saudi Arabia	CT scans	21.21

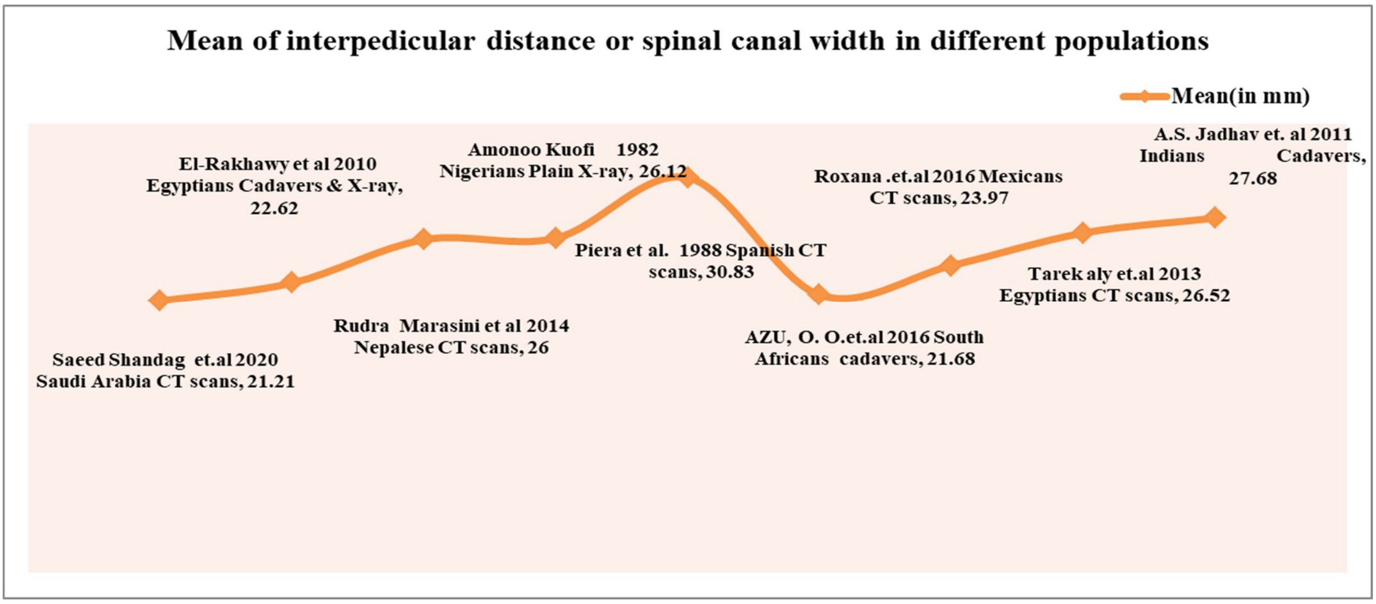

Figure 4.13:Interpedicular distant of lumbar vertebra pedicles obtained in studies performed in different populations

Table.4.18:Demonstrated the mean values of the (PDAL) or chord length of lumbar vertebrae (L1 -L5) between gender using independent sample t-test ,the results are expressed in (mm).

		Male	Female	T-values	Significance
L1	Mean	49.08	48.83	879	.380
	SD	2.12	1.83		
	Maximum	54.40	54.40		
	Minimum	46	46		
L2	Mean	49.96	49.44	1.523	.129
	SD	2.56	2.25		
	Maximum	59	59		
	Minimum	46	46		
L3	Mean	50.08	49.91	.435	.664
	SD	2.80	2.62		
	Maximum	57.70	57.70		
	Minimum	46.80	46		
L4	Mean	49.69	49.56	.654	.514
	SD	1.52	1.35		
	Maximum	55.80	55.90		
	Minimum	47	47.40		
L5	Mean	50.66	50.80	-.442	.659
	SD	2.25	2.26		
	Maximum	56	56.20		
	Minimum	47.10	47.80		

First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)Third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) Fifth Lumbar Vertebra (L5) ,SD=standard deviation,. P>0.05 statistically insignificant between female and male at the lumbar level

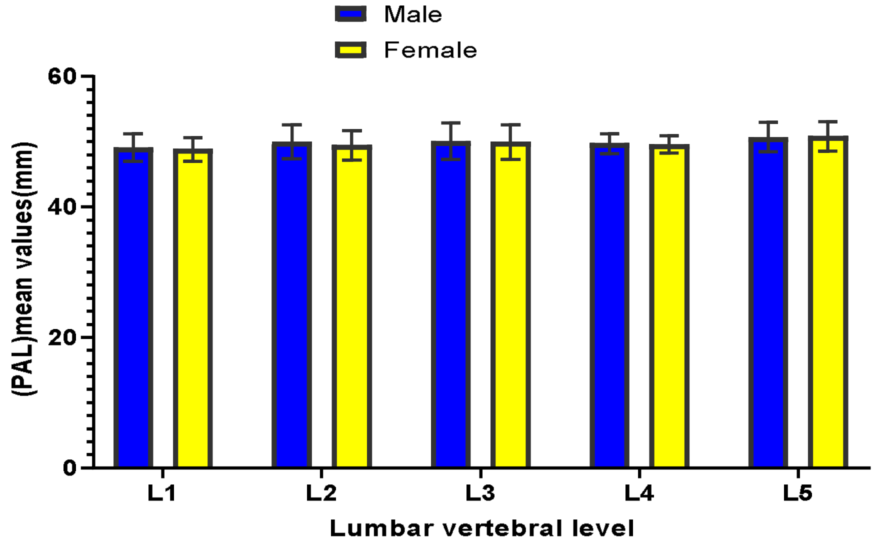

Figure 4.14: Demonstrated Bar chart showing the mean values of the PDAL or chord length at each level between the gender among participants.

Table 4.19: Demonstrated comparison of pedicle chord length(PDAL) between younger (26-35 yrs.) and older (More than 55 yrs.) age categories using (ANOVA) table among Jazan population.

Vertebral Levels	26-35 yrs. Mean ±SD (mm)	More than 55 yrs. Mean ±SD (mm)	P-value
Chord length L1	49.19±1.97	47.58 ±0.70	0.001*
Chord length L2	50.76 ±2.13	47.96±0.54	0.000*
Chord length L3	51.39±2.03	47.76±0.94	0.000*
Chord length L4	49.44±1.36	49.63±0.55	0.045*
Chord length L5	50.83±2.08	49.70±0.99	0.009*

*P<0.05 statistically significant differences

Table 4.20: Depicted Pair wise (post hoc Bonferroni) comparison of the mean Chord length of younger and older categories of Jazan population.

Vertebral Levels	26-35years **Vs** > 55years p- value
L1	.002*
L2	.000*
L3	.000*
L4	1.000
L5	0.202

*Statistically significant values(P<0.05)

Table 4.21: Correlation Coefficient between the Pedicle Chord length(PDAL) and age

	Unstandardized Coefficients		Standardized Coefficients		
Age	B	Std. Error	Beta	T	Sig
(Constant)	-.044 51.611	.008 .336	-.371	-5.629 153.707	.000 .000

Established equation to predict the Pedicle Chord length(PDAL) for Saudi –Jazan region population of known age. Correlation is significant at($p \leq 0.05$),R^2=.138

Chord length (PDAL) =51.611+(-.044)*age.

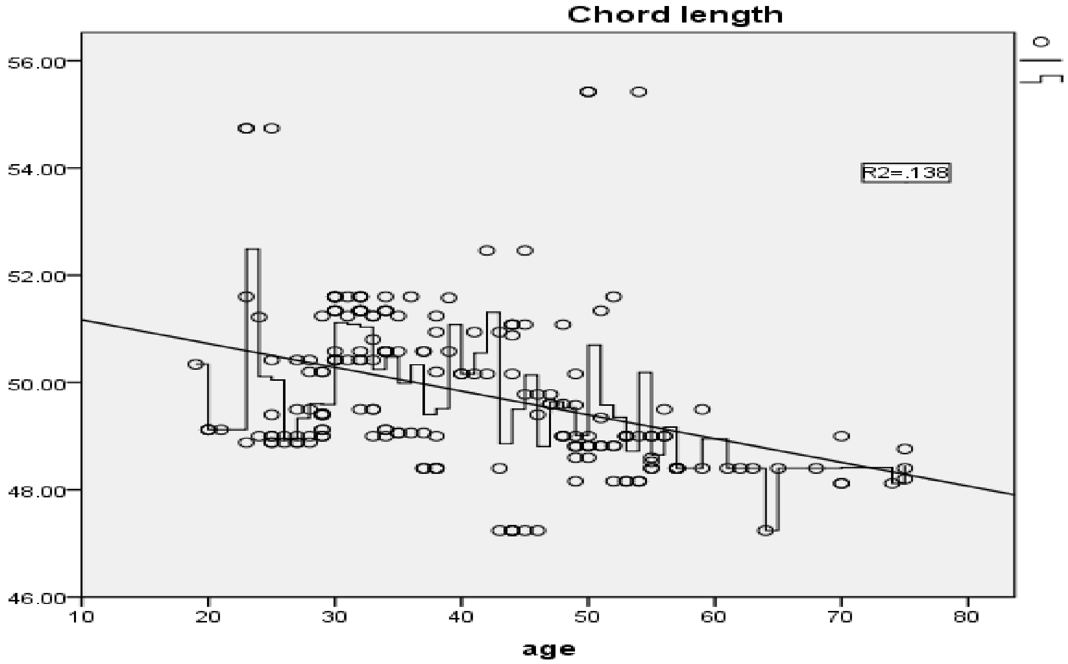

Figure 4.15:Ascatter plot diagram demonstrated the negative linear relationship between the pedicle chord length (PDAL) and age

Table:4.22: Demonstrated the mean values, SD and range of pedicle axial length(PDAL) of lumbar vertebrae(L1-L5), using descriptive statistics analysis, the results are expressed in (mm).

	N	Range	Minimum	Maximum	Mean	Std. Deviation
pedicle axial length L1	200	8.40	46.00	54.40	48.9625	1.98564
pedicle axial length L2	200	13.00	46.00	59.00	49.7080	2.42231
pedicle axial length L3	200	11.70	46.00	57.70	49.9945	2.71049
pedicle axial length L4	200	8.90	47.00	55.90	49.6315	1.43620
pedicle axial length L5	200	9.10	47.10	56.20	50.7305	2.25280

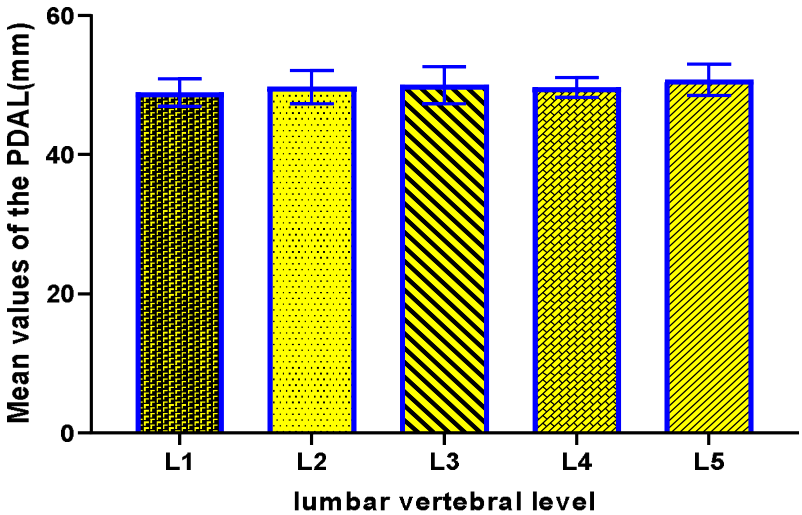

Figure 4.16: Demonstrated Bar chart showing dimension of (PDAL) mean values (mm) and SD in sample at each lumbar vertebral level between participants.

Table 4.23:demonstrated comparison of mean values of pedicle axial length(PDAL) of the study with other previous studies performed in different world populations.

Author	Year	Population	Method	Mean (in mm)
Ebraheim et al	1996	USA	Dry bones	48.87
Alon Wolf et al	2001	Israel	CT scans	46.73
Mitra SR et al	2002	India	Cadaveric	46.55
Tan et al	2004	Singapore	Dry bones	41.78
Acharya S et al	2010	India	CT scans	47.68
K. Zafer Yuksel	2013	Turkey	CT scans	47.91
Dhaval K. Patil et al	2014	India	Dry bones	44.71
A. Pavan Kumar et al	2016	India	CT scans	50.31
İsmail Emre Ketenci et al	2018	Turkey	CT scans	48.13
Hassan Yauri Sani	2018	South Africa	Dry bones	47.6
The current study.	2020	Saudi Arabia	CT scans	49.80

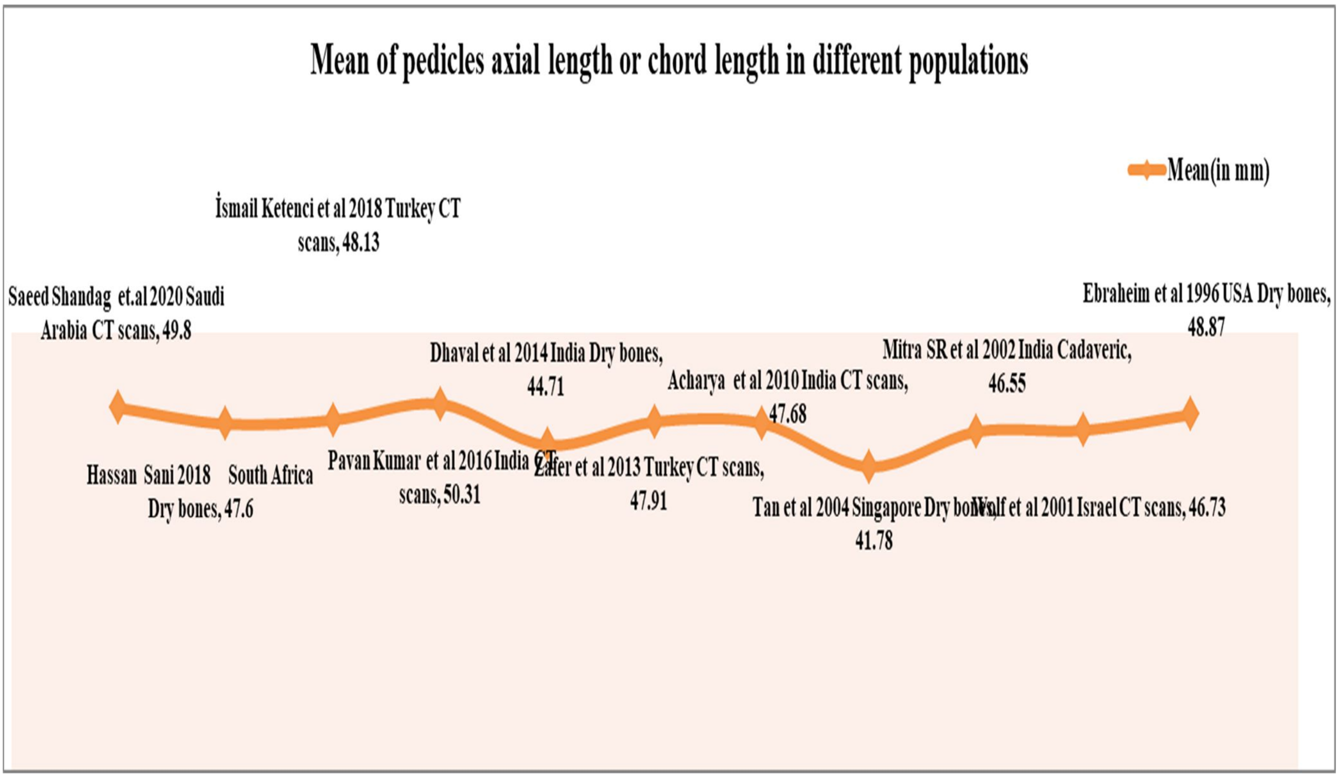

Figure 4.17:Chord length of lumbar vertebral pedicles obtained in studies performed in different populations

Table.4.24:Depicted comparison of (TPA) of lumbar vertebrae (L1-L5 between gender using independent sample t-test ,the results are expressed in (degree).

		Male	Female	T-values	Significance
L1	Mean	18.71	18.49	0.76	0.45
	SD	1.97	2.01		
	Maximum	22.90	22.90		
	Minimum	14.70	14.70		
L2	Mean	19.21	19.20	0.04	0.96
	SD	1.92	1.78		
	Maximum	23.50	22.40		
	Minimum	14.70	14.70		
L3	Mean	19.94	19.90	0.19	0.85
	SD	1.76	1.80		
	Maximum	23.70	23.70		
	Minimum	13	13		
L4	Mean	22.32	22.44	-0.40	0.68
	SD	2.28	2.22		
	Maximum	26.60	26.60		
	Minimum	18	18.50		
L5	Mean	25.71	26.16	-1.07	0.29
	SD	3.19	2.76		
	Maximum	30	30.70		
	Minimum	14	14		

First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)Third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) Fifth Lumbar Vertebra (L5) ,SD=standard deviation,. P>0.05 statistically insignificant between female and male at the lumbar level.

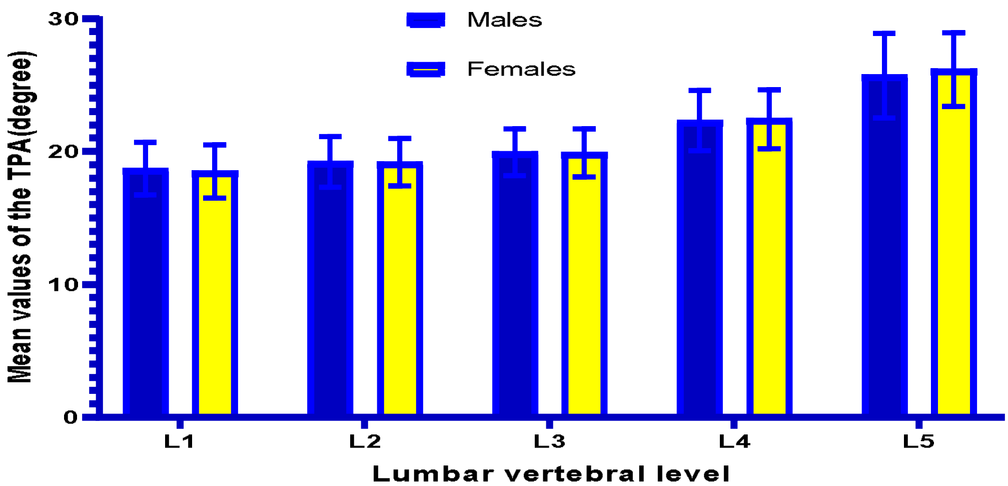

Figure 4.18: Demonstrated Bar chart showing the mean values of the transverse pedicles angle at each level between the gender among participants.

Table 4.25: demonstrated comparison of transverse pedicle angle (TPA) between younger (26-35 yrs.) and older (>55 yrs.) age categories using (ANOVA) table among Jazan population.

Vertebral Levels	26-35 yrs.	More than 55 yrs.	P-value
	Mean ±SD(degree)	Mean ±SD(degree)	
(TPA) L1	18.33±1.47	19.8±42.00	0.000*
(TPA) L2	18.47±1.24	21.38±1.54	0.000*
(TPA) L3	18.96±0.95	21.80±2.04	0.000*
(TPA) L4	21.53±2.16	23.19±0.84	0.000*
(TPA) L5	23.60±1.48	28.24±3.06	0.000*

*P<0.05 statistically significant differences

Table 4.26: Pair wise (post hoc Bonferroni) comparison of the mean transverse pedicle angle of younger and older categories of Jazan population.

Vertebral Levels	26-35years Vs > 55years p- value
L1	.002*
L2	.000*
L3	.000*
L4	.006*
L5	.000*

*P<0.05 statistically significant differences

Table 4.27: Correlation Coefficient between the Transverse pedicle angle(TPA) and age

	Unstandardized Coefficients		Standardized Coefficients		
Age	B	Std. Error	Beta	T	Sig
(Constant)	.005 19.249	.009 .369	.042	.591 52.226	.555 .000

Established equation to predict the transverse pedicle angle (TPA) for Saudi –Jazan region population of known age. Correlation is significant at($p \leq 0.05$),R^2=.002.

transverse pedicle angle(TPA)= 19.249+.005*age.

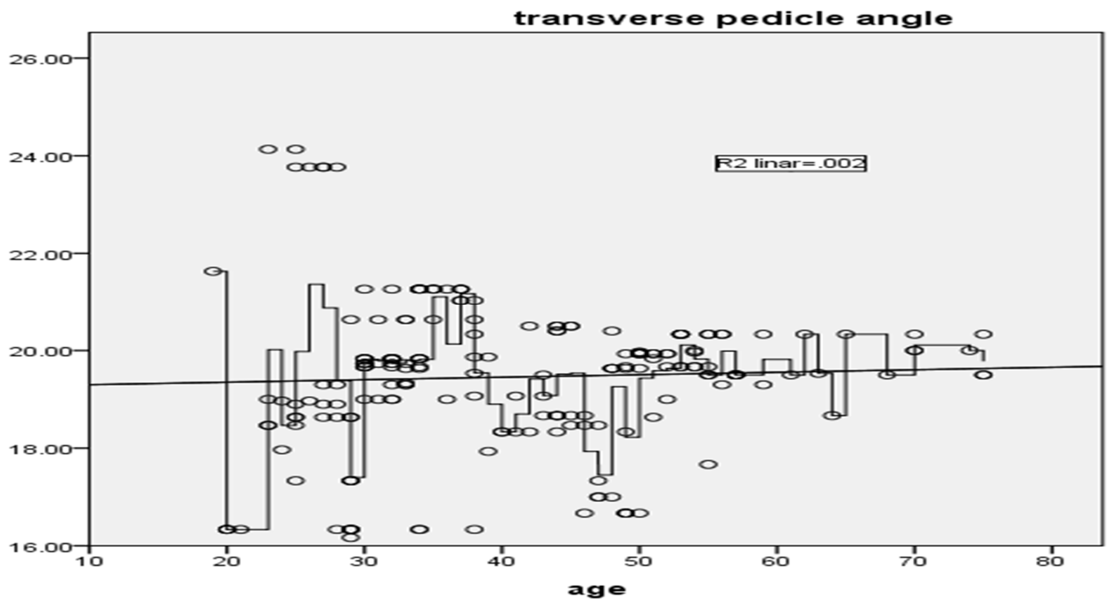

Figure 4.19: Ascatter plot diagram demonstrated the positive linear relationship between the transverse pedicle angle (TPA) and age.

Table:4.28: Demonstrated the mean values, SD and ranges of transverse pedicles angle (TPA) of lumbar vertebrae(L1-L5) using descriptive Statistics analysis, the results are expressed in (degrees).

	N	Range	Minimum	Maximum	Mean	Std. Deviation
TPA L1	200	8.20	14.70	22.90	18.5985	1.99102
TPA L2	200	8.80	14.70	23.50	19.2040	1.85011
TPA L3	200	10.70	13.00	23.70	19.9205	1.78036
TPA L4	200	8.60	18.00	26.60	22.3805	2.24597
TPA L5	200	16.70	14.00	30.70	25.9340	2.98260

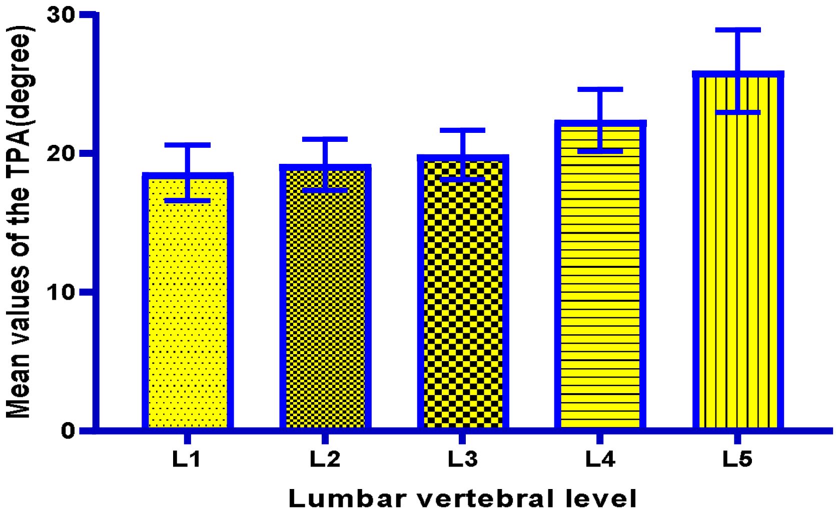

Figure 4.20: Bar chart showing dimension of (TPA) mean values in (degrees) and SD in sample at each lumbar vertebral level between participants.

Table:4.29: Demonstrated comparison of mean transverse pedicles angle (TPA) of the study with other previous studies of different world populations Results are expressed in (degrees).

Study	Year	Country	Study Method	Mean (In degrees)
Ebraheim et al	1996	USA	Dry bones	28.82
Alon Wolf et al	2001	Israel	CT scans	12.42
Mitra SR et al	2002	India	Cadaveric	11.24
Shiu-Bii Lien et al	2007	Taiwan	Dry bones, cadaveric	13.73
Acharya S et al	2010	India	CT scans	14.2
K. Zafer Yuksel	2013	Turkey	CT scans	19.52
Dhaval K. Patil et al	2014	India	Dry bones	11.73
Muhammad M. Alam et al	2014	Pakistan	CT scans	16.6
Hassan Yauri Sani	2018	Black South Africa	Dry bones	24.18
Mohamed Tall et al	2018	Burkina Faso	CT scans	21.58
The current study.	2020	Saudi Arabia	CT scans	21.21

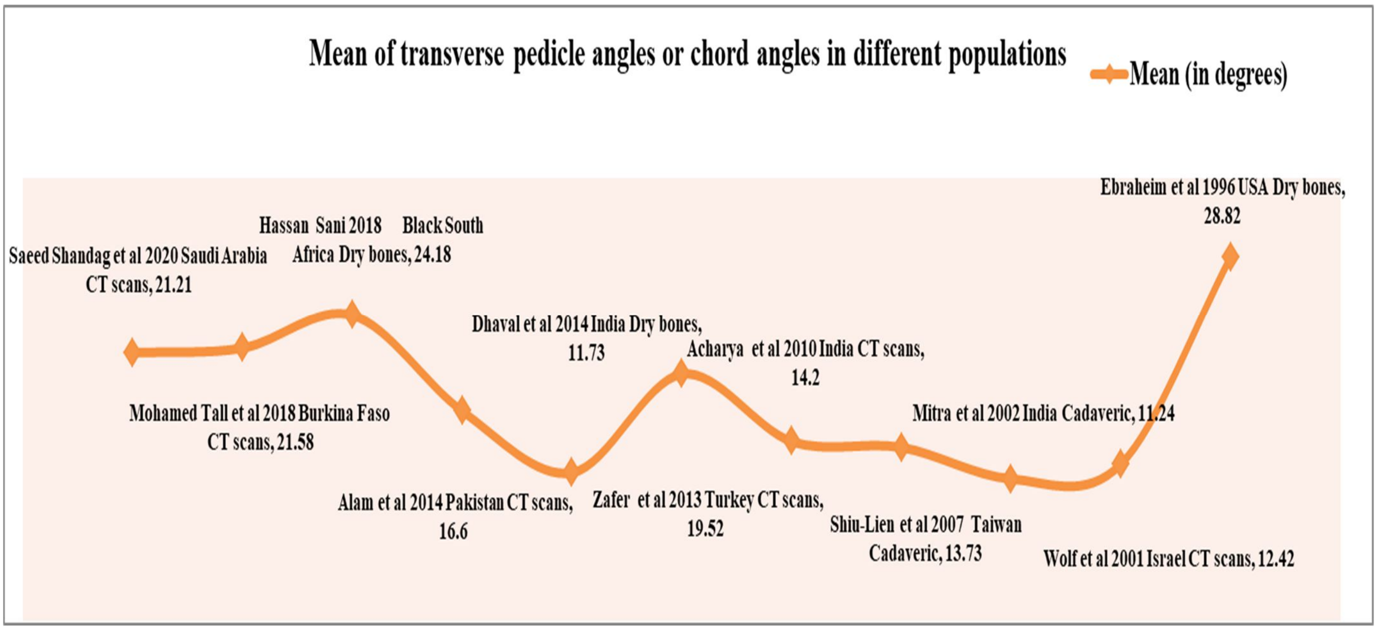

Figure 4.21 :showing transverse pedicles angle of lumbar vertebral pedicles obtained from studies performed in different populations

Table.4.30: Demonstrated comparison of (SPA) of lumbar vertebrae (L1-L5) between gender using independent sample t-test ,the results are expressed in (degree).

		Males	Females	T-values	Significance
L1	Mean	14.09	13.97	.444	0.657
	SD	1.84	1.88		
	Maximum	20.20	20.20		
	Minimum	11	11		
L2	Mean	15.17	15.19	-.051	0.959
	SD	2.68	2.55		
	Maximum	19.50	19.50		
	Minimum	10.50	10.50		
L3	Mean	14.96	15.19	- 481	0.631
	SD	3.00	3.67		
	Maximum	37	36		
	Minimum	11	11		
L4	Mean	15.07	14.50	1.292	0.198
	SD	3.70	2.54		
	Maximum	39	20.10		
	Minimum	11	11		
L5	Mean	18.01	17.45	.905	0.366
	SD	4.65	4.02		
	Maximum	44	36		
	Minimum	12	13		

First Lumbar Vertebra (L1)Second Lumbar Vertebra (L2)Third Lumbar Vertebra (L3)Fourth Lumbar Vertebra (L4) Fifth Lumbar Vertebra (L5) ,SD=standard deviation,. P>0.05 statistically insignificant between female and male at the lumbar level.

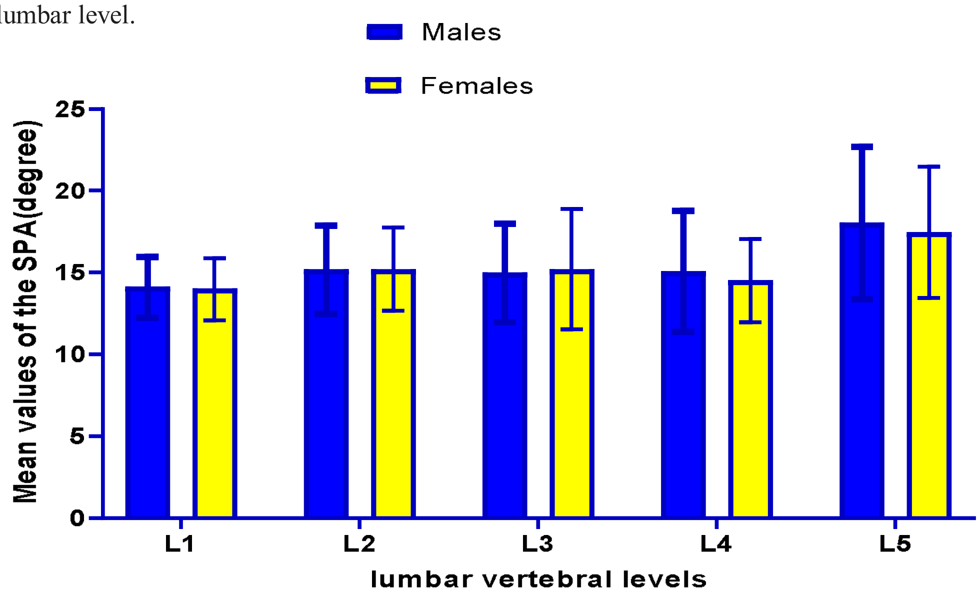

Figure.4.22: Demonstrated bar chart showing the mean values of the (SPA) at each level between the gender among participants.

Table:4.31:Depicted the mean values, SD and ranges of (SPA) of lumbar vertebrae (L1-L5)using descriptive Statistics analysis, the results are expressed in (degrees).

	N	Range	Minimum	Maximum	Mean	Standard deviation
SPA L1	200	9.20	11.00	20.20	14.0315	1.85812
SPA L2	200	9.00	10.50	19.50	15.1765	2.61038
SPAL3	200	26.00	11.00	37.00	15.0770	3.34842
SPA L4	200	28.90	11.00	39.90	14.7860	3.18017
SPA L5	200	32.00	12.00	44.00	17.7305	4.34941

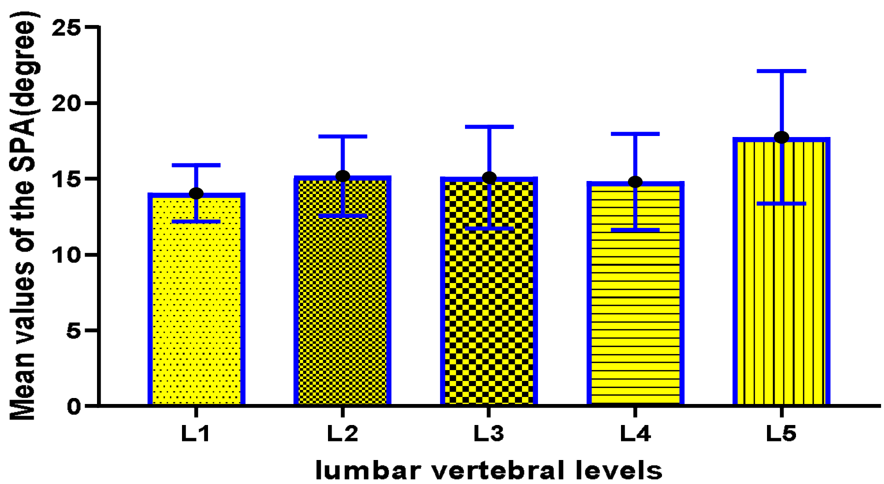

Figure 4.23: Demonstrated bar chart showing dimension of (SPA)mean values in (degrees) and SD in participants at each lumbar vertebral level between participants

Table 4.32: Demonstrated comparison of mean (SPA) of the study with other previous studies performed with different world populations, results are expressed in (degrees)

Study	Year	Country	Method	Mean in degrees
Ebraheim et al	1996	USA	Dry bones	4.65
Mitra SR et al	2002	India	Cadaveric	9.16
Shiu-Bii Lien et al	2007	Taiwan	Dry bones, cadaveric	4.98
K. Zafer Yuksel	2013	Turkey	CT scans	8.38
Dhaval et al	2014	India	Dry bones	4.72
Muhamma Alam et al	2014	Pakistan	CT scans	4.39
Nithya Marimuth	2018	India	Dry bones	5.1
Mohamed Tall et al	2018	Burkina Faso	CT scans	11.64
The current study	2020	Saudi Arabia	CT scans	15.36

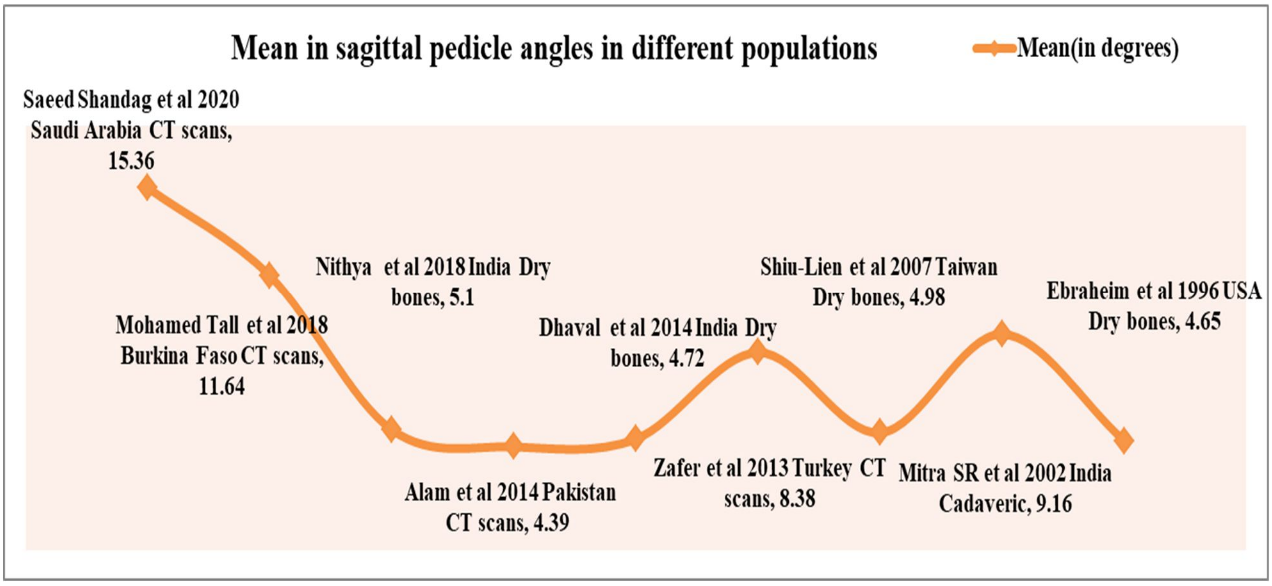

Figure 4.24:Demonstrated (SPA)of lumbar vertebral pedicles obtained from studies performed in different populations.

Table.4.33:Depicted comparison of vertebral body width (VBW) of lumbar vertebrae (L1 toL5) between gender using independent sample t-test ,the results are expressed in (mm).

		Male	Female	T-values	Significance
L1	Mean	33.29	32.90	1.03	0.30
	SD	2.80	2.54		
	Maximum	38.10	38.10		
	Minimum	28	28		
L2	Mean	34.02	33.72	0.87	0.39
	SD	2.66	2.23		
	Maximum	39.60	38.80		
	Minimum	29	29		
L3	Mean	35.78	34.97	2.16	0.03*
	SD	2.66	2.63		
	Maximum	40.50	40.50		
	Minimum	25	23		
L4	Mean	38.11	37.32	2.25	0.02*
	SD	2.73	2.20		
	Maximum	43.50	43.50		
	Minimum	28.80	34		
L5	Mean	43.97	43.57	1.00	0.32
	SD	3.09	2.51		
	Maximum	51	51		
	Minimum	29	39.40		

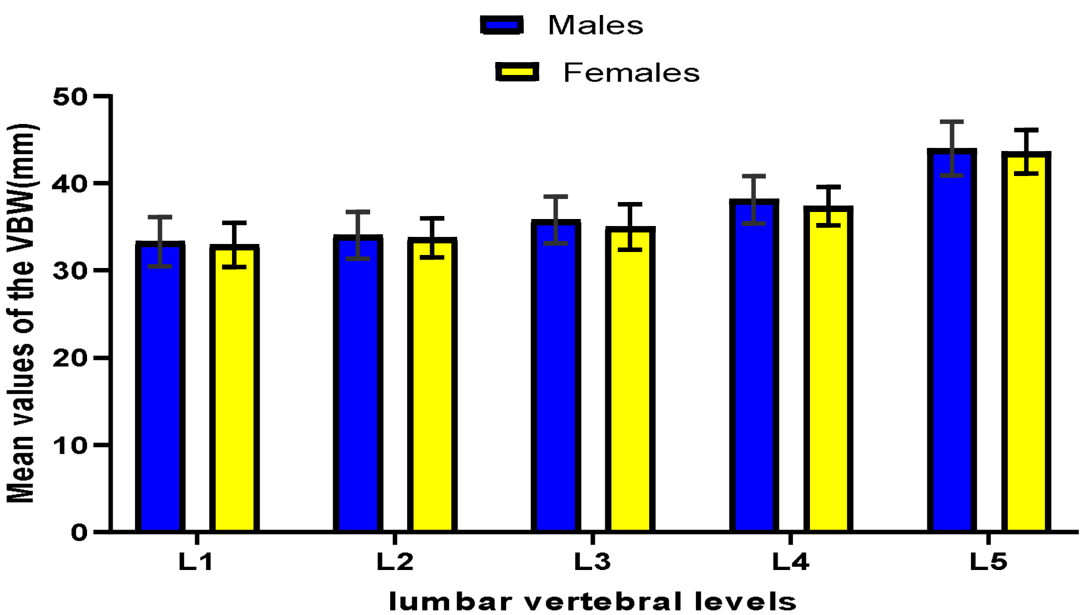

Figure 4.25: Demonstrated bar chart showing the mean values of the VBW at each level between the gender among participants.

Table:4.34: Show the mean values, SD and ranges of vertebral body width (VBW) of lumbar vertebrae(L1-L5)using descriptive Statistics analysis, the results are expressed in (mm).

	N	Range	Minimum	Maximum	Mean	Std. Deviation
VBW L1	200	10.10	28.00	38.10	33.09	2.68
VBW L2	200	10.60	29.00	39.60	33.87	2.45
VBW L3	200	17.50	23.00	40.50	35.37	2.67
VBW L4	200	14.70	28.80	43.50	37.72	2.50
VBW L5	200	22.00	29.00	51.00	43.77	2.82

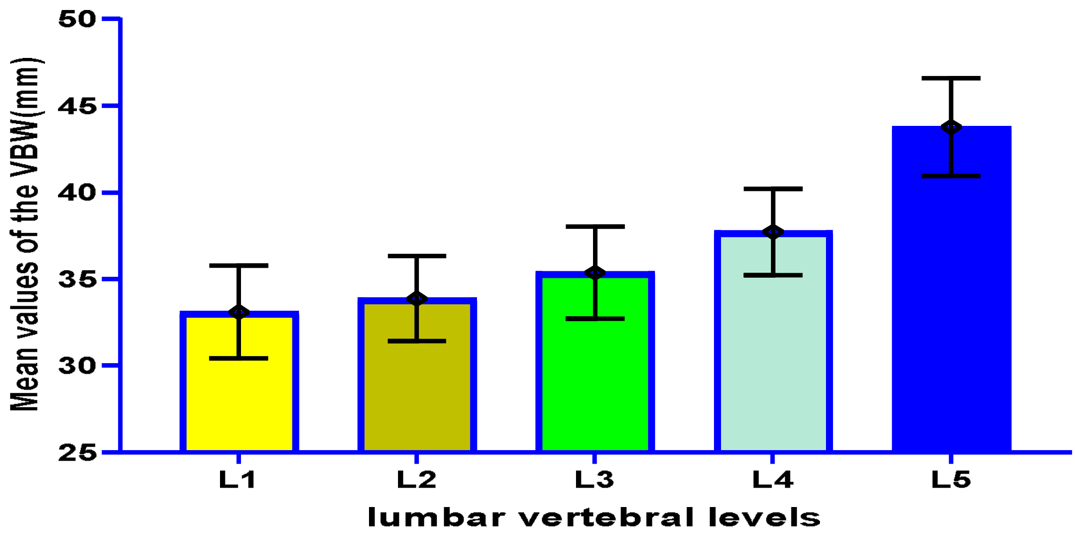

Figure 4.26: demonstrated bar chart showing dimension of (VBW) mean values in (mm) and SD among participants at each lumbar vertebral level

Table:4.35: Demonstrated comparison of mean vertebral body width (VBW) of the study with other previous studies of different world populations .

Study	Year	Country	Study Method	Mean (In mm)
Amonoo Kuofi H.S	1982	Nigeria	Radiograph	46.48
Alon Wolf et al	2001	Israel	CT scans	43.56
El-Rakhawy et al	2010	Egypt	Dry bones, radiographs	40.20
Mukesh Mallik et al	2014	Nepal	CT scans	40.50
Mohamed Tall et al	2018	Burkina Faso	CT scans	40.78
Saeed Shandag .This study.	2020	Saudi Arabia	CT scans	36.77

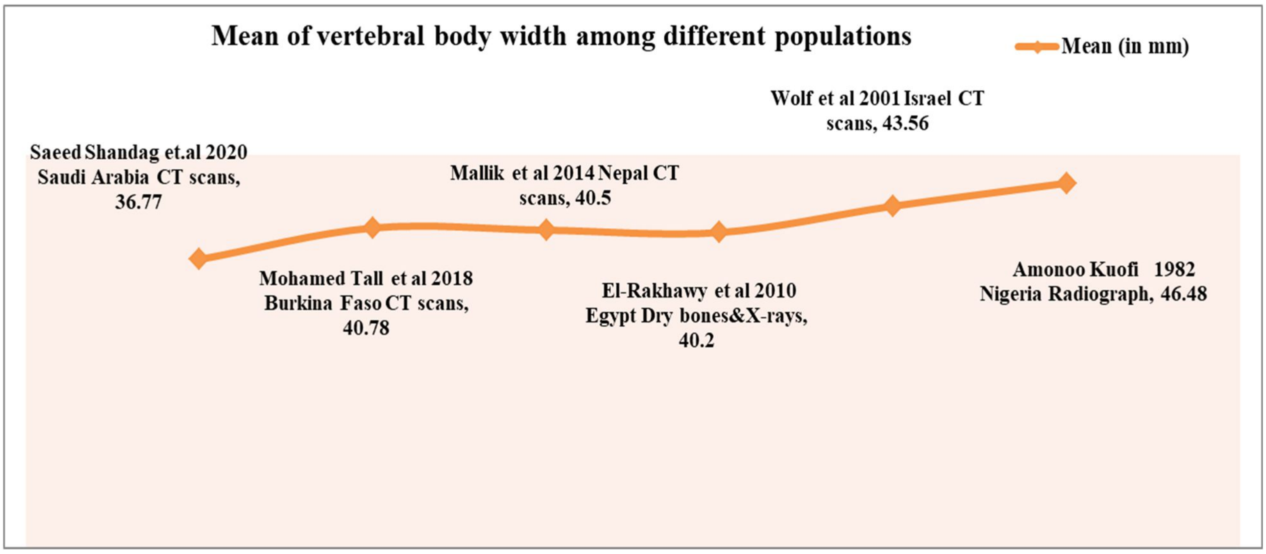

Figure 4.27:Demonstrated vertebral body width(VBW) of lumbar vertebral obtained from studies performed in different populations.

Table.4.36:Demonstrated comparison of vertebral body Depth(VBD) of lumbar vertebrae (L1-L5) between gender using independent sample t-test ,the results are expressed in (mm).

		Male	Female	T-values	Significance
L1	Mean	25.13	24.68	1.86	0.06
	SD	1.86	1.53		
	Maximum	30.40	30.40		
	Minimum	22	22		
L2	Mean	26.07	25.66	2.01	0.04
	SD	1.68	1.16		
	Maximum	31	30.90		
	Minimum	24	24		
L3	Mean	26.59	25.82	2.62	0.01
	SD	2.35	1.80		
	Maximum	33.10	33.10		
	Minimum	23	21		
L4	Mean	27.41	26.71	2.06	0.04
	SD	2.68	2.10		
	Maximum	34.40	34.40		
	Minimum	23	23		
L5	Mean	31.05	30.50	1.26	0.21
	SD	3.30	2.89		
	Maximum	38.80	38.80		
	Minimum	23	23		

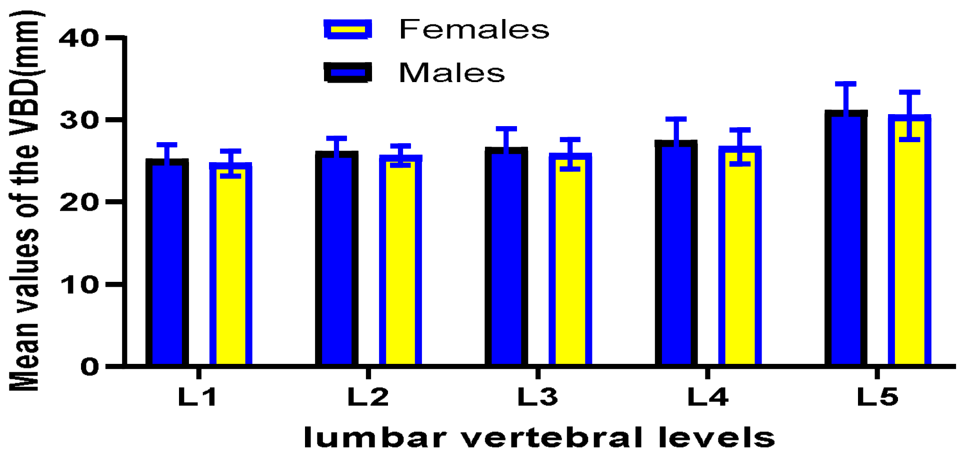

Figure4.28: Demonstrated a bar chart showing the mean values of the VBD at each level between the gender among participants.

Table:4.37: Demonstrated the mean values, SD and ranges of (VBD)of lumbar vertebrae (L1-L5)using descriptive Statistics analysis, results are expressed in (mm).

	N	Range	Minimum	Maximum	Mean	Std. Deviation
VBD L1	200	8.40	22.00	30.40	24.9025	1.71738
VBD L2	200	7.30	24.00	31.30	25.8640	1.45961
VBD L3	200	12.10	21.00	33.10	26.2048	2.12604
VBD L4	200	11.40	23.00	34.40	27.0595	2.42995
VBD L5	200	15.80	23.00	38.80	30.7775	3.10814

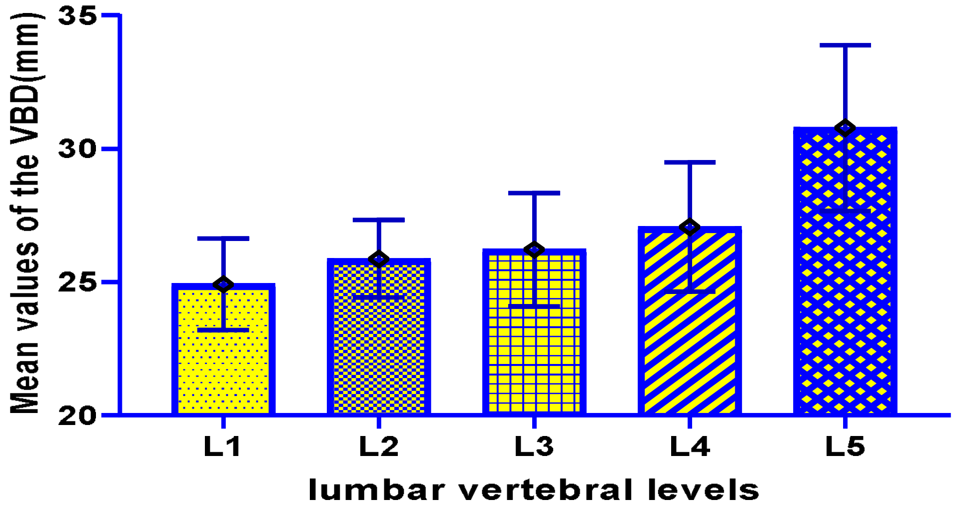

Figure 4.29: Demonstrated bar chart showing dimension of (VBD) mean values in (mm) and SD in sample at each lumbar vertebral level between participants.

Table:4.38: Demonstrated comparison of mean vertebral body width (VBD) of the study with other previous studies of different world populations.

Study	Year	Country	Method	Mean (In mm)
Alon Wolf et al	2001	Israel	CT scans	31.04
Edgar Urrutia et.al	2009	Mexico	CT scans	33.10
Muhammad M. Alam	2014	Pakistan	CT scans	31.00
O. O.Azu et.al	2016	South Africa	Dry bones	31.96
Mohamed Tall et al	2018	Burkina Faso	CT scans	30.4
The current study.	2020	Saudi Arabia	CT scans	27.96

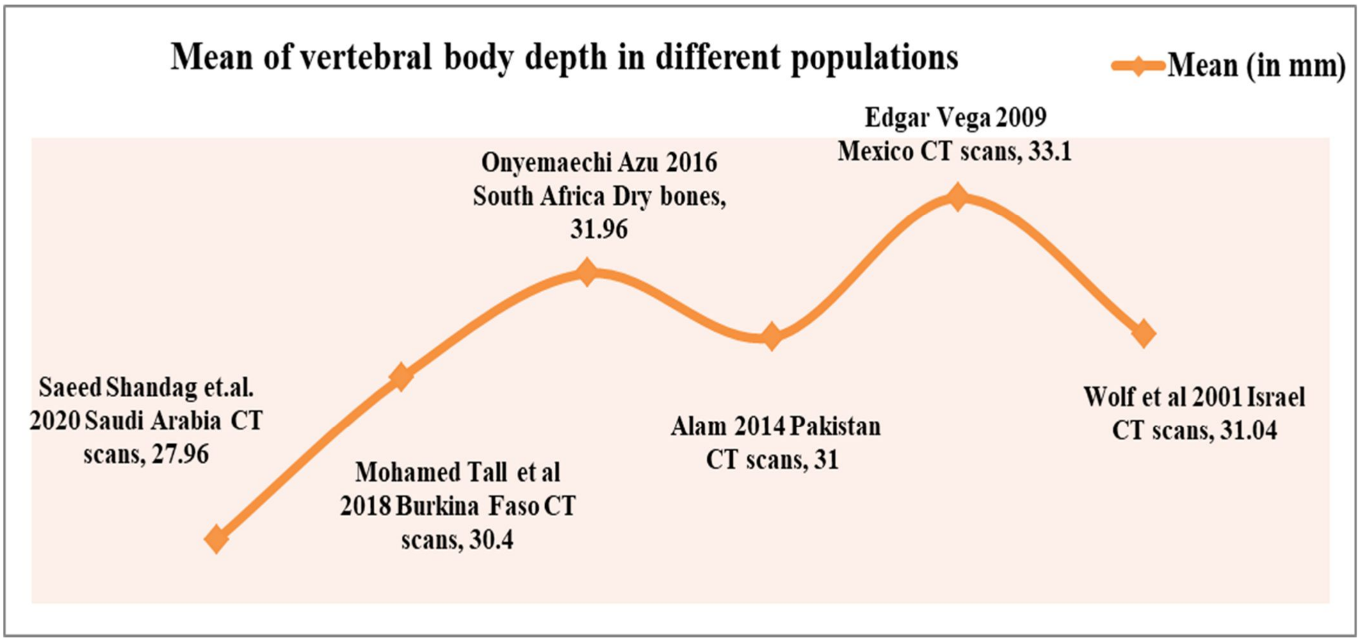

Figure 4.30:Demonstrated vertebral body width(VBD) of lumbar vertebral obtained from studies performed in different populations.

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Table.4.39: demonstrated comparison of vertebral body height(VBH) of lumbar vertebrae (L1-L5) between gender using independent sample t-test ,the results are expressed in (mm).

		Males	Females	T-values	Significance
L1	Mean	21.97	21.82	0.70	.49
	SD	1.67	1.47		
	Maximum	25.40	25.40		
	Minimum	18.40	18.40		
L2	Mean	22.37	22.32	0.15	.88
	SD	2.27	2.367		
	Maximum	26.90	26.90		
	Minimum	18	18		
L3	Mean	23.39	23.41	-0.07	.94
	SD	1.77	1.77		
	Maximum	26.90	26.90		
	Minimum	18	19		
L4	Mean	24.53	24.33	0.94	.35
	SD	1.52	1.55		
	Maximum	27	27		
	Minimum	21	21		
L5	Mean	24.89	24.86	0.07	.94
	SD	2.60	2.82		
	Maximum	30.90	31		
	Minimum	22	22		

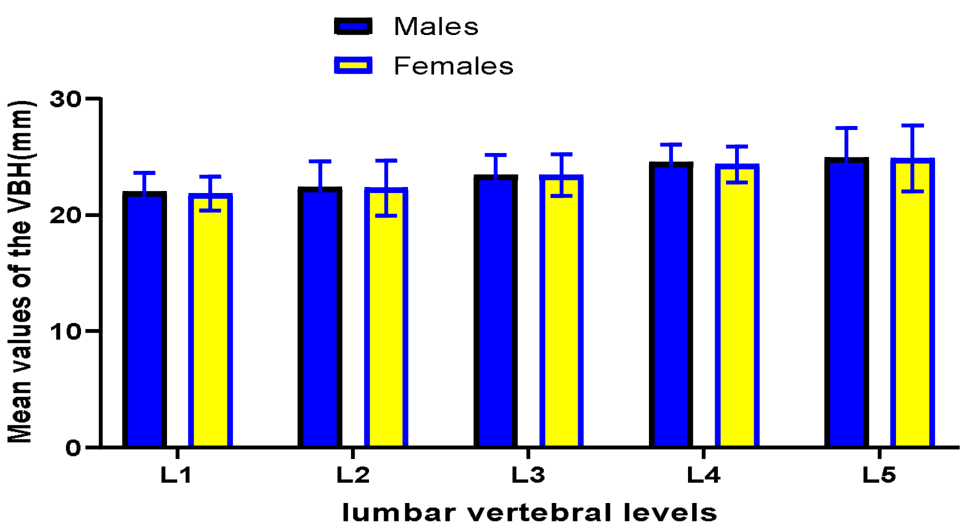


Figure.4.31: demonstrated bar chart showing the mean values of the (VBH) at each level between the gender among participants.

Table:4.40: Demonstrated the mean values, SD and ranges of vertebral body width (VBH) of lumbar vertebrae(L1-L5)using descriptive Statistics analysis, e results are expressed in (mm).

	N	Range	Minimum	Maximum	Mean	Std. Deviation
VBH- L1	200	7	18.4	25.4	21.90	1.57
VBH- L2	200	8.90	18	26.9	22.35	2.31
VBH- L3	200	8.90	18	26.9	23.40	1.77
VBH- L4	200	6	21	27	24.43	1.54
VBH- L5	200	9	22	31	24.88	2.71

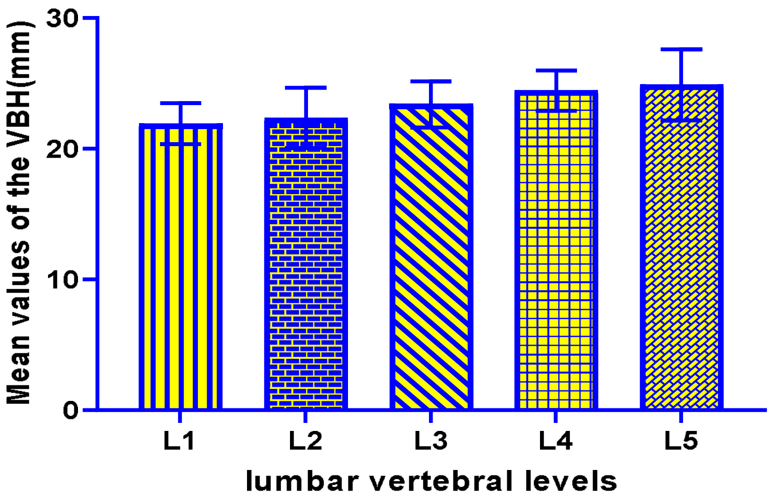


Figure 4.32: Bar chart showing dimension of (VBH) mean values in (mm) and SD in sample at each lumbar vertebral level between participants.

Table:4.41: Comparison of mean vertebral body width (VBH) of the study with other previous studies of different world populations, results are expressed in (mm).

Study	Year	Country	Method	Mean (In mm)
El Sayed .Atta-Alla et al	2014	Lebanon	Plain X-ray	32
Alon Wolf et al	2001	Israel	CT scans	26.20
Edgar Urrutia et al	2009	Mexico	fluoroscopy	29
Mohamed Tall et al	2018	Burkina Faso	CT scans	25.72
Theodoros B. et al	2019	Greek	CT scans	27.47
The current study.	2020	Saudi Arabia	CT scans	24.50

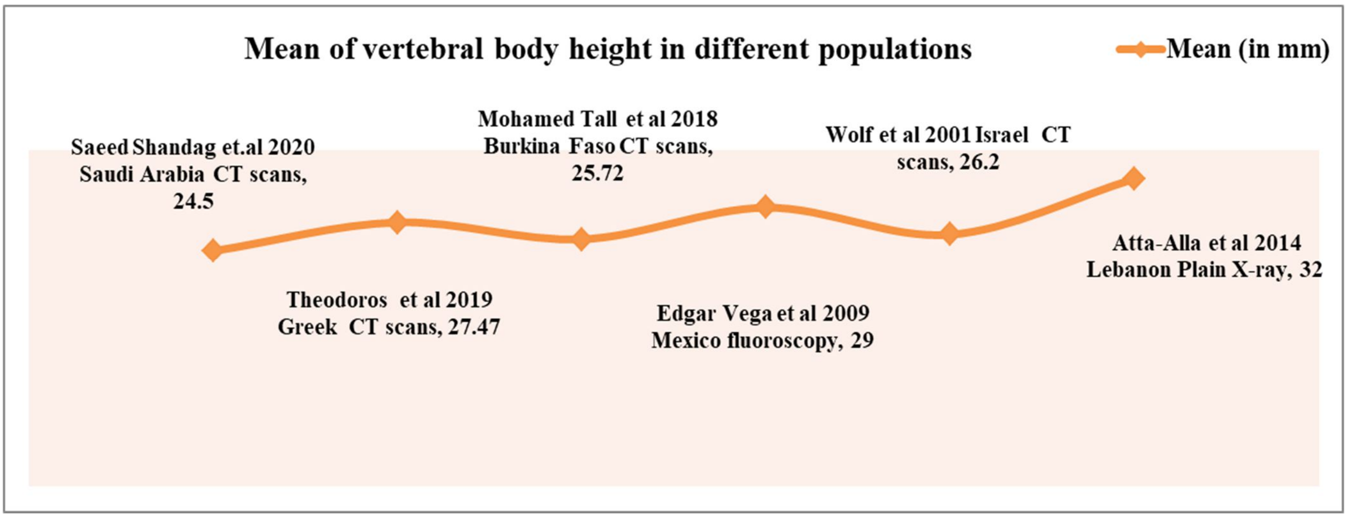


Figure 4.33:showing vertebral body width(VBH) of lumbar vertebral obtained from studies performed in different populations.

Table.4.42: Demonstrated comparison of spinal canal depth(SCD) of lumbar vertebrae (L1 -L5) between gender using independent sample t-test ,the results are expressed in (mm).

		Males	Females	T-values	Significance
L1	Mean	17.82	17.80	0.08	0.93
	SD	1.84	2.00		
	Maximum	21.40	21.40		
	Minimum	15	15		
L2	Mean	16.66	16.92	-1.05	0.29
	SD	1.65	1.88		
	Maximum	20.80	20.80		
	Minimum	14	14.20		
L3	Mean	16.03	16.36	-1.50	0.13
	SD	1.43	1.58		
	Maximum	19.50	19.50		
	Minimum	12.50	12.50		
L4	Mean	16.16	16.21	-0.18	0.86
	SD	1.96	1.88		
	Max	21	21		
	Min	13	13.40		
L5	Mean	16.34	16.48	-0.58	0.56
	SD	1.84	1.67		
	Max	19	19		
	Min	12.90	12.90		

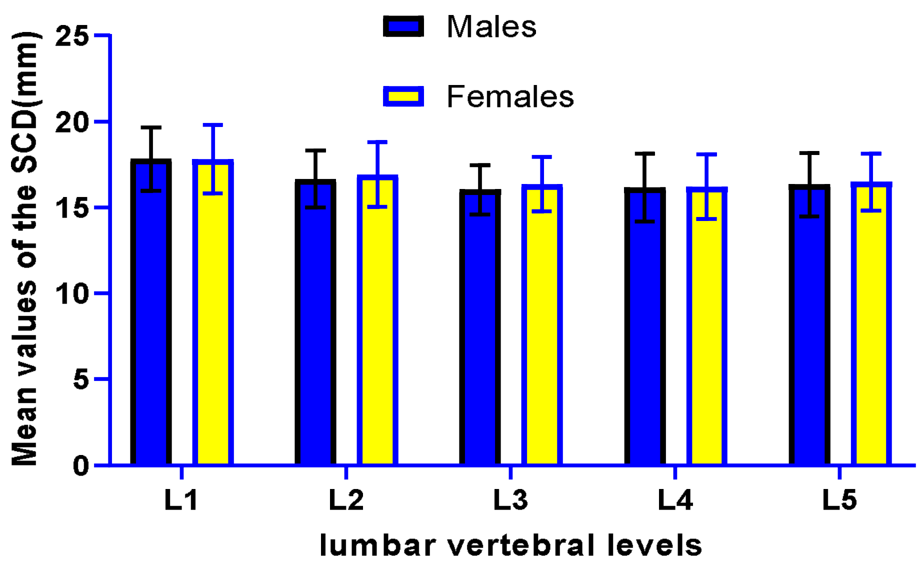


Figure.4.34: Demonstrated a bar chart showing the mean values of the SCD at each level between the gender among participants.

Table:4.43: Demonstrated the mean values, SD and ranges of(SCD) of lumbar vertebrae (L1-L5)using descriptive Statistics analysis, the results are expressed in (mm).

	N	Range	Minimum	Maximum	Mean	Std. Deviation
SCD L1	200	6.40	15	21.4	17.81	1.92
SCD L2	200	6.60	14.2	20.8	16.79	1.77
SCD L3	200	7	12.5	19.5	16.19	1.51
SCD L4	200	8	13	21	16.19	1.92
SCD L5	200	7	12.9	19.9	16.41	1.76

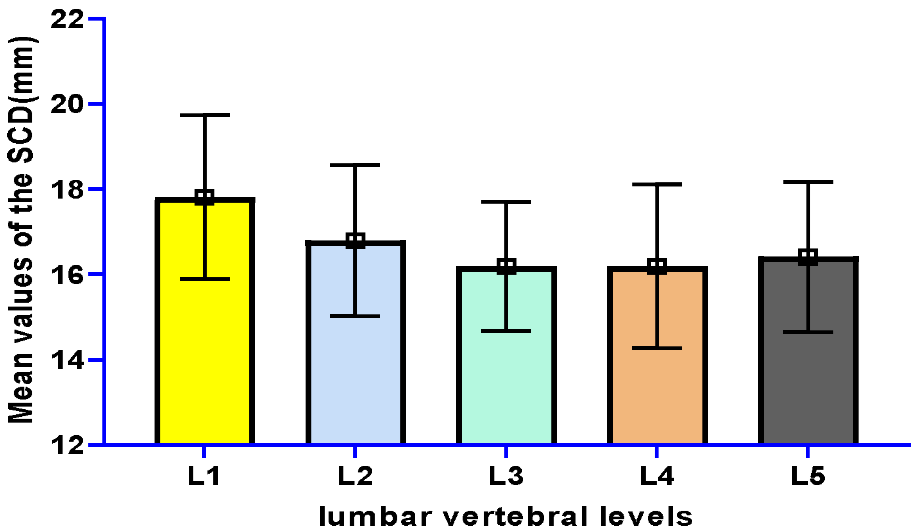


Figure.4.35: Bar chart showed dimension of (SCD) mean values in (mm) and SD in sample at each lumbar vertebral level between participants.

Table:4.44: Demonstrated comparison of mean (SCD) of the study with other previous studies of different world populations .Results are expressed in (mm).

Study	Year	Country	Material for Study	Mean (In mm)
El-Rakhawy et al	2010	Egypt	Dry bones, radiographs	14.86
Tarek Aly	2013	Egypt	Dry bones	15.90
AZU, O. O.et.al	2016	South Africa	Human cadavers	17.41
Roxana ToRRes et al	2016	Mexico	CT scans	16.4
Mohamed Tall et al	2018	Burkina Faso	CT scans	15.16
Elhassan, et al	2019	Sudan	MRI	17.19
The current study.	2020	Saudi Arabia	CT scans	16.68

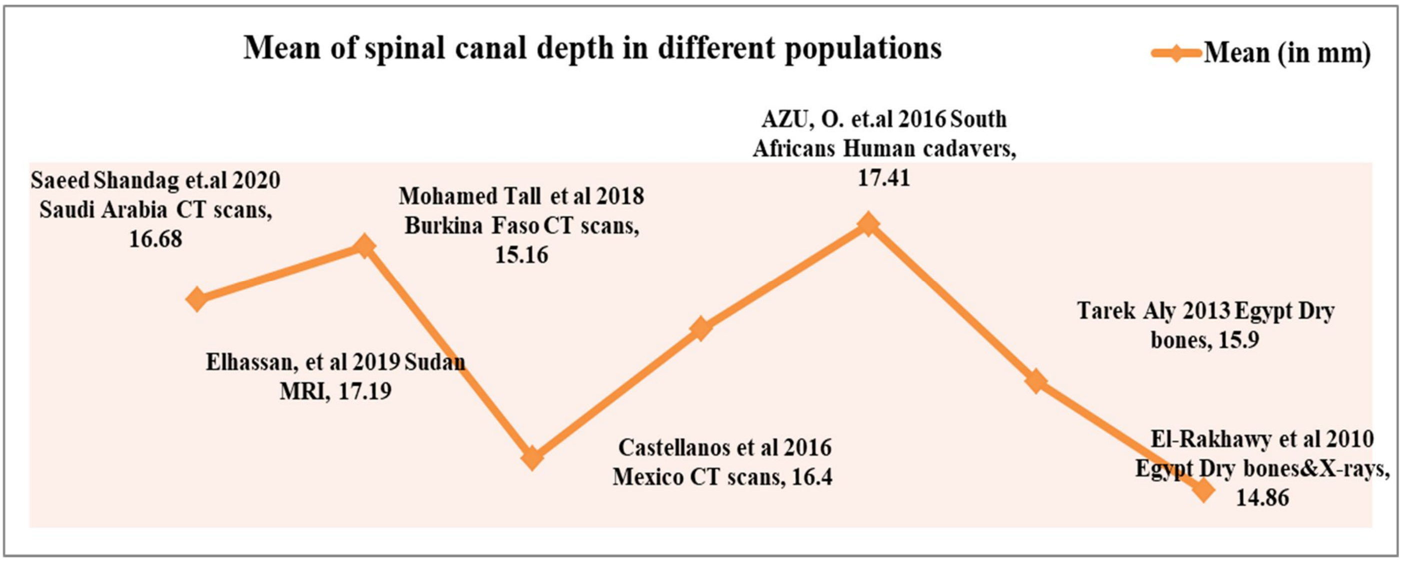


Figure 4.36: demonstrated spinal canal depth(SCD) of lumbar vertebral obtained from studies performed in different populations.

4.3: Measurements of Pedicle index(PI) :

It's the ratio of the pedicle width to the pedicle height at each lumbar vertebral level, that is to say

Pedicle index = Pedicle width (PDW)/Pedicle height (PDH)

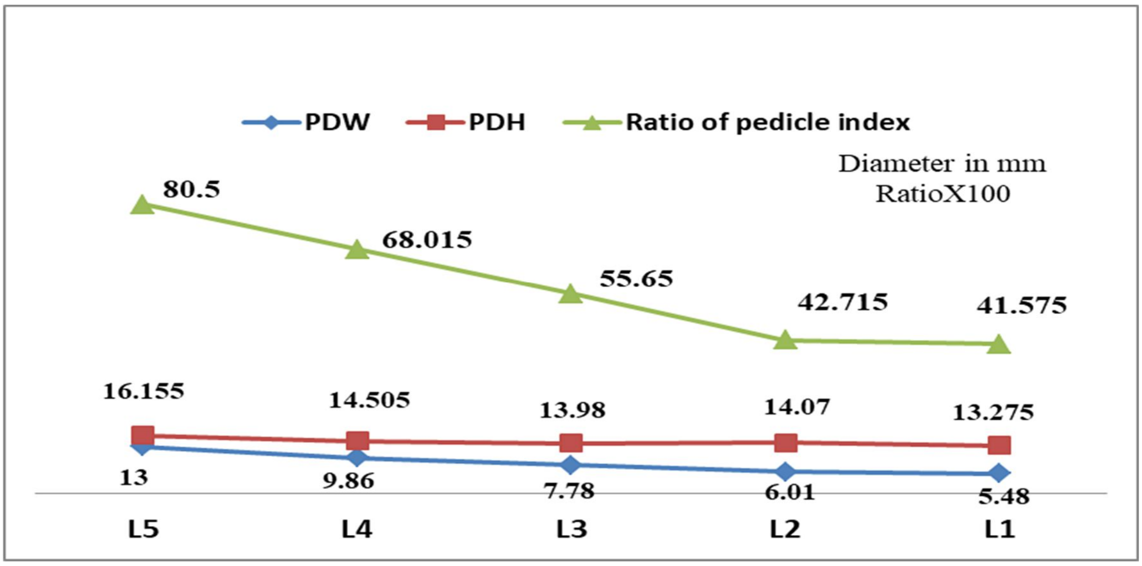
Table 4.45: Demonstrated Pedicle width &Pedicle height (mean ± SD, mm):

	Pedicle width (PDW)			Pedicle height (PDH)		
Level	Male	Female	Total	Male	Female	Total
L1	5.56±.95	5.39±.68	5.48±.828	13.36±1.83	13.19 ± 1.86	13.275±1.84
L2	5.98±.653	6.04±.83	6.01±1.74	14.04±1.91	14.1±1.92	14.07±1.95
L3	7.67±.75	7.89±.65	7.78±2.70	13.98±1.25	13.98± 1.20	13.98±1.225
L4	9.74±.900	9.99±1.17	9.86±1.05	14.57±1.64	14.44±1.50	14.505±1.57
L5	12.99±1.29	13.02±1.05	13.00±1.17	16.19 ±1.41	16.12±1.52	16.155±1.465

Table 4.46: Depicted the ratio of pedicle width to Pedicle height (mean ± SD, %):

Level	Pedicle index		
	Male	Female	Total
L1	42.29± 4.15	40.86±3.05	41.575± 3.6
L2	42.59± 3.22	42.84± 3.75	42.715±3.485
L3	54.86± 3.30	56.44± 2.81	55.65±3.055
L4	66.85± 3.98	69.18± 3.63	68.015±3.805
L5	80.23± 4.54	80.77 ± 4.66	80.5±4.6

A-



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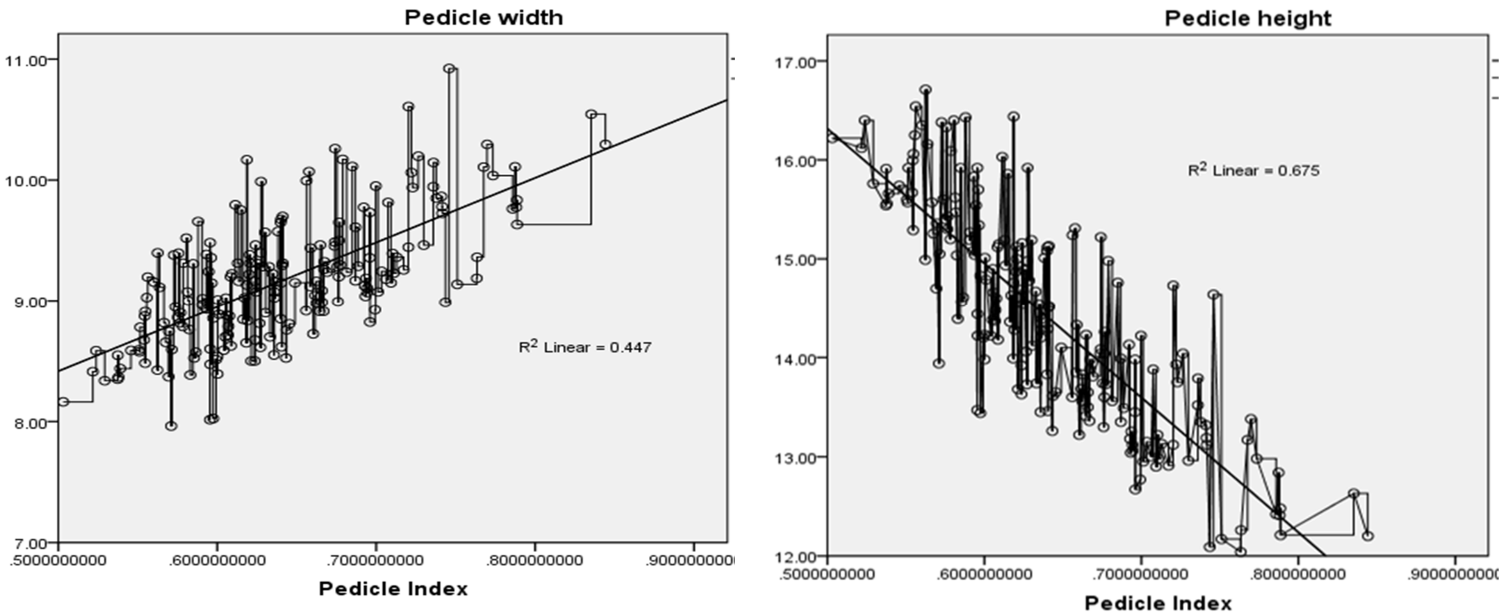


Figure 4.37: A-The mean PDW, PDH, and the ratio of (PDW/PDH X 100) L1–L5 are demonstrated on a linear graph. B- The pedicle index curve is more similar to both the PDH (r2 = 0.675) curve and the PDW (r2 = 0.447) curve, especially at lumbar levels of L1–L3,PDW curve depicted positive linear relationship with Pedicle index and PDH curve depicted negative linear relationship with Pedicle index.

4.4 Measurements of (CT ratio) or pedicle ratio:

The ratio of pedicle width (PDW) to the vertebral body width (VBW).

Pedicle ratio (CT ratio) = Pedicle width (PDW)/Vertebral body width (VBW)

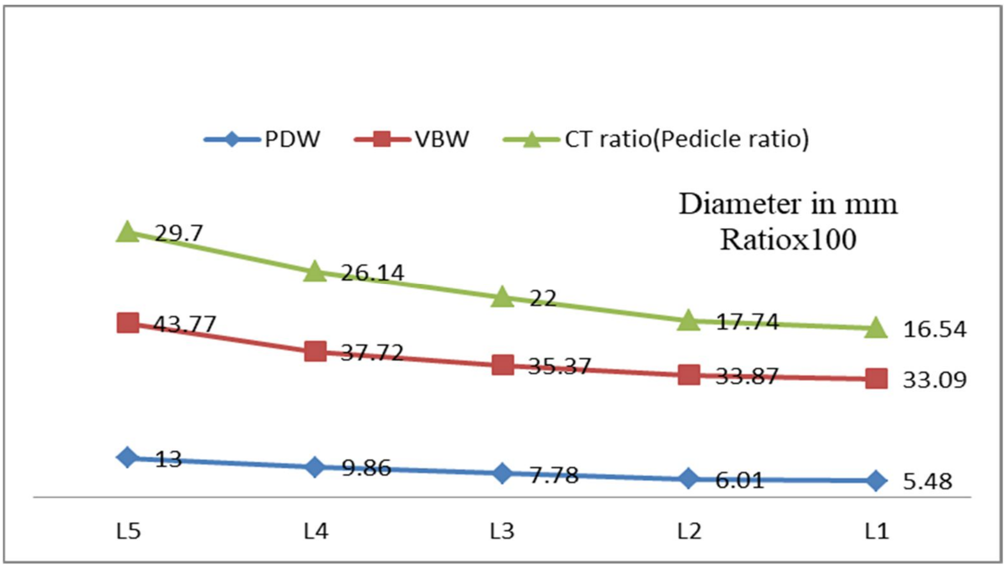
Table 4.47: Depicted the Pedicle width& vertebral body width (mean ± SD, mm):

	Pedicle width (PDW)			Vertebral body width		
Level	Male	Female	Total	Male	Female	Total
L1	5.56±.95	5.39±.68	5.48±.828	33.29±2.80	32.90±2.54	33.09± 4.00
L2	5.98±.653	6.04±.83	6.01±1.74	34.02±2.66	33.72±2.23	33.87± 4.11
L3	7.67±.75	7.89±.65	7.78±2.70	35.78±2.66	34.97± 2.63	35.37± 4.66
L4	9.74±.900	9.99±1.17	9.86±1.05	38.11±2.73	37.32±2.20	37.72± 3.88
L5	12.99±1.29	13.02±1.05	13.00±1.17	43.97±3.09	43.57±2.51	43.77± 4.89

Table 4.48 Showed CT ratio or pedicle ratio of the pedicle width to vertebral body width (mean ± SD, %):

Level	CT ratio (pedicle ratio)		
	Male	Female	Total
L1	16.70 ± 2.45	16.38 ± 2.07	16.54 ± 4.16
L2	17.58 ± 2.00	17.91 ±2.77	17.74 ± 4.35
L3	21.44 ± 2.13	22.56± 2.81	22.00± 3.88
L4	25.56 ± 2.98	26.77± 2.55	26.14± 3.95
L5	29.54± 2.54	29.88 ± 3.66	29.70± 4.56

A-



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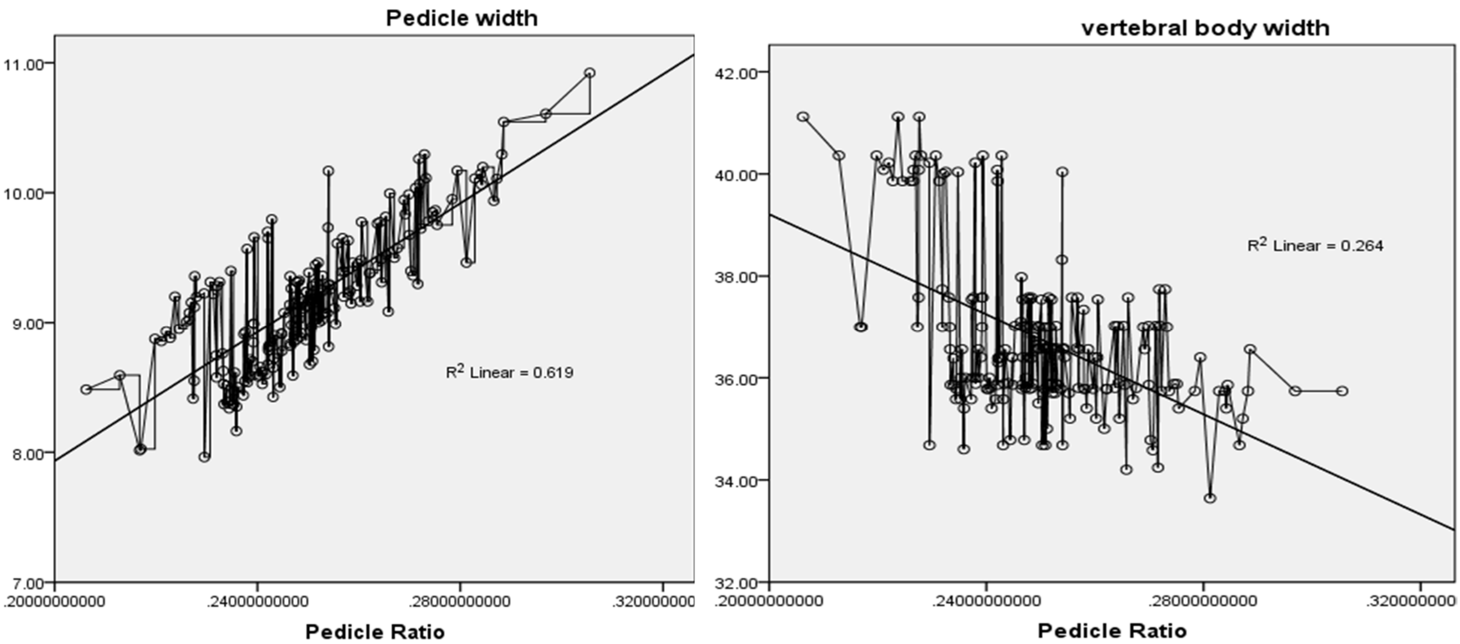


Figure 4.38: A-The mean PDW,VBW,and the ratio of (PDW/VBWX100) L1–L5 are demonstrated on a linear graph. B- The pedicle ratio curve is more similar to the PDW curve (r2 = 0.619) than the VBW (r2 = 0.264) curve, especially at lumbar levels of L1–L2,PDW curve depicted highly positive linear relationship with Pedicle ratio and VBW curve depicted negative linear relationship with Pedicle ratio.

4.5: Spinal canal ratio: Spinal canal ratio SCW/VBW =

Mean spinal canal width /Mean vertebral body width

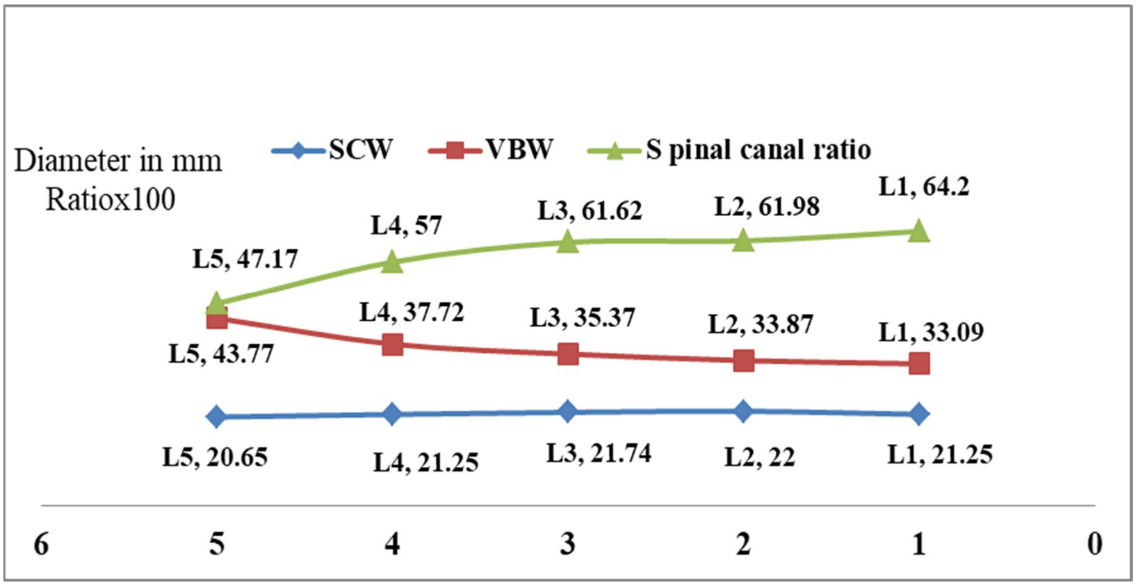
Table 4.49Demonstrated the spinal canal width and vertebral body width (mean ± SD, mm):

Level	Spinal canal width(SCW)			Vertebral body width (VBW)		
	Male	Female	Total	Male	Female	Total
L1	21.36 ±1.24	21.14±1.1	21.25 ± 1.26	33.29±2.80	32.90±2.54	33.09± 4.00
L2	21.21±2.00	20.78±2.4	22.00± 2.2	34.02±2.66	33.72±2.23	33.87± 4.11
L3	22.04±2.90	21.45±2.5	21.74 ± 2.7	35.78±2.66	34.97± 2.63	35.37± 4.66
L4	22.04±2.90	20.96±2.7	21.25 ±2.8	38.11±2.73	37.32±2.20	37.72± 3.88
L5	20.85±2.89	20.45±2.5	20.65 ± 2.70	43.97±3.09	43.57±2.51	43.77± 4.89

Table 4.50: Demonstrated the ratio of spinal canal to at each level (mean ± SD, %):

Level	Spinal canal ratio		
	Male	Female	Total
L1	64.16 ± 2.02	64.25± 3.05	64.20 ± 3.83
L2	62.34 ± 2.33	61.62 ± 3.75	61.98 ± 3.35
L3	61.60 ± 2.78	61.65 ± 2.81	61.62 ± 3.19
L4	57.83± 3.98	56.16± 3.63	57.00 ± 3.94
L5	47.42 ± 4.54	46.93 ± 4.66	47.17 ± 4.6

A-



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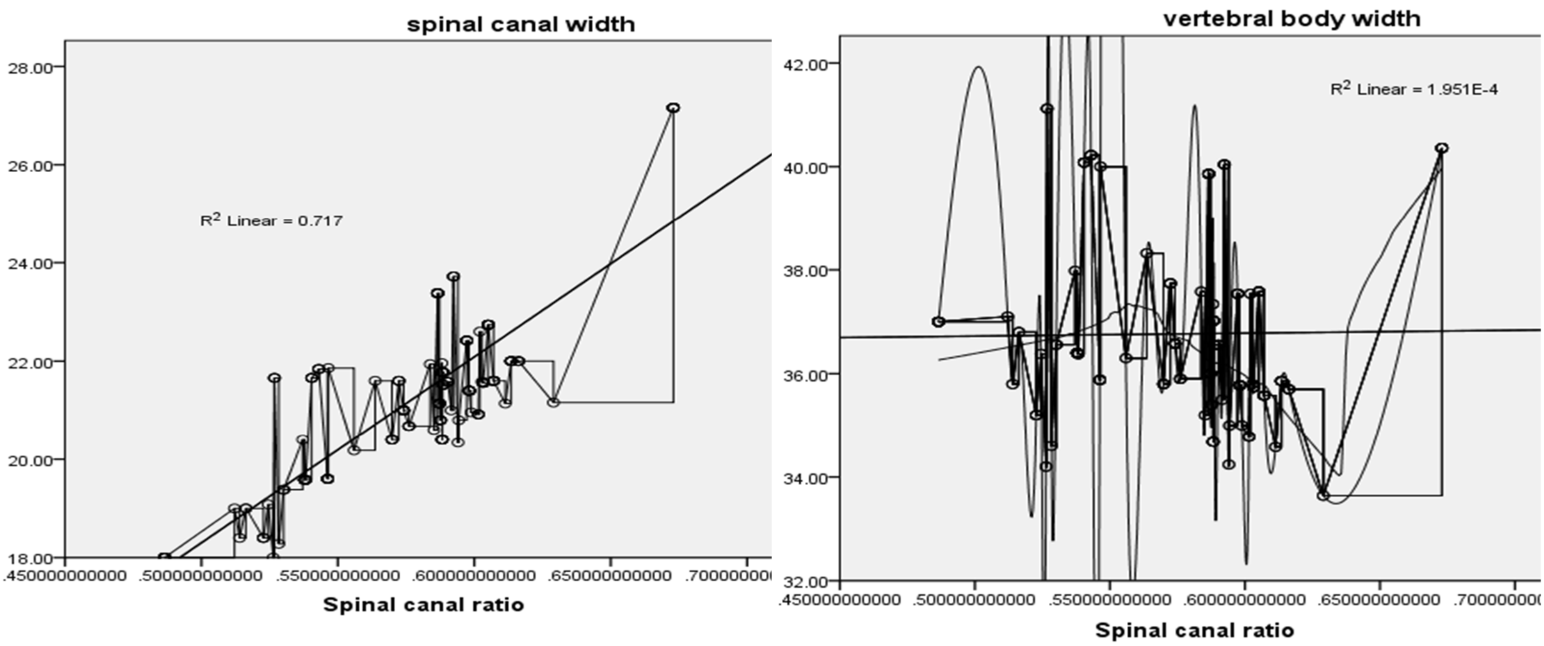

Figure 4.39: A. The mean SCW, VBW, and the ratio (SCW/VBWx100) for L1–L5 are depicted on a linear graph. B. The Spinal canal ratio curve is more similar to the SCW (r2 = 0.717) curve than the VBW (r2 = 1.951E) curve, along lumbar vertebral levels of L1–L5. SCW curve demonstrated a positive linear relationship with spinal canal ratio and VBW curve depicted no linear relationship with spinal canal ratio.

Chapter Five

Discussion, Conclusion and Recommendations

Chapter Five

Discussion, Conclusion and Recommendations

5.1.Discussion:

This study analyzed 200 participants, lumbar vertebral level (L1-L5)(1000 vertebrae,2000 pedicles) ,with the mean age of the 100 male was 41.36 years and the mean age of the 100 female patients was 40.70 years.(Figure.4.1).

The participants ranged from 19-75 years, were subdivided into 5 categories. The frequency and percentage of each age category among participants is depicted in (Table 4.1) and (Figure 4.2) .Participants in the categories of 26-36 years represent the highest percentage (36%) among the study sample, followed by 46-55yrs (22%). Participants with age less than 25years are only 9%,followed by 36% between 26-35yrs of age, 18.5% falling in 36-45years age group, 22.00% in 46-55years age group and 14.50% above 55years.

Pearson's correlation coefficient was used to check for relation between age of participants and the whole variables at each lumbar vertebral level, the correlation results found that there were a high significant correlation between age and lumbar measurements, pedicle width(PDW) was significantly correlated with age at L1,L2 and L5, pedicle axis length(PAL) at L2,L3 and L4 only, pedicle height (PDH) correlated at all level except L1, for angles measurements the correlation was significant in both variables for each level with exception of L1 in transverse pedicle angle (TPA) and L5in sagittal pedicle angle(SPA). For the vertebral body variables, vertebral body width(VBW) was significantly correlation at each lumbar level(the strongest correlation among all variables),vertebral body depth(VBD) and vertebral body height (VBH) were both significantly correlated with age at each level with exception of L2 in (VBD) and L1in (VBH).spinal canal width(SCW) correlated at L2,L4 andL5 whereas, spinal canal depth(SCD) correlated with age at all level except L5 (Table.4.2).

The total participants was N = 200. The interest was in determining a significant mean difference between the right and the left pedicles width in terms of pedicle width (L1 to L5) .As such, a two-tailed dependent samples t-test ($\alpha = 0.05$) was used to compare the means. The mean ± Standard Deviation (in mm)for the right pedicles width of the lumbar vertebrae [L1, L2, L3, L4 and L5] were (5.46± .90, 6.01± .81, 7.81± .76, 9.83± 1.11 and 13.00± 1.20) and (5.49 ±.88,6.01±.79,7.75±.80,9.90±1.08,13.01±1.23) for the Left pedicles width respectively.
The range (in mm) for the right pedicles width of the lumbar vertebrae[L1, L2, L3, L4 and L5] were (4.00 -9.23,4.80-9.06,5.00-9.80,8.00-12.90 and 10.00-15.70) and (4.00-9.87,4.90-9.06,5.00-9.70,8.00-12.90 and9.00-15.50) for the Left pedicles width respectively. The minimum (4.0 mm) and maximum (15.70 mm) readings for both right and left pedicles width were noted at both (Rt and Lt)L1 and only (Rt) L5respectively. The results were not significant ($P>0.05$).There was not enough evidence to conclude that right pedicle are any different from left pedicles of the lumbar vertebrae[L1, L2, L3, L4 andL5]t(199)=L1(-0.62,p=0.54),L2(-.14,p=.88),L3(1.32,p=.19),L4(1.58,p=.12) and L5 (-.29,p=.77) respectively. The mean pedicle width of the pedicle on the left side was (8.43 ± 0.95 mm) and on the right side was (8.42 ± 0.96 mm). Data regarding these comparison are listed in (Table 4.3) and presented as graphs in (Figure 4.3).The result of measurements of the right and left pedicles width (PDW) of the lumbar vertebral increased gradually from L1 to L5 level, the minimum width of the pedicles was measured at L1 and the maximum width of

the pedicle was measured at L5 level and our measurements are in line with that of other studies.

The Student's t-test (two-tailed independent samples) table was used to analyze for differences between gender male (n = 100) and female (n = 100) at α = 0.05 of the lumbar vertebrae [L1, L2, L3, L4 and L5]. The mean ± Standard deviation (in mm)for the males were(5.56±.95),(5.98±.65),(7.67±.75),(9.74±.90)and(12.99±1.29)and(5.39±.68), (6.04±.83),(7.89±.65),(9.99±1.17) and 13.02±1.05) for the females respectively. The pooled data of gender are listed in(Table4.4)and presented as a bar chart graphs in (Figure 4.4) .The results suggest that the average pedicle width L3 is less for male (M = 7.67±0.74) than for female (M = 7.89±0.65), t(198) = -2.156, p =0.032(P<0.05),whereas the results for other levels suggest no significant difference (P>0.05) between male and female t(198) = (L1=1.49, P =0.13), (L2= -.62, P= 0.535),(L4= -1.76,P=.080)and(L5= -.18,P=.85) respectively.

The largest mean lumbar pedicle width was seen at vertebral level L5 in both males (12.99±1.29) and females (13.02±1.04) and the least was at vertebral level L1 in both males (5.56±.94) and females (5.39±.68) (Figure 4.4). The minimum (5.39mm) and maximum (13.02mm) readings for both male and female pedicles width were noted both at (female L1) and (female L5)respectively. In all the vertebral levels, the mean pedicle width was slightly larger in females than in males and the difference was statistically insignificant (p >0.05) except at vertebral level L1 (Table 4.4).

The result in (Table 4.4) and(Figure 4.4) demonstrated that the mean values of pedicle width of L3 in male (7.6 mm) was slightly smaller than that of L3 female (7.88 mm). lumbar vertebrae increased gradually from L1 to L5 in both males and females ,the largest PDW was located at female L5 (13.02 mm) and the smallest PDW was located at female L1 (5.39 mm). The mean (PDW) of the pedicle in males was (8.39 ± 1.23) mm and in females was 8.47 ± 1.17 mm (Table 4.4).

Post-hoc ,Bonferroni-corrected pairwise analysis demonstrated that the mean pedicle width at vertebral levels L5 in the lumbar spine was significantly larger in older age categories (more than 55) than in younger age category(26-35) (p≤ 0.05) (Table 4.6). No significant differences were found between the mean pedicle width and both categories in all the other lumbar vertebral levels.

The overall results of the mean values ,SD and range of pedicles width(PDW) of lumbar vertebrae(L1-L5),for the total participants Jazan population, demonstrated at (Table 4.8) (Figure 4.6) using descriptive Statistics analysis, the table and the figure declared the gradually increase of the mean vaules from L1 to L5. This finding was supported by most of pedicles width measurement in different populations with slight differences in values (Table 4.9)(Figure 4.7),such as; Amonoo Kuofi (1995 in Saudi Arabians)Kim et al (1994 in Koreans) ; Single et al(2004 in Indians) and Anastasios et al(2005 in Greek).The mean values (in mm) ± SD were (L1=5.48±.828, L2 6.012±.74, L37.78±.71, L49.87±1.049 and L513.008±1.176) respectively. and the (Mean value for the PDW(L1 to L5) =(8.43 mm ± 1.43).

The results of pedicle width in our study(Jazan population)compared with different populations are demonstrated in (Table4.9)(Figure 4.7) ,these studies depicted corresponding with our study in gradually increase in pedicle width from L1 to L5.

The results (Table 4.9) convinced that there was a great variation in (PDW) between this study and the study of Amoono kaufi in 1995 among Saudi Arabians though both studies were employed in the same country but with different in races and ethnicities and the method of each study (Amoono kaufi ,1995) used the plain radiograph where in our study we were used CT scan as a method of measurement. The greatest variation that shown in the mean value seen in the table was between Jazan population and Spanish by (Olmos, Villas et.al) published in 2002 with the use of CT scan as a measurement method.

The range of the pedicle width for typical lumbar vertebrae has been mentioned by (Zindrick MR et al.1976) as 4- 17 mm, (Ebraheim et al,1996) as 5 - 17 mm and (Aruna N et al,2011) as 4.5- 20 mm as compared to (4.25mm -15.60mm) in the present study.

Pedicle height also influences pedicle screw selection. However, in all studies, it has been established that the pedicle height is always greater than the pedicle width (Dhaval et al 2014).Our study agrees with this finding. Some authors claim that pedicle height should not be considered as a morphometric parameter for proper selection of a transpedicular screw (Maillot and Gabel, 1993).

The total participants was N = 200. The interest was in determining a significant mean difference between the right and the left pedicles height in terms of pedicle height (L1 to L5) .As such, a two-tailed dependent samples t-test (α = 0.05) was used to compare the means. The mean ± Standard Deviation (in mm)for the right pedicles height of the lumbar vertebrae [L1, L2, L3, L4 and L5] were (13.25 ± 1.85, 14.06± 1.93,13.99±1.32,14.51±1.61and16.17±1.48)and(13.30±1.92,14.08±1.94,13.98±1.25,14.49 ±1.57,16.15±1.51) for the Left pedicles height respectively.The range (in mm) for the right pedicles height of the lumbar vertebrae[L1, L2, L3, L4 and L5] were (10.90-17.90, 11-18, 11.70-17.90,11.50-17.60,12.80-19.50) and ((11-17.90,11-17.90,11.90-17.90,11.50-17.70, 12.80-19.40) for the Left pedicles height respectively.

The minimum (10.90 mm) and maximum (19.50 mm) readings for both right and left pedicles height were noted at (Rt)L1 and (Rt) L5 respectively. The results were not significant. There is not enough evidence to conclude that right pedicle are any different from left pedicles of the lumbar vertebrae[L1, L2, L3, L4 and L5] t(199) = (-1.040 , sign = .300),(-.667,sign=.505),(.196,sign= .845),(.298,sign=.766) and (.390,sign=.697) respectively. The mean pedicles height (PDH) of the pedicle on the left side was 14.4 ± 1.638 mm and on the right side was 14.396 ± 1.638 mm. Data regarding this comparison are listed in (Table 4.10) and presented as graphs in bar chart (Figure.4.8).The result of measurements of the right and left pedicles height (PDH) of the lumbar vertebral increased gradually from L1 to L2 level, then reduced for a little bit in L3 and then again increased gradually from L3 to L5 ,the minimum of the pedicles height was measured at right L1(13.25 ± 1.85) and the maximum of the pedicle was measured at right L5(16.17±1.48) level.

In gender comparison regarding (PDH),the mean pedicle height (L1,L2,L3.L4 and L5) for males (n =100) and females (n = 100) was statistically compared using the *Student's t-test (two-tailed independent samples) at α = 0.05*. The results suggested that average male scores (13.36±1.83,14.04±1.91,13.98±1.25,14.57±1.64and16.19±1.41) and average female scores ((13.19±1.86,14.10±1.92,13.98±1.20,14.44±1.50,16.12±1.52)) are not significantly different between males and females, t(198) = (L1=0.627, P =0.531), (L2= -.232, P= 0.817),(L3= -0.018,P=.0.986) (L4= 0.569, P= 0.570)and(L5= 0.347,P=0.729) for the vertebral pedicles height respectively. The pooled data of gender that listed in (Table4.11) (Figure.4.9) ,presented the largest mean lumbar pedicle height was seen at vertebral level L5 in both males (16.19±1.41) and females (16.12±1.52) and the least was at vertebral level L1 in both males (13.36±1.83) and females (13.19±1.86). The minimum (13.19 mm) and maximum (16.19mm) readings for both male and female pedicles height were noted at (females L1) and (males L5)respectively.

The mean pedicle height was slightly larger in males than in females and the difference was statistically insignificant ($p > 0.05$) . (Table 4.11). The mean pedicles height (PDH) of the pedicle in males was 14.43 ± 1.98 mm and in females was 14.37 ± 1.69 mm. Data regarding this comparison are listed in (Table 4.11) (Figure.4.9)

The result in (Table 4.11) and(Figure 4.9) demonstrated that the lumbar vertebrae increased gradually from L1 to L5 in both males and females ,the largest PDH was located at male L5 (16.19 mm) and the smallest PDH was located at female L1 (13.19 mm).

The overall result of measurements of the pedicles height (PDH) of the lumbar vertebral among Jazan population increased gradually from L1 to L2 level, then reduced in L3 and then again increased gradually from L3 to L5,our measurements in (PDH) are in line with that of some other studies.(Table 4.12) (Figure.4.10).

The mean values(mm) for pedicle height (14.40mm)in our study compared with other races and ethnicities in the world the results demonstrated (Table.4.13) (Figure.4.10)high corresponding with other population such as; Egyptian(14.55mm),Indians(14.65mm)and Israel(14.8mm).

The results (Table 4.13) convinced that there was no great variation in (PDH) between this study and that of Amoono kaufi in 1995 among Saudi Arabians as both studies were employed in the same country but with different in races and ethnicities and the method of each study (Amoono kaufi ,1995) used the plain radiograph where in our study we were used CT scan as a method of measurement. The study by (Amonoo-Kuofi ,1995)depicted that the height of pedicles in males & females are maximum at L5 with 20.7mm & 17.5mm respectively(Table 4.14), the present study reveals that the height of pedicles is maximum also at L5,with 16.19 and 16.12 respectively. Amonoo-Kuofi convinced that there was a cephalocaudal gradient of increase (from L1-L5) of the pedicles (height) in males and females, this later result corresponding with our study. But it is quite intriguing that, some studies showed a gradually decrease in height of pedicles (male & female) from L1-L5.,such as Kim NH et al in 1994 (T1 to L5), Prakash et. al 2007 (L1 to L5) and Karkhyle et.al 2015 (L1 to L5).(Table 4.14).

The greatest variation that shown in the mean value of (PDH) seen in (Table 4.13) and (Figure 4.10) was between Jazan population (14.40mm) and by (Amonoo-Kuofi) published in 1995 (17.93mm) with the use of different study method plain X-ray for (Amonoo-Kuofi) and CT scan as a measurement method for our study.

The range of pedicle height for typical lumbar vertebrae has been mentioned by Ebraheim et al as (10 - 18 mm) , Aruna N et al as (10.5 - 20 mm) and Dhaval. patel.(10.22 - 17.54 mm) as compared to(10.95 - 19.25 mm) in the present study.

Pedicle Interpedicular distance (IPD):or spinal canal width(SCW) represents a very important role in the measurement of the spinal canal ratio regarding spinal stenosis.

CT and myelography are important in patients who, for technical reasons, cannot enter the MRI scanner (such as; those with pacemakers or claustrophobia) or in patients whose MRI findings do not correlate with clinical symptoms(Haaga JR, 2008).spinal stenosis, is a rising phenomenon due to aging of the population, and has been diagnosed increasingly in the last two decades(El-Rakhawy,2010).The pathology of this disease is most typically due to degenerative changes.(Zindrick MR,1986). (SCW) or (IPD) is a reliable index for the assessment of the size of the canal (Hamanashi,1994).Measurements of the interpedicular distance may be a preliminary, but useful aid in the diagnosis of the lumbar canal stenosis syndrome(Amonoo-Kuofi, 1982). Diagnostic imaging (radiographs and MRI scans) continues to play a pivotal role in the diagnosis and clinical decision making.(Amonoo-Kuofi,1982) and (Speciale AC et al., 2002) in their studies, have reported variable values of the ratio.
In comparing the gender regarding (the IPD)or (SCW).The interest was in determining a significant mean difference between these two groups in terms of Pedicle Interpedicular distance L1,L2,L3,L4 and L5 as such, a two-tailed independent samples t-test ($\alpha = 0.05$) was used to compare the means.

The results were not significant. There is not enough evidence to conclude that male scores (21.36 ±1.24,21.21±2.00,22.04±2.90 and 20.85±2.89) are any different from female scores (21.14±1.11,20.78±2.14,21.45±2.15,20.96±2.37 and 20.45±2.55), t(198) = (L1=1.34, P =0.18), (L2= 1.48, P= 0.14),(L3= 1.36,P=0.11), (L4= 1.79,P=0.08)and(L5= 1.05,P=.0.30) respectively. The pooled data of males and females are listed in (Table 4.15)and presented as a bar chart graphs in (Figure.4.11).presented the largest mean lumbar (IPD) was seen at vertebral level L3 in both males (22.04±2.90) and females (21.45±2.15) and the least was at vertebral level L5 in both males (20.85±2.89) and females (20.45±2.55).

The minimum (20.45 mm) and maximum (22.04mm) readings for both male and female (IPD) were noted at (females L5) and (males L3)respectively.

The mean interpedicular (IPD) distance was larger in males than in females and the difference was statistically insignificant (p >0.05) . (Table 4.15). The mean (IPD) of the pedicle in males was 21.42 ± 2.40mm and in females was 20.96 ± 2.06 mm. Data regarding this comparison are listed in (Table 4.15) and presented as graphs in bar chart (Figure.4.11)

The result in (Table4.15) and (Figure4.11)demonstrated that the lumbar vertebrae (IPD)decreased gradually from L1 to L2 in both males and females then increased in L3in both, this level(L3) represents the largest (IPD) in both males &females, then in level L4&L5 the gradual decreased again.

Measurements of lumbar vertebral (IPD)Or(SCW) is very important as its related to spinal canal ratio measurement for rule out the stenosis of the lumbar vertebrae.

The overall measurements of the (IPD) of the lumbar vertebral among Jazan population showing between the levels, L1(21.247), reduced in L2 to(20.997),then increased in L3(21.8190), then reduced gradually at L4 (21.3055),L5 (20.6520).,our measurements in (IPD) are totally not in line with that of other studies.(neither increase gradually from(L1-L5) nor decrease) .(Table 4.16) (Figure.4.12).

Our study mean value in(mm) (Table.4.17) (Fig.4.13)for interpedicular distant (IPD) compared with other different races and ethnicities in the world the mean of our result (21.21mm) was in close relation with some population though the difference in methods used between our study and others such as; south Africans(21.68mm)by AZU, O. O.et.al ,Egyptians (22.62mm)by Mohammed El-Rakhawy and Mexicans by Roxana Torres Castellanos.et.al (23.97mm).There was a large variation between our (IPD) mean value and some populations such as; Indians by A.S. Jadhavet.al(27.68),Spanish by Piera et al. (30.83) and Nigerians by Amonoo Kuofi HS. (26.12).(Figure.4.13).

Screws or chord length appeared to be safe at all lumbar levels when minimum mean chord length was determined. At the lower lumbar levels, higher lateral inclination of the pedicle should be kept in mind, as it may lead to the breach of the medial cortex of the pedicle with resultant risk to the neural tissues.

The morphometric characteristics of the vertebrae, and especially the pedicle axial length or chord length, determine the size of pedicle screw path length at the moment of introduction. Knowledge of the chord length is important for the surgeon to avoid pedicle cortex, meningeal, nerve root, facet joint, viscera or adjacent vascular structure lesions due to poor placement or improper screw orientation (Okutan et al.,2004).There are no studies to date in CT scan that analyze the morphometric characteristics of the lumbar vertebral pedicle in Jazan population, with this being of great importance for the proper planning, execution, and outcome of transpedicular lumbar spinal fusion.

The comparison between gender in relation to pedicle axis length (PDAL)or chord length or screw pathway showing that there were no a significant mean difference between these two groups regarding lumbar vertebral levels L1,L2,L3,L4 and L5 , as such, a two-tailed independent samples t-test (α = 0.05) was used to compare the means. The results were significant between males (49.08±2.13,49.97±2.57,50.07±2.78,49.70±1.52 and 50.66±2.25) and females (48.84±1.84,49.45±2.25,49.91±2.63,49.56±1.35 and 50.80±2.26), t(198)= (L1= 879,P .380), (L2= 1.523, P.129,(L3= .435,P.664), (L4=-.654,P.514) and (L5= -.442,P.659)respectively. The pooled data of males and females are listed in(Table 4.18)and shown also as a bar chart graphs in (Figure.4.14).The mean pedicle axial length was slightly larger in males in L1-L4 (in L5 the mean of females were larger than in males)than in females and the difference was statistically insignificant (p >0.05) (Table 4.18).The mean (PDAL) of the pedicle in males was 49.89± 2.30 mm and in females was 49.71 ± 2.06 mm. Data regarding this comparison are listed in (Table 4.18) and presented as graphs in bar chart (Figure.4.14).The largest mean lumbar chord length was seen at vertebral level L5 in both males (50.66±2.25) and females (50.80±2.26) and the least was at vertebral level L1 in both males (49.08±2.12) and females (48.83±1.83). The minimum (48.83 mm) and maximum (50.80mm) readings for both male and female pedicle axis length were noted at (females L1) and (females L5)respectively. The result in (Table 4.18) and(Figure 4.14) demonstrated that the lumbar vertebrae increased gradually from L1 to L5 in both males and females (PDAL) ,the largest (PDAL) was located at female L5 (50.80 mm) and the smallest (PDAL) was located at female L1 (13.19 mm).

The results of comparison of (PDAL) between younger (26-35 yrs.) and older (More than 55 yrs.) age categories using (ANOVA) table among Jazan population, found that the mean pedicle chord length in the younger age category(26-35 years) was larger than the mean pedicle chord length in the older age(More than55 years) category with statistically significant differences ($p \leq 0.05$) being depicted at all vertebral levels L1 to L5 (Table 4.19). whereas there was No statistically significant differences were found between male and female in all the vertebral levels ($p \geq 0.05$) (Table 4.19).

Post-hoc,Bonferroni-corrected pairwise analysis demonstrated that the mean pedicle chord length at vertebral levels L1,L2 and L3 in the lumbar spine was significantly larger in younger age categories (26 -35 years) than in older age category(>55years) ($p \leq 0.05$) (Table 4.20). No significant differences were found between the mean pedicle chord length and both categories in L4 and L5 lumbar vertebral levels.

The overall result of measurements of the pedicle axial length (chord length) (PDAL) of the lumbar vertebral among the 200 participants showed ,L1(48.96), increased gradually to L2 (49.71), L3(49.99), then reduced suddenly in L4 (49.63),then increment again in L5 (50.73).,our measurements in (PDAL) were in line with that of other studies.(Table 4.22) (Figure.4.16). the mean value for (PDAL)for the total participants was(49.80mm)

Our study mean value in(mm) (Table.4.23) (Figure.4.17) for chord length (PDAL) compared with other different races and ethnicities in the world the results showing that there were not a greater variation in the mean values of vertebra levels of our study (49.80mm) and others such as; USA (48.87mm) ,Turkey (47.91)and India (47.68mm), whereas the greater variation shown between our study and population of Singapore(41.78mm).(Ebraheim et al,1996) noted that the range of chord length for typical lumbar vertebrae is (38 - 58 mm) as compared to (48.83 -50.80mm) in our study. Screws of 41 to 42 mm length appeared to be safe at all lumbar levels as the minimum mean chord length was 48.83 mm.

Knowledge of transverse pedicle angle is important while placing screws because any inadvertent medial perforation due to wrong placement of the pedicle screw can put the spinal cord at risk or cause vascular injury (Dhaval and Pritha 2014 p.431).it's the angle of screw path inclination. Surgical intervention in this lumbar region requires thorough knowledge of the anatomy to identify a suitable site for instrumentation for fixation of spine.(Kunal Chawla et al ,2013) particularly the transverse pedicle angle which represents the angle of inclination.

A two-tailed independent samples t-test was used to compare the mean difference in transverse pedicle angle L1,L2,l3,L4 and L5 between males and females, the type I error rate was set at alpha = 0.05. The results suggest no significant difference between males (L118.71o ±1.97,L219.21 o ±1.92,L319.94 o ±1.76,L4 22.32o±2.28 and L5 25.71 o ±3.19) and females (L118.49 o ± 2.01,L2 19.20 o ±1.78,L3 19.90 o ±1.80,L4 22.44 o ±2.22 and L526.16 o ±2.76)respectively , t(198) = L1 (0.76,p=0.45),L2(0.04,P=0.96),L3(0.19,P=0.85),L4(-0.40,P=0.68)andL5(-1.07,P=0.29) respectively. The pooled data of males and females are listed in (Table4.24)and shown also as a bar chart graphs in (Figure.4.18) to explain the comparison between gender. The results of the TPA showed gradually increase in the degrees of angles from L1 to L5,the maximum TPA found to be among female at L5=(30.70 o) and minimum (TPA) found in both males and females (13 o) at L3.

The mean (TPA) was slightly larger in males in than in females and the difference was statistically insignificant (p >0.05) (Table 4.24).The mean (TPA) of the pedicle in males was 21.18 o ± 2.40 and in females was 19.24 o ± 2.33. Data regarding this comparison are listed in (Table 4.24) and presented as graphs in bar chart (Figure.4.18).

The largest mean lumbar transverse pedicle angle was seen at vertebral level L5 in both males (25.71^{o} ±3.19) and females (26.16^{o} ±2.76) and the least was at vertebral level L1 in both males (18.71^{o}±1.97) and females (18.49^{o}±2.01).The result in (Table 4.24) and(Figure 4.18) demonstrated that the lumbar vertebrae increased gradually from L1 to L5 in both males and females (TPA) ,the largest (TPA) was located at female L5 ((30.70 ^{o}) and the smallest (TPA) was located at female L1 (18.49 ^{o}).

The results found that the mean transverse pedicle angle (TPA) in the older age category (>55 years) was larger than the mean transverse pedicle angle (TPA) in the younger age category (26 to 35 years) with highly statistically significant differences ($p \leq 0.05$) being depicted at all vertebral levels L1to L5(Table4.25). No statistically significant differences were found between males and females at all the vertebral levels ($p \geq 0.05$) (Table:4.24). post-hoc, Bonferroni-corrected pairwise analysis also convinced that the mean transverse pedicle angle (TPA) at all vertebral levels L1-L5 in the lumbar spine was significantly larger in older age categories(> 55) than in younger age category(26-35) ($p \leq 0.05$) (Table:4.26).

The overall result of the mean values of the transverse pedicles angle (TPA) of the lumbar vertebrae among the 200 participants showed gradually increase from ,L1(18.59^{o}), L2 (19.20 ^{o}), L3(19.92 ^{o}),L4 (22.38 ^{o}) and L5 (25.93 ^{o}).,our measurements in (TPA) are totally in line with that of other studies.(Table 4.28) (Figure.4.20)

Our study mean value for the transverse pedicles angle(TPA) in(degrees) (Table.4.29) (Figure.4.21) compared with other populations in the world the results showing that the mean values of our study of this variable (TPA) (21.21 ^{o}) were totally different with some populations such as; USA(28.82 ^{o}),Israel(12.42 ^{o}),India(11.24 ^{o}),Taiwan(13.73 ^{o}) ,Pakistan(16.6 ^{o}) whereas there were no greater variation shown between our study and some populations of Burkina Faso (21.58 ^{o}) and Black South Africans (24.18 ^{o}).Measurement of the (TPA) represents very important vertebral measurements because it's the angle of pedicle screw insertion.(Ebraheim et al,1996) among USA population found that the transverse pedicle angle ranged between (20 - 40 ^{o}) for typical lumbar vertebrae as compared to (13-30.70 ^{o}) in the present study.The differences in the results of the present study and those of the previous studies with respect to some of the parameters may be due to differences in race, ethnicity, environmental factors as well as methods used for the studies.
Sagittal pedicle angle is important in accurate screw placement as inferior migration of the screw may result in injury to the nerve root.

The mean sagittal pedicle angles (SPA) L1,L2,l3,L4 and L5 for males and female respectively, was statistically compared using a two-tailed independent sample t-test at $\alpha = 0.05$. The results suggest that average males scores (14.09 ^{o} ±1.84,15.17 ^{o} ±2.68,14.96 ^{o} ±3.00,15.07 ^{o} ± 3.70 and 18.01 ^{o} ±4.65) and average female scores (13.97 ^{o} ±1.88 ,15.19 ^{o} ±2.55,15.19 ^{o} ±3.67,14.50 ^{o} ±2.54 and (17.45 ^{o} ±4.02) respectively are not significantly different, $t(198)$ = L1 (.444, p=0.657),L2(-.051,P=0.959),L3(- 481, P=0.631),L4(1.292,P=0.198) and L5(.905,P=0.366).data for males and females are listed in (Table 4.30) and shown also as a bar chart graphs in (Fig.4.22) to explain the comparison between genders. The results of the (SPA) showing gradually increase in the degrees of angles from L1 to L2 in both male and females, then reduced in L3 and L4 in both ,and increased in L5 for both.

The largest (SPA) found to be among males at L5=(18.01 ^{o}) and minimum (SPA) found in females at L1 (13.97 ^{o}). The largest (SPA) was found in both males and females at L5(18.01 ^{o}) and L5(17.45 ^{o}) respectively, and the lowest (SPA) was found in males and females at L1(14.09 ^{o})and L1 (13.97 ^{o}) respectively.

The mean (SPA) was slightly larger in males in than in females and the difference was statistically insignificant ($p > 0.05$) (Table 4.30).The mean (SPA) of the pedicle in males was 15.36 ^{o} ± 3.11 and in females was 15.26 ^{o} ± 3.33 Data regarding this comparison were listed in (Table 4.30) and presented as graphs in bar chart (Figure.4.22).The result in (Table 4.30) and(Figure 4.22) demonstrated that the lumbar vertebrae slightly gradually increase from L1 to L5 in both males and females (SPA),with exception of slightly reduction in L4 in both gender.

The overall result of the mean values of the Sagittal pedicles angle (SPA) of the lumbar vertebrae among the 200 participants depicted gradually increase from ,L1(14.0315 ^{o}), L2 (15.1765 ^{o}), reduced in L3(15.0770^{o}),then increased in L4 (14.7860 ^{o}) and L5 (17.7305 ^{o}). (Table 4.21) (Figure.4.23)

Our study mean value for the sagittal pedicles angle(SPA) in(degrees) (Table.4.32) (Figure.4.24) compared with other populations in the world the results demonstrated that the mean values of our study of (SPA) (15.36^{o}) were totally different with other populations depicted in the table, the measurement of the (SPA) was very large compared with other populations such as; USA(4.65o),India(9.16^{o}),Taiwan(4.48 ^{o}),Turkey(8.38^{o}),Pakistan(4.39^{o})and Burkina Faso (11.64^{o}). this variation may associated with way of measurements in each study and the variation of races and ethnicities. In our study the sagittal section of the lumbar spine passing through the pedicles angle posteriorly and tangent to the upper plate of the vertebral body and the axis of inclination of the vertebral pedicle on the horizontal.
(Ebraheim et al,1996) found that the sagittal pedicle angle ranged between(2 - 9 ^{o})for typical lumbar vertebrae as compared to (11 - 34 ^{o}) in the present study.

Most of studies in the past about morphometry of lumbar vertebrae were concentrated on pedicle diameters and their angulations. Only little importance was given to the vertebral body parameters ,Taking into account the important of the lumbar spine, this study has given importance to the morphometry of the vertebral body.
Vertebral body width(VBW) represents a very important variable as it was playing a big role in the measurements of the spinal canal ratio and pedicle ratio or (CT ratio).

As a part of vertebral body parameters, vertebral body width in the total 100 males and 100 females, a Student's t-test (two-tailed independent samples) table was used to analyze for differences between gender at $\alpha = 0.05$ of the lumbar vertebrae [L1, L2, L3, L4 and L5]. The mean ± SD (in mm)for the males were (33.29±2.80, 34.02±2.66, 35.78±2.66, 38.11±2.73 and 43.97±3.09) and (32.90±2.54, 33.72±2.23, 34.97± 2.63, 37.32±2.20 and 43.57±2.51) for the females respectively. The pooled data of gender are listed in(Table 4.33)and presented as a bar chart graphs in (Figure.4.25) .The results suggest that the average mean values **v**ertebral body width (VBW) L1 to L5 is higher in males than in females, and there was statistically significant difference ($p \leq 0.05$) at vertebral levels L3 and L4 ,at $t(198)$ = (2.16, $p = 0.03$) for L3 and (2.25,P=0.02) for L4 respectively, whereas for other levels they were at t(198) L1=(1.03,P 0.30),L2= (0.87,P 0.39) and L5= (1.00,P 0.32).The largest mean values lumbar vertebral body width was seen at vertebral level L5 in both males (43.97±3.09) and females (43.57±2.51) and the least was at vertebral level L1 in both males (33.29±2.80) and females (32.90±2.54) (Table4.23). The minimum (33.29±2.80,) and maximum (43.97±3.09) readings for both males and females lumbar vertebral body width were noted both at (males L1) and (males L5)respectively.

The overall of the mean values of the vertebral body width (VBW) of the lumbar vertebrae among the participants showed gradually increase from(L1 to L5) ,L1(33.09), L2 (33.87), L3(35.37),then increased in L4 (37.72) and L5 (43.77). (Table 4.34) (Figure.4.26)

The comparison of our study mean value in(mm) (Table.4.35) (Figure.4.27) for vertebral body width (VBW) compared with other different races and ethnicities in the world the results demonstrated that there were greater variation in the mean values of vertebra levels of our study (36.77mm) and others such as; Nigeria (46.48mm) , Israel(43.56),Burkina Faso (40.78mm),Nepal (40.40) and Egypt(40.20) .

Although measurements of the AP diameter of the vertebral body is not widely used in the previous studies of the spinal canal morphometry regarding spinal stenosis, its being used by some authors such as; (Jones and Thomsons,1968) and (Janjua MZ and Muhammad F,1989).

The Student's t-test (two-tailed independent samples) table was used to analyze for differences between gender at $\alpha = 0.05$ of the lumbar vertebrae [L1, L2, L3, L4 and L5].The mean±SD(in mm)for the males were (25.13±1.86,26.07±1.68,26.59±2.35,27.41±2.68 and 31.05±3.30) and (24.68 ±1.53,25.66± 1.16,25.82± 1.80,26.71± 2.10 and 30.50±2.89) for the females respectively. The pooled data of gender are listed in(Table 4.36) and presented as a bar chart graphs in (Figure 4.28) .The results suggest that the average mean values **v**ertebral body depth (VBD) L1 to L5 is higher in males than in females. There were statistically significant different ($p \leq 0.05$) for level L2,L3 and L4 at t=(198) the results showed L2=(2.01 P=0.04),L3=(2.62 P=0.01) and L4=(2.06 P=0.04) respectively, for L1 and L5 results there were no statistical significant ($p > 0.05$). The largest mean values lumbar vertebral body depth seen at vertebral level L5 in both males (31.05±3.30) and females (30.50±2.89) and the least was at vertebral level L1 in both males (25.13±1.86) and females (24.68 ±1.53) (Table4.26). The minimum (24.68 ±1.53)and maximum (31.05±3.30) readings for males and females .lumbar vertebral body depth were noted both at (females L1) and (males L5)respectively.

The mean values of the vertebral body depth (VBD) of the lumbar vertebrae among the participants showed gradually increase from ,L1(24.9025), L2 (25.8640), L3(26.2048), L4 (27.0595) and L5 (30.7775) respectively. (Table 4.37) (Figure.4.29).

(Table.4.38) (Figure.4.30)for vertebral body depth (VBD) compared with other different populations in the world the results showed that there were no greater variation in the mean values of vertebral levels of our study (27.96 mm) and others such as; Mexico

(33.10mm) , Israel(31.04mm),Burkina Faso(30.4mm),South Africa (31.96mm) and Pakistan(31.00mm).

Most methods for measuring vertebral body morphometry use radiographic analysis (Cyteval et al,2002) but there was no volumetric data about both body of lumbar vertebrae and intervertebral discs using stereological technique. Komemushi et al. aimed to evaluate the relationships between volume of vertebral bodies via CT on the cases with compression fracture before percutaneous vertebroplasty. The authors decelerated that average vertebral body volume was 26.3 +/- 8.1 cm3 (Komemushi et al,2005). The observations presented here have defined many of the anatomical and volumetric parameters that should be taken into consideration for screw fixation to avoid injury of vascular and neural structures during spinal instrumentation involving the lumbar vertebrae and intervertebral discs.
(Chou et al., 2008).found that measurements of size and volumetric definition for body of lumbar vertebrae and intervertebral discs are of importance for preventing complications after anterior approach such as cage dislocations and adjacent level vertebral body fractures after placement of expandable cages.

Student's t-test (two-tailed independent samples) table was used to analyze for differences between gender at $\alpha = 0.05$ of the lumbar vertebrae [L1, L2, L3, L4 and L5]. The mean ± SD (in mm)for the males were (21.97 ±1.67,22.37 ± 2.27,23.39 ± 1.77,24.53 ± 1.52 and 24.89± 2.60) and (21.82 ± 1.47,22.32 ± 2.37,23.4 ±1.77, 24.32 ± 1.55 and 24.86 ± 2.82) for the females respectively.

Data of gender were scheduled in (Table4.39)and presented as a bar chart graphs in (Fig.4.31) .The results suggest that the average mean values vertebral body height (VBH)L1 to L5 were higher in males than in females. The results showed no statistical significant different between the level regarding this variable as(($p > 0.05$) at t(198) the results showed L1=(0.70 P=0.49),L2=(0.15 P=0.88) ,L3=(-0.07 P=0.94) L4=(0.94 P=0.35) and L5=(0.07 P=0.94)The largest mean values lumbar vertebral body height seen at vertebral level L5 in both males (24.89± 2.60) and females (24.86 ± 2.82) and the least was at vertebral level L1 in both males (21.97 ±1.67) and females (21.82 ± 1.47) (Table4.29). The minimum (21.82 ± 1.47)and maximum (24.89± 2.60) readings for males and females lumbar vertebral body height were noted both at (females L1) and (males L5)respectively.

The total results of the mean values of the vertebral body height (VBH) of the lumbar vertebrae among the participants showed gradually increase from ,L1(21.90±1.57), L2 (22.35± 2.31), L3(23.40±1.77), L4 (24.43±1.54) and L5(24.88±2.71). (Table 4.40) (Figure.4.32)

Our study mean value in(mm) (Table.4.41) (Fig.4.33)for vertebral body height (VBH) compared with other populations in the world the results showed that there were slightly variation in the mean values of vertebra levels of our study (24.50mm) and others such as; Lebanese (32mm) Mexican (29mm) and there were slightly close correlation with populations of Burkina Faso(25.72mm),Israeli (26.20) and Greek (27.47) .

Spinal canal depth was measured from the posterior margin of the vertebral body to the cortex of the neural arch at the base of the spinous process.(Schizas C et al,1976). Anteroposterior spinal canal development is fully complete by 5 years of age while transverse spinal canal diameter increases until 15–17 years (Watts R,2013).Spinal canal depth or AP of the vertebral foramen measurement though it has no more literature covered it, it plays an important role in the measurement of the spinal canal ratio.
As a part of spinal canal parameters, spinal canal depth in the total 100 males and 100 females, a Student's t-test (two-tailed independent samples) table was used to analyze for differences between gender at $\alpha = 0.05$ of the lumbar vertebrae [L1, L2, L3, L4 and L5]. The mean± SD (in mm)for the males were (17.82±1.84,16.66±1.65,16.03±1.43, 16.16±1.96 and 16.34±1.84) and (17.80±2.00, 16.92±1.88, 16.36±1.58, 16.21±1.88,and 16.48±1.67) for the females respectively. The pooled data of gender are listed in (Table 4.42)and presented as a bar chart graphs in (Figure.4.34) .The results showed no statistical significant different between the level regarding this variable as(($p > 0.05$) at t(198) the results showed L1=(0.08 ,P= 0.93),L2=(-1.05,P=0.29) ,L3=(-1.50, P=0.13),L4=(-0.18,P=0.86) and L5=(-0.58,P=0.56).The largest mean values lumbar (SCD) seen at vertebral level L1 in both males (17.82 ± 1.84) and in females (17.80± 2.00) and the least was at vertebral level L3 in males (16.03±1.43) and at vertebral level L4 in females (16.21± 1.88) (Table4.42). The minimum (16.03±1.43) and maximum (17.82 ± 1.84) readings for males and females lumbar vertebral (SCD) were noted at (males L3) and (males L1)respectively.

The total results of the mean values of the spinal canal depth (SCD) of the lumbar vertebrae among the participants showed gradually decrease from ,L1(17.81±1.92), L2 (16.79±1.77), L3(16.19±1.51), L4 (16.19±1.92) and L5(16.41±1.76). (Table 4.43) (Figure.4.35).there was a gradually decrease in the mean vales of (SCD) from L1 to L4 and the mean increase again in L5.

Our study mean value in (mm) (Table.4.44) (Figure.4.36) for spinal canal depth (SCD) compared with other populations in the world the results showed that there were no grater variation in the mean values of vertebra levels of our study (16.68 mm) and others such as; Egypt (15.90 mm) , South Africa(17.41) ,Burkina Faso(15.16mm),Mexico (16.4mm) and Sudan (17.19mm) .

The result of the pedicle index (The ratio of the pedicle width to the pedicle height at each lumbar vertebral level) in this study found that the lowest (PI ratio was observed at L1 (mean ± SD 41.575± 3.6%), and the highest ratio was at L5 (mean ± SD 80.5±4.6 %) (Table 4.46) there was gradually increasing from L1 (mean ± SD 41.575± 3.6%),L2 (mean ± SD 42.715± 3.485%),L3(mean ± SD 55.65±3.055%),L4(mean ± SD 68.015±3.805%) and L5(mean ± SD 80.5±4.6%). The result among gender convinced that pedicle index ratio were greater in females than males at each lumbar level with exception of L1 which was greater in males.(Table 4.45)(Table 4.46).

(Figure 4.37- A) depicted the mean of PDW , the mean of PDH, and the ratio of (PDW/PDH X 100) for each level (L1–L5) the linear graph demonstrated there was a high correlation between the mean of PDW , the mean of PDH.

(Figure 4.37- B) depicted that The pedicle index curve is more similar to both the PDH (r2 = 0.675) curve and the PDW (r2 = 0.447) curve, especially at lumbar levels of L1–L3, PDW curve demonstrated positive linear relationship with Pedicle index and PDH curve demonstrated negative linear relationship with Pedicle index.

The CT ratio was a unique radiologic parameter when it was first presented in the study covered by (Kang et al,2011).(Table 4.47) and (Table 4.48) demonstrated the result of the pedicle ratio or (CT ratio) (the ratio of the PDW to the VBW at each lumbar vertebral level) it was found that there was gradually increasing from L1 (mean ± SD 16.54 ± 4.16 %),L2 (mean ± SD 17.74 ± 4.35%),L3(mean ± SD 22.00± 3.88%),L4(mean ± SD 26.14± 3.95 %) and L5(mean ± SD 29.70± 4.56 %). The result among gender convinced that pedicle ratio were greater in females than males at each lumbar level with exception of L1 which was greater in males for a little bit. lowest (Pedicle ratio) was observed at L1 (mean ± SD 16.38 ± 2.07%)and the highest ratio was at L5 (mean ± SD 29.88 ± 3.66 %),both the smallest and largest pedicle ratios were observed among females.

(Figure 4.38- A) this linear graph figure demonstrated that the mean of PDW and VBW and the ratio of (PDW/VBWX100) for each level (L1–L5) there was a correlation between the mean of PDW , the mean of VBW, whereas (Figure 4.38-B) had observed that the ratio curve is more similar to the PDW curve (r2 = 0.619) than the VBW (r2 = 0.264) curve, especially at lumbar levels of L1–L2,PDW curve depicted highly positive linear relationship with Pedicle ratio and VBW curve depicted negative linear relationship with Pedicle ratio.

El-Rakhawy et.al among Egyptians in 2010 had found that the ratio between the SCW and VBW was found to be constant (0.6) at L1, L2 and L4,their result correlated with that estimated in Nigerians, and Saudis, which was also 0.6 in both cases. In this study, the ratio between the width of spinal canal and lumbar vertebral body is also 0.6 at L1, L2 and L3 but it becomes 0.5 at L4 and 0.4 at L5, this signifies that in L4 andL5 levels the vertebral bodies are larger than the canal ,so the spinal canals are thus susceptible to stenosis.

(Table 4.49) and (Table 4.50) demonstrated the result of the spinal canal ratio i.e.(the ratio of the SCW to the VBW at each lumbar vertebral level) the tables demonstrated that in the total ratio there was gradually decreasing from L1 (mean ± SD 64.20 ± 3.83%),L2 (mean ± SD 61.98 ± 3.35%),L3(mean ± SD 61.62 ± 3.19 %),L4(mean ± SD 57.00 ± 3.94%) and L5(mean ± SD 47.17 ± 4.6 %).The tables also demonstrated that spinal canal ratio were greater in males than in females at each lumbar level with exception of (L1 and L3) which were greater in females for a little bit. lowest (spinal canal ratio) was observed at L5 (mean ± SD 46.93 ± 4.66 %) and the highest ratio was at L1 (mean± SD 64.25± 3.05 %),both the smallest and largest pedicle ratios were observed among females.

(Figure 4.39- A) the A figure demonstrated that in the mean of SCW and VBW and the ratio of (SCW/VBWX100) for each level (L1–L5) there was a correlation between the mean of SCW and the mean of VBW. (Figure 4.39-B) demonstrated that the ratio curve of the spinal canal ratio was more similar to the SCW ($r2 = 0.717$) curve than the VBW ($r2 = 1.951E$) curve, along lumbar vertebral levels of L1–L5 ,SCW curve demonstrated a positive linear relationship with spinal canal ratio and VBW curve depicted no linear relationship with spinal canal ratio.

5.2. Conclusion:

Because of the great important of the anthropometric ,biomechanical and clinical applications, of the lumbar vertebral measurements particularly pedicle measurements many anatomical and morphometric studies have been conducted.

This study established dimensions measurement of the lumbar vertebrae (L1 to L5) in adult Saudi Arabians (Jazan population) then compared with other studies from the other parts of world. Those dimensions of the lumbar vertebrae shall provide a baseline normative data for evaluation of patients presenting with any pathological condition in lumbar vertebrae such as; low backache and lumbar canal stenosis among Jazan population.

The study showed high statistical significant correlation between age and all lumbar vertebral variables, particularly vertebral body width. The pedicle width demonstrated no statistical significant differences between the right and left pedicle width at all five levels, this variable also explained that there were no statistical significant difference between males and females at each vertebral level with except of L3,in general the the mean values of lumbar pedicle width in Jazan population showed gradually increasing from (L1 to L5) in both males and females, this finding was supported by most of pedicles width measurement in different populations with slight differences in values .No significant differences were found between the mean pedicle width and both younger and older categories in all the other lumbar vertebral levels i.e. there was a positive linear relationship between the pedicle width and age among Jazan population.

There was variation between our results with different world races and ethnicities at each vertebral level in the mean values, although some populations showed close or slightly close corresponding with our results such as; Turkish (Kadioglu, Takci, Levent et.al) , there was a great variation in (PDW) between this study and the study of Amoono kaufi in 1995 among Saudi Arabians though both studies were employed in the same country but with different in races and ethnicities and the method of each study (Amoono kaufi ,1995) used the plain radiograph where in our study we were used CT scan as a method of measurement.

Our study convinced that there was a positive linear relationship between the pedicle width and the participants age, we had established an equation to predict the (PDW) for Jazan population,Correlation is significant at ($p \leq 0.05$) ,R^2 =.122.

$$\text{Pedicle width(PDW)} = 8.58 + 0.015 * \text{age}.$$

The mean pedicle height was slightly larger in males than in females and there was no statistically difference , lumbar vertebrae increased gradually from L1 to L5 in both males and females and also there was a high corresponding with other population in the world such as; Egyptian

Measurements of lumbar vertebral (IPD) or (SCW) is very important as its related to spinal canal ratio measurement for rule out the stenosis of the lumbar vertebrae. our measurements in (IPD) are totally not in line with that of other studies.(neither increase gradually from(L1-L5) nor decrease) though this variable was in close relation with some population in the world.

This study was found that no significant difference between males and females in the mean of pedicle chord length and the chord length mean among younger age category was larger than the mean pedicle chord length in the older age category .The overall result of measurements of the pedicle axial length (chord length) increased gradually from L1 to L3 then reduced suddenly in L4 then increment in L5 ,our measurements in (PDAL) were in line with that of other studies. Screws of 41 to 42 mm length appeared to be safe at all lumbar levels as the minimum mean chord length was 48.83 mm.

We established an equation in our study between the pedicle chord and known age which can be used beneficially in pedicle surgeons for Saudi –Jazan region.Correlation is significant at($p \leq 0.05$),R^2=.138

$$\text{Chord length (PDAL)} = 51.611 + (-.044) * \text{age}.$$

In the study the results of the TPA showed gradually increase in the degrees of angles from L1 to L5, in males and females. The mean (TPA) was slightly larger in males in than in females and the difference was statistically insignificant .The mean (TPA) at all vertebral levels L1-L5 in the lumbar spine was significantly larger in older age categories(> 55) compared with younger age category(26-35).our study mean value for the transverse pedicles angle (TPA) in(degrees) found totally different with some populations such as; USA, Israel and India The differences in the results of the present study and those of the previous studies with respect to some of the parameters may be due to differences in race, ethnicity, environmental factors as well as methods used for the studies.

In this study we proved that there was appositive linear relationship between the transverse pedicle angle and the participants age, our study established an equation to predict the (TPA) for Jazan population,Correlation is significant at ($p \leq 0.05$) ,R^2 =.002.

$$\text{Transverse pedicle angle (TPA)} = 19.249 + 0.005 * \text{age}.$$

The mean values of sagittal pedicle angle (SPA) was slightly larger in males in than in females the difference was statistically insignificant , there was slightly gradually increase from L1 to L5 in both males and females .The overall result demonstrated gradually increase from L1to L5.

Vertebral body width(VBW) represents a very important variable as it was playing a big role in the measurements of the spinal canal ratio and pedicle ratio or (CT ratio). The measurements of the mean (VBW) in this study convinced that (VBW) L1 to L5 is higher in males than in females, and there was statistically significant difference at vertebral levels L3 and L4 and also showed gradually increase from(L1 to L5).When

(VBW) was compared with other population in the world ,the results demonstrated that there were greater variation in the mean values of vertebra levels of our study.

The results of measurements of the (VBD) found that there were no greater variation in the mean values of vertebral levels of our study compared with other studies in the world.

In the measurements of pedicle index ratio, our study convinced that there was gradually increasing from L1 to L5 in the pedicle index ratio and the result among gender explained that pedicle index ratio were greater in females than males at each lumbar level with exception of L1 which was greater in males, and the pedicle index curve is more similar to both the PDH ($r2 = 0.675$) curve and the PDW ($r2 = 0.447$) curve, especially at lumbar levels of L1–L3, PDW curve demonstrated positive linear relationship with Pedicle index and PDH curve demonstrated negative linear relationship with Pedicle index.

The CT ratio or pedicle ratio was covered in this study by measuring the ratio of the PDW to the VBW at each lumbar vertebral level) it was found that there was gradually increasing from L1 to L5 in this ratio. Pedicle ratio were greater in females than males at each lumbar level with exception of L1 which was greater in males for a little bit. CT ratio linear graph figure demonstrated that the mean of PDW and VBW and the ratio of (PDW/VBWX100) for each level (L1–L5) there was a correlation between the mean of PDW , the mean of VBW, whereas had observed that the ratio curve is more similar to the PDW curve ($r2 = 0.619$) than the VBW ($r2 = 0.264$) curve, especially at lumbar levels of L1–L2,PDW curve depicted highly positive linear relationship with Pedicle ratio and VBW curve depicted negative linear relationship with Pedicle ratio.

The result of the spinal canal ratio demonstrated that in the total ratio there was gradually decreasing from L1 to L5 and the spinal canal ratio were greater in males than in females at each lumbar level with exception of (L1 and L3) which were greater in females for a little bit. The study also demonstrated that the ratio curve of the spinal canal ratio was more similar to the SCW ($r2 = 0.717$) curve than the VBW ($r2 = 1.951E$) curve, along lumbar vertebral levels of L1–L5 ,SCW curve demonstrated a positive linear relationship with spinal canal ratio and VBW curve depicted no linear relationship with spinal canal ratio.

(Porter et al.1989) suggested that increasing levels of physical activity were associated with increased strength of vertebral column in individuals aged over 18 years. The variation in diameter of pedicles in different age groups may be due to the weight-bearing function. The gradual increase in dimensions of typical lumbar vertebrae from cranial to caudal direction is related to their mechanical load.

Finally, this study provides various dimensions of lumbar vertebrae for Saudi Arabians (Jazan population. Racial morphometric difference must be taken into account when using international transpedicular screw systems. The dimensions in this study may help in the development of pedicular screws for Jazan population.

Use of a 5.5 to 7.5 screw would be safer in Jazan population. A lumbar pedicle with a diameter of 8.43 mm will easily accommodate a 7.5 mm screw, especially if the pediculation is performed under guidance of CT or fluoroscopy. Screws of 41 to 42 mm length appeared to be safe at all lumbar levels as the minimum mean chord length was 48.83 mm.

though the information in this study were perfect regarding morphometry of lumbar vertebrae in the Saudi-Jazan population, it has some limitations. The data obtained from the hospitals of the region might be from different Saudi people from different geographic region i.e. (different races and ethnicities).The number of participants was low compared to number of parameters and the value of the study. Furthermore the variety of CT scans models, manufacturers and slices. Though its recommended before surgery CT imaging would be performed with thinner slices as possible for a more accurate assessment of the morphometric characteristics of the lumbar vertebrae.

5.3. Recommendations:

The various parameters of lumbar vertebrae between females and males in this study found significant differences ,furthermore there was a statistically significant difference in pedicle parameters among Saudi-Jazan population and other populations. These differences have critical implications for spinal surgeons to perform a safe operation on patients, though the results.

A greater number of anatomical imaging studies and a larger number of samples are necessary to analyze the morphometric characteristics of the lumbar vertebral pedicle to determine its true dimensions and establish variations according to age, gender, and vertebral level, taking into account the participants weight and body mass index (BMI) which could be of a great value in the measurement.

The available morphological results of the lumbar vertebrae particularly the lumbar pedicles hopefully could be of some use possibly in transpedicular screw fixation to prevent after surgery complications in addition to suspected spinal stenosis. The measured data could also be of forensic importance because of the known racial, ethnic and regional variations.

Further similar study by CT scan using different cuts of the MPR or even by using other modalities is recommended. The radiologic technologist should know the normal range of lumbar vertebra measurement particularly the pedicle morphometry and the vertebral canal to have correct image interpretation.

The differences in the results of the present study and those of the previous studies with respect to some of the parameters may be due to differences in race, ethnicity, environmental factors as well as methods used for the studies.

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Appendix 1

Images

Appendix 1:Images

Image (1): Demonstrated the Steffee pedicle screws.(Santoni et al.2009)

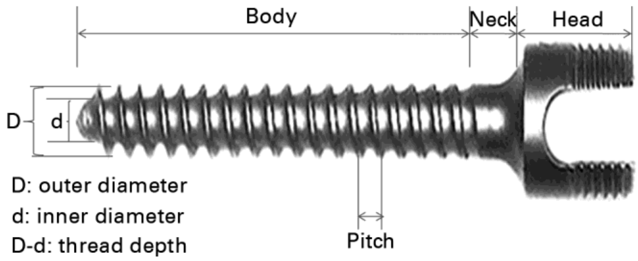


Image (2): Demonstrated the parts of a pedicle screw(Santoni et al.2009)

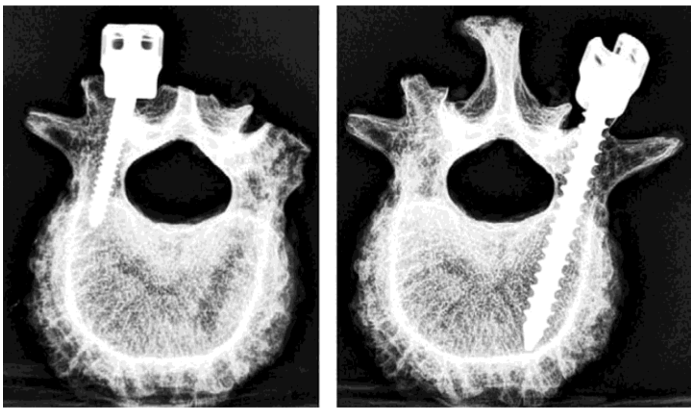


Image (3): Depicted new cortical trajectory (left) versus traditional trajectory (right) (Santoni et al.2009)

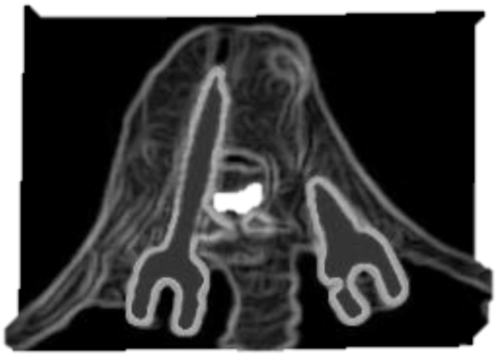


Image (4): Depicted CT scan of the medial pedicle wall violation(Santoni et al.2009)

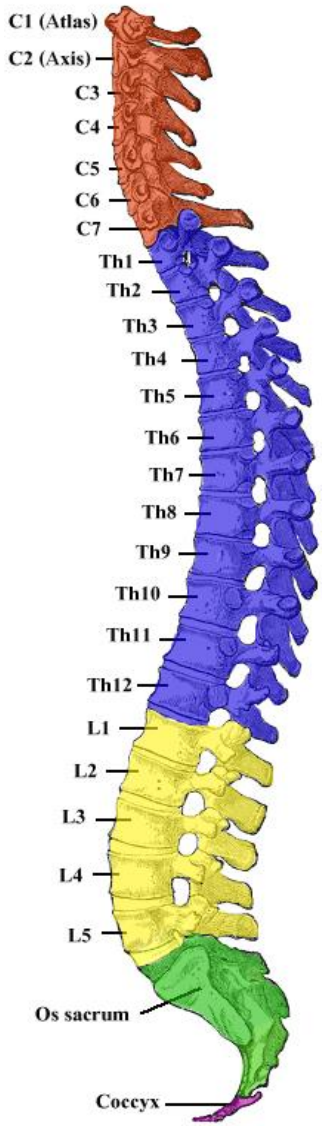


Image (5): Demonstrated lateral view for the vertebrae of the human spinal column.

(L. drake et.al 2014).

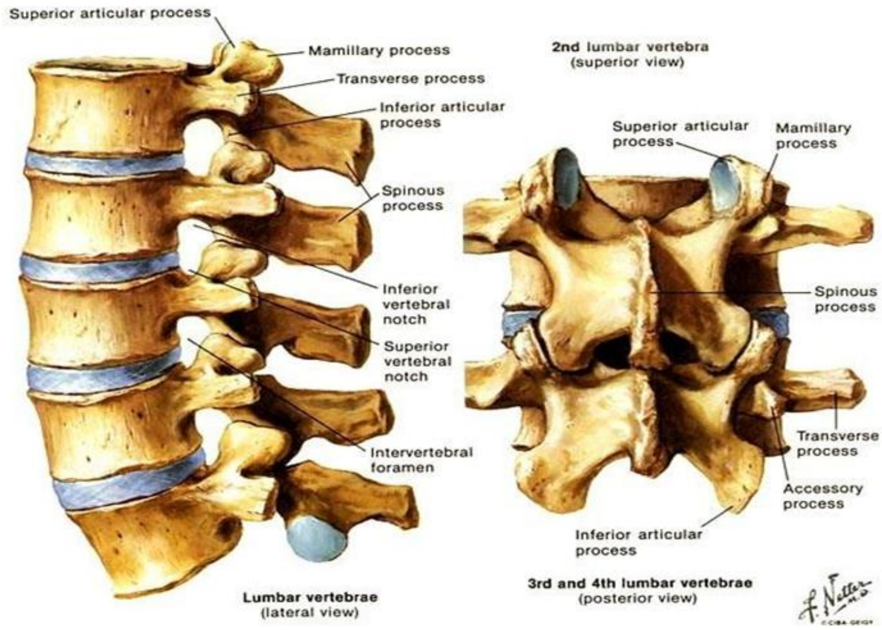
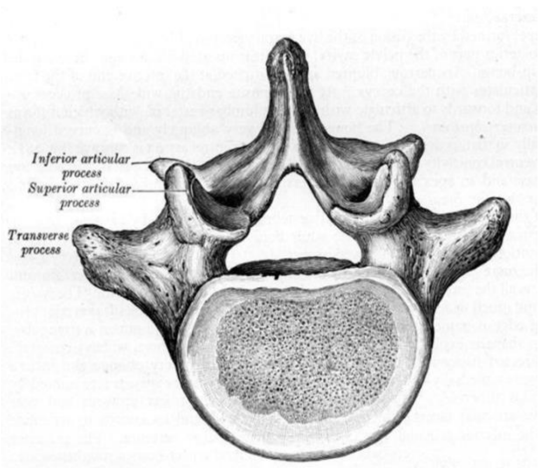


Image (6)**:** Demonstrated lumbar spine and normal anatomical structure(L. drake et.al 2014).



Image(7) : Illustrated Superior aspect of lumbar vertebra showing the pedicle and spinal canal. (L. drake et.al 2014).

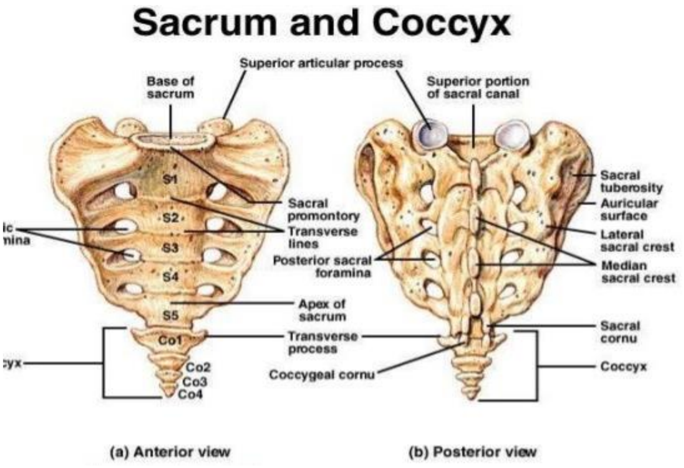


Image (8): Illustrated anterior and posterior aspects of sacrum and coccyx (L. drake et.al 2014)

.

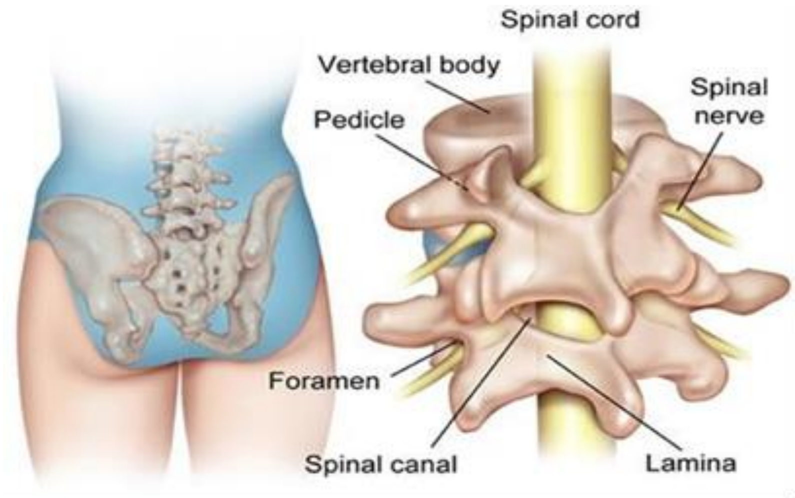
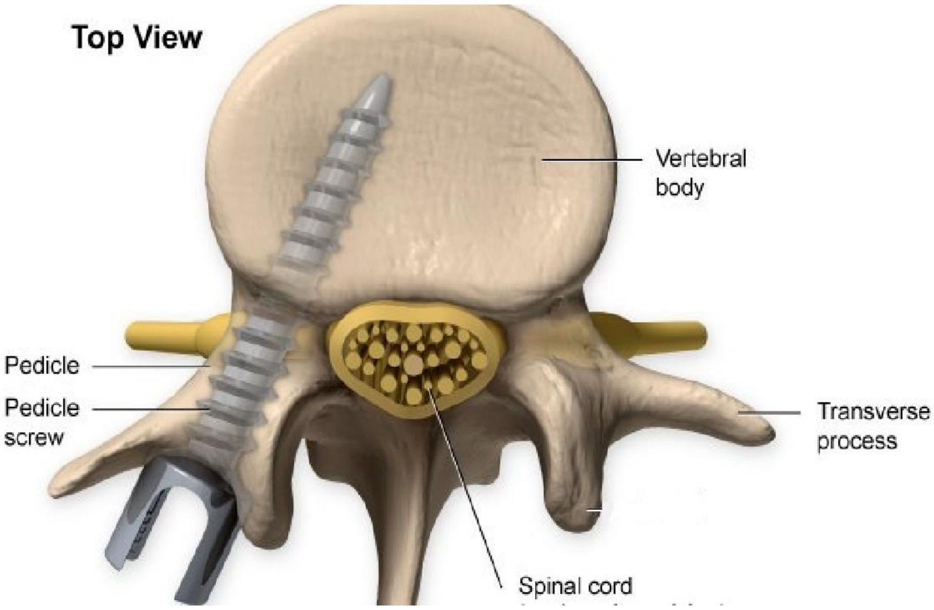


Image (9) : Depicted transformational lumbar in tear body fusion (L. drake et.al 2014)



Image(10): Illustrated pedicle screw insertion (L. drake et.al 2014)

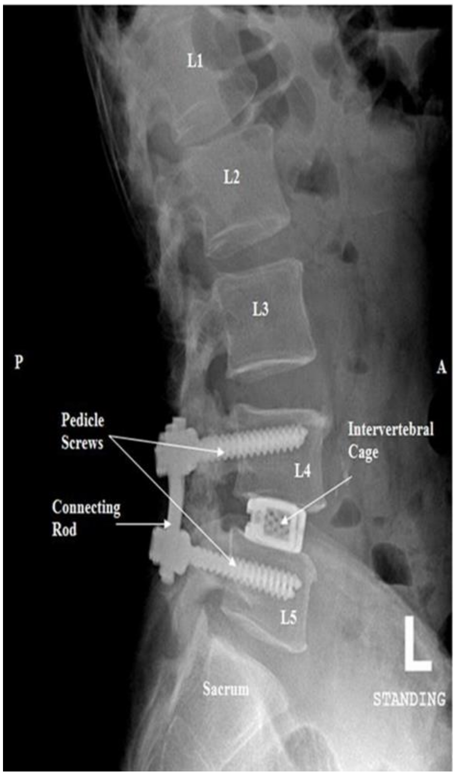


Image (11): Demonstrated pedicle screw instrumented fusion.

Appendix 2

Data Collection Sheet

Appendix 2: Data collection sheet:

Pt No	gender	age	vertebral level	Rt PDW	Lt PDW	PDAL	PDH	TPA	SPA	VBW	VBD	VBH	SCW	SCD
			L1											
			L2											
			L3											
			L4											
			L5											

Appendix 3

Achievements

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Morphometric Study of lumbar vertebral pedicles using CT axial sections: pedicle width, chord length and inclination angle.

Saeed Taha Mohamed Ali [1], Fathia Abd El Rahman Mohamed Alamin[2], Caroline Edward Ayad[3]

1 Diagnostic Radiography Technology ,College of Applied Medical Science, Jazan University,Jazan,KSA
2 Diagnostic Radiography Technology ,College of Applied Medical Science, Jazan University,Jazan,KSA
2College Medical Radiological Science, Sudan University of Science and Technology

Abstract: *The aim of this study is to determine the dimensions of lumbar pedicles, carried out to find an index for the Jazan population (KSA) inorder to deduce safety parameters for surgical procedures placements in lumbar region, the correlations between these parameters were according to age, gender and lumbar level.CT scan axial images were taken .200 patient images were analyzed, L1 - L5 (1000 vertebrae,2000 pedicles) with the mean age of the total patients was 40years old. Pedicle width, axial length, and transverse angle were determined in each axial image.*

The results suggested that the largest mean lumbar pedicle width was seen at vertebral level L5 in both males (12.99±1.29mm) and females (13.024±1.05mm) and the least was at vertebral level L1 in both males (5.56±.95mm) and females (5.39±.68mm). The lumbar pedicle width increased gradually from L1 to L5 in both males and females .The mean pedicle width in males was (8.39 ± 1.23mm) and in females was (8.47 ± 1.17 mm). The mean pedicle chord length in males was (49.89± 2.30 mm) and in females was (49.71 ± 2.06 mm). The largest mean lumbar chord length was seen at vertebral level L5 in both males (50.66±2.25mm) and females (50.80±2.26mm) and the least was at vertebral level L1 in both males (49.08±2.12mm) and females (48.83±1.83mm).Lumbar vertebrae increased gradually from L1 to L5 in both males and females pedicle chord length. There were gradually increase in the degree of angles from L1- L5,the maximum transverse pedicle angle found to be among female at L5=(30.70^o)and minimum transverse pedicle angle found in both males and females (13^o) at L3.The mean transverse pedicle angle of the pedicle in males was 21.18^o ± 2.40 and in females was 19.24^o ± 2.33. Significant differences were observed ($P<0.05$) when groups were compared. The current study established the dimensions of the pedicle for Jazan population (KSA).which might be of great value for successful pedicle screw fixation

Keywords - *pedicle, vertebra, morphometry, lumbar, transpedicular*

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I. INTRODUCTION

The morphometric dimensions of the vertebral pedicle determine the size and shape of pedicle screws [1]. There are no studies to date in the morphometric dimensions of the lumbar vertebral pedicle among Saudi Arabia Jazan population[2] even there are no existed reports about the vertebrae in Saudi population [3] Most patients with spinal fusion surgery prefer transpedicular fixation over other fusion methods since it has replaced many other techniques [[4,5]].It became the nineteenth most popular surgical procedure in 2003, and it increased from 22 to 51 procedures performed per 100,000 inhabitants [[6]].In order to examine lumbar vertebral morphometry, many studies were applied [[7,8]]as awareness, significance the precision of the lumbar spine anatomy which is crucial not only for finding the biomechanical and dynamic characteristics of the spine, but also for various interventions [9].Due to its dynamic nature, the lumbar region is particularly vulnerable to injuries arising from road traffic accidents, use of heavy mechanical devices and adventure sports besides surgical procedures as well as other different conditions[10].Screws are used to attach various devices to the spinal column for immobilization.[[11]].The use of implants requires an accurate screw path and a good quality of bone for screw reinsertion [12].Transpedicular screw insertion procedures have gained favor in recent years [13].The pedicles' particular architecture makes them an ideal location for screw implantation in reconstructive spine procedures to maintain and restore stability .[[14]]A mismatch in pedicle and screw size can result in screw loosening, pedicle fracture, and other damages [13-15].The screw path is determined by the transverse width and height of the pedicle. The CT scan has been established as the best method of evaluating pedicle radiographic morphology [15].However, according to many studies [13 -16-17]., there is no significant statistical difference between data collected from CT scan and direct cadaveric measurements. The morphological features of the vertebrae, and especially the pedicle, determine the size of the implants in both width and length, as well as the ideal shape, direction and angle of the screw at the time of insertion [18].Due to inadequate placement or wrong screw orientation, the surgeon must be aware of these traits in order to avoid problems [19-20].The aim of this study is to determine the morphometric variability of the lumbar vertebral pedicle among Saudi Arabians(Jazan population) by using CT scan and hence provide morphometric data of crucial parameters useful for a precision designing and placement of lumber pedicle screw.

II. MATERIALS AND METHODS

This study performed an observational, cross-sectional, descriptive, and prospective study by analyzing 200patients, L1 to L5 (1000 vertebrae,2000 pedicles) The mean age of the total patients was 40.79 years (range between 19 and 75 years), with the mean age of 100 male being 41.6 years (range 21–75years) and the mean age of 100 female patients being 39.9 years (range 22–66 years).The 2000 vertebrae were analyzed with CT scans, patients were selective randomly according to their fulfilling the inclusion criteria [age above 18] and exclusion criteria [patients with a certain degree of skeletal pathology which was interpreted by their chronic back pain, back pain related to age factor, arthritis prior back surgery, pregnancy and degenerative conditions, spondylolisthesis, retrolithesis, and disk space collapse. The study was carried out between March 2016 and April 2019.The study was conducted at Jazan region [Saudi Arabia], cases collected from governmental hospitals CT scanner departments. The patients were informed of the exam subject and all information was used with confidentiality, no patient data were published also the data was kept in personal computer with personal password.

Measurement Method:

For all patient axial plane are obtained using slice thickness 3-10 mm for all planes, the study was executed using multi-detector computed tomography scanner MDCT[8-Slice scanner,16 slice,64 slice,128slice (0.625mm slices): 0.625mm collimation, table feed 10 mm/rotation, effective tube current 685 mAs at 120 kV. Pitch = 10/40 mm collimation = 0.25. Average scan time = 5 s, fan beam shape, CT monitor for controlling scanning and processing and PACS system, the images were measured on bone window settings, cases were diagnosed by a senior radiologist in Jazan university and the various morphometric software parameters were measured using DICOM viewer.[Radiant DICOM Viewer 4.6.9 (64-bit) reviewed April 14, 2019].We determined if significant differences existed between the mean values of the various parameters studied using a parametric correlation test (Student's t test), considering a P value < 0.05 as significant.

Measurements parameters [Figure1]

Measurement parameters were carried out using the following;

[1] Pedicle width(PDW)in (mm) were measured bilaterally, 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 also known as (isthmus), transverse or axial width, as proposed by (Zindrick et al.1987)[12].

[2] The pedicle axis length (PDAL) in (mm) also known as; (Chord length) or (screw path 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 on the axial plane, as described or reported by (Olszewskiet al. 1990) [18].

[3] Transverse Pedicle angle (TPA) (in degree) also known as; Chord angle is determined the 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.

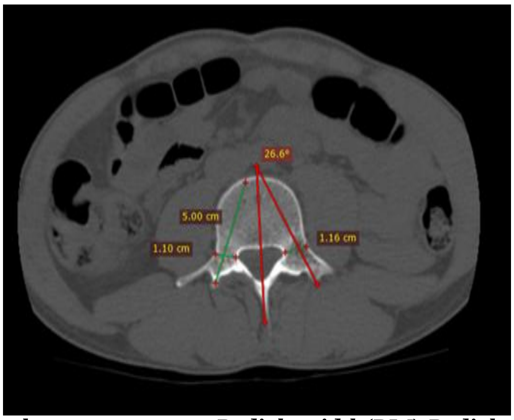

Figure1: demonstrated the three parameters: Pedicle width(PW),Pedicle axial length(PDAL) in (mm) and Transverse pedicle angle(TPA) in degree at Lumbar level four

III. RESULTS

Pedicle width (PDW):

The range (in mm) for the right pedicles width of the lumbar vertebrae [L1, L2, L3, L4 and L5] were (4.00 -9.23,4.80-9.06,5.00-9.80,8.00-12.90 and 10.00-15.70) and(4.00-9.87,4.90-9.06,5.00-9.70,8.00-12.90 and9.00-15.50) for the Left pedicles width respectively. The mean pedicle width of the pedicle on the left side was (8.43 ± 0.95439 mm) and on the right side was (8.42 ± 0.95683mm). The mean±SD (in mm)for the males were(5.56±.95),(5.98±.653),(7.67±.75),(9.74±.900)and(12.99±1.29)and(5.39±.68),(6.04±.83),(7.89±.65),(9.99± 1.17) and 13.02±1.05) for the females respectively.

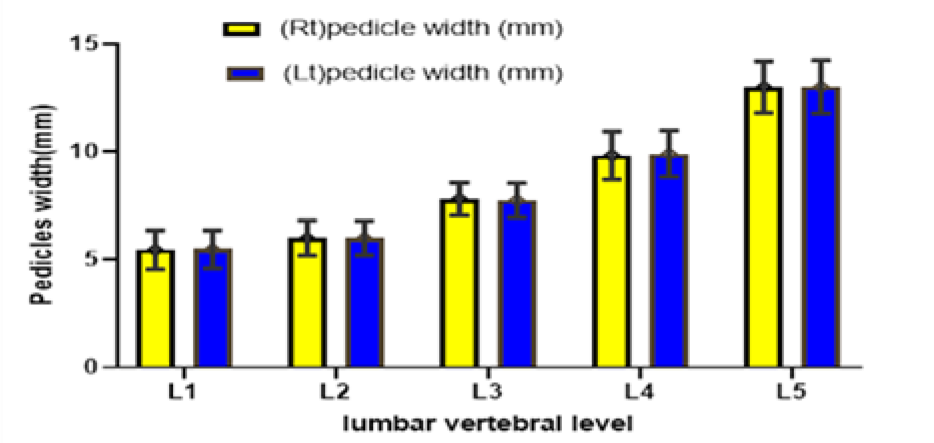

Figure 2: Bar chart demonstrated comparison of the mean values and SD between the right and left pedicles width at each lumbar vertebral level.

The pooled data of gender are listed in(Table 1).The results suggest that the average pedicle width L3 is less for male (M = 7.67±0.74) than for female (M = 7.89±0.65), t(198) = -2.156, p =0.032(P<0.05),whereas the results for other levels suggest no significant difference (P>0.05) between males and females t(198) = (L1=1.498, P =0.13), (L2= -.622, P= 0.535),(L4= -1.760,P=.080)and(L5= -.188,P=.851) respectively. The largest mean lumbar pedicle width was seen at vertebral level L5 in both males (12.99±1.29) and females (13.024±1.047) and the least was at vertebral level L1 in both males (5.56±.948) and females (5.3901±.68104) .The minimum (5.39mm) and maximum (13.023mm) readings for both male and female pedicles width were noted both at (female L1) and (female L5) respectively. In all the vertebral levels, the mean pedicle width was slightly larger in females than in males and the difference was statistically insignificant (p >0.05) except at vertebral level L1 .The result in (Table 1) demonstrated that lumbar vertebrae increased gradually from L1 to L5 in both males and females, the largest PDW was located at female L5 (13.024 mm) and the smallest PDW was located at female L1 (5.39 mm). The mean (PDW) of the pedicle in males was (8.39 ± 1.23) mm and in females was 8.47 ± 1.17 mm.

Table 1: Demonstrated comparison of (PDW) of lumbar vertebrae (L1 -L5) between gender using independent sample t-test ,the results are expressed in mm.

		Male	Female	T-values	Significance
L1	Mean	5.56	5.39	1.498	0.138
	SD	.95	.68		
	Maximum	9.44	9.07		
	Minimum	4.34	4.25		
L2	Mean	5.98	6.04	-.622	0.535
	SD	.65	.83		
	Maximum	8.00	9.03		
	Minimum	4.85	5.00		
L3	Mean	7.67	7.89	-2.156	**.032***
	SD	.74	.65		
	Maximum	9.35	9.50		
	Minimum	5.17	6.05		
L4	Mean	9.73	9.99	-1.760	0.080
	SD	0.900	1.17		
	Maximum	11.85	8.15		
	Minimum	8.25	12.90		
L5	Mean	12.99	13.02	-0.188	0.851
	SD	1.29	1.05		
	Maximum	15.60	15.25		
	Minimum	9.50	10.95		

First lumbar vertebra (L1)second lumbar vertebra (L2)third lumbar vertebra (L3)fourth lumbar vertebra (L4) fifth lumbar vertebra (L5) ,SD=standard deviation**,.* $p<0.05$** between female and male at each lumbar level. The post-hoc ,Bonferroni-corrected pair wise analysis demonstrated that the mean pedicle width at vertebral levels L5 in the lumbar spine was significantly larger in older age categories (more than 55) than in younger age category(26-35) ($p\leq 0.05$) (Table 2). No significant differences were found between the mean pedicle width and both categories in all the other lumbar vertebral levels.

Table 2: Pair wise (post hoc Bonferroni) comparison of the mean pedicle width between younger and older categories. *Statistically significant value

Vertebral Levels	26-35years Vs> 55years (p-value)
L1	.160
L2	.075
L3	1.000
L4	1.000
L5	0.000*

This study has established an equation to predict the correlation coefficient between the pedicle width and age for Saudi –Jazan region population of a known age with correlation significant at ($p \leq 0.05$) ,**R^2 =.122. Pedicle width(PDW) =8.58+0.015*age.(Table 3).**Our study also convinced that there was positive linear relationship between thepedicle width and age among participants according to the scatter plot diagram (Figure.3)

Table 3: Demonstrated correlation coefficient between the Pedicle width and age:

	Unstandardized Coefficients		Standardized Coefficients		
Age (Constant)	B	Std. Error	Beta	T	Sig
	.015 8.576	.003 .118	.349	5.240 72.456	.000 .000

Established equation to predict the pedicles width for Saudi –Jazan region population of known age.
Correlation is significant at ($p \leq 0.05$) ,**R^2 =.122. Pedicle width(PDW) =8.58+0.015*age.**

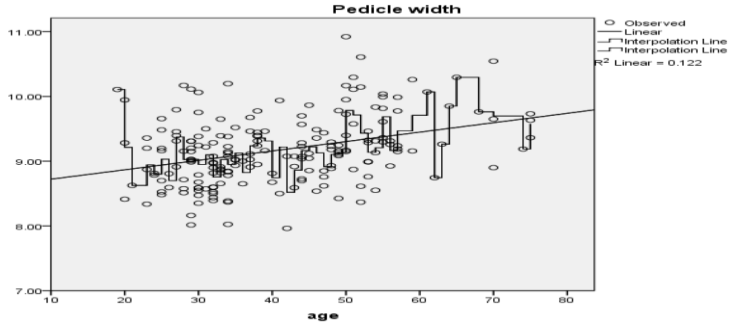

Figure 3: A scatter plot diagram demonstrated the positive linear relationship between the pedicle width and age among Jazan population.

The overall results of the mean values, SD and range of pedicles width (PDW) of lumbar vertebrae (L1-L5),for the total participants Jazan population were (L1=5.48±.828, L2 6.012±.74, L37.78±.71, L49.87±1.049 and L513.008±1.176) respectively(Figure 4) and the (Mean value for the PDWs (L1 to L5) =(8.43 mm ± 1.432805). The result depicted gradually increase of the mean values from L1 to L5. This finding was supported by most of pedicles width measurement in different populations with slight differences such as; Amonoo Kuofi (1995 in Saudi Arabians),Kim et al (1994 in Koreans) .

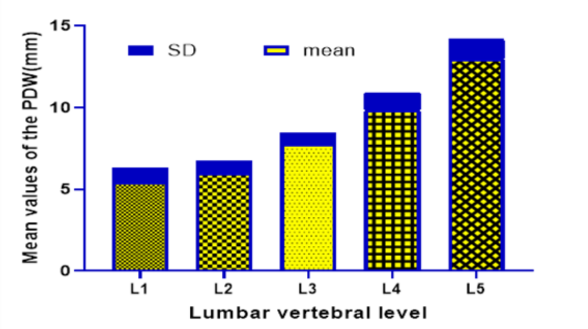

Figure 4: Bar chart demonstrated the mean values (mm) and SD of the (PDW) at each lumbar vertebral level among participants

The results of pedicle width in our study when compared with different populations demonstrated these studies depicted corresponding with our study in gradually increase in pedicle width from L1 to L5, (Olmos,Tomé,2002[20]; Urrutia Vega, et al.,2009[28]; Lien,2007[29]; Li,B et al, 2004 [30];Nojiri,et al.,2005 [31] ;Acharya, et al,2010[26] ; Kang,et al.,2011[32] ; Amonoo-Kuofi,1995[33] ; Singel,et al 2004[34] ; Olsewski, et al.,1990[18] ;Wolf,et al., 2001[35] and Maaly, et al 2010 [36]).There was a great variation between our results with some other races and ethnicities at each vertebral level in the mean values, although some populations showed close or slightly close corresponding with our results such as; Turkish (Kadioglu, et.al 2003 [37]), Israelis (Wolf, et al.2001[34]), Indians (Acharya,et al2010[26]), Chinese (Li Jiang, et al.(2004)[30], Mexicans (UrrutiaVega, et.al 2009)[28] and Japanese(Nojiri, et al.2005)[31].

Pedicle axis length (PDAL): (Chord length) or (screw path length):

Screws or chord length appeared to be safe at all lumbar levels when minimum mean chord length was determined previously[19].

The comparison between gender in relation to pedicle axis length (PDAL)or chord length or screw pathway showed there were significant between males (49.08±2.13,49.97±2.57,50.07±2.78,49.70±1.52 and 50.66±2.25) and females (48.84±1.84,49.45±2.25,49.91±2.63,49.56±1.35 and 50.80±2.26) respectively. The pooled data of males and females are listed in(Table 4). The mean pedicle axial length was slightly larger in males in L1-L4 (in L5 the mean of females were larger than in males)than in females and the difference was statistically insignificant (p >0.05) (Table 4.).The mean (PDAL) of the pedicle in males was 49.89± 2.30 mm and in females was 49.71 ± 2.06 mm. The largest mean lumbar chord length was seen at vertebral level L5 in both males (50.66±2.25) and females (50.80±2.26) and the least was at vertebral level L1 in both males (49.08±2.12) and females (48.83±1.83). The minimum (48.83 mm) and maximum (50.80mm) readings for both male and female pedicle axis length were noted at (females L1) and (females L5) respectively. The result in (Table 4) demonstrated that the lumbar vertebrae increased gradually from L1 to L5 in both males and females

(PDAL) ,the largest (PDAL) was located at female L5 (50.80 mm) and the smallest (PDAL) was located at female L1 (13.19 mm).

Table 4:Demonstrated the mean values of the (PDAL) or chord length of (L1 -L5) between gender using independent sample t-test ,the results are expressed in (mm).

		Male	Female	T-values	Significance
L1	Mean	49.08	48.83	879	.380
	SD	2.12	1.83		
	Maximum	54.40	54.40		
	Minimum	46	46		
L2	Mean	49.96	49.44	1.523	.129
	SD	2.56	2.25		
	Maximum	59	59		
	Minimum	46	46		
L3	Mean	50.08	49.91	.435	.664
	SD	2.80	2.62		
	Maximum	57.70	57.70		
	Minimum	46.80	46		
L4	Mean	49.69	49.56	.654	.514
	SD	1.52	1.35		
	Maximum	55.80	55.90		
	Minimum	47	47.40		
L5	Mean	50.66	50.80	-.442	.659
	SD	2.25	2.26		
	Maximum	56	56.20		
	Minimum	47.10	47.80		

First lumbar vertebra (L1)Second lumbar vertebra (L2)Third lumbar vertebra (L3)Fourth lumbar vertebra (L4) Fifth lumbar vertebra (L5) ,SD=standard deviation,. P>0.05 statistically not significant between female and male at the lumbar level. Post-hoc,Bonferroni-corrected pairwise analysis demonstrated that the mean pedicle chord length at vertebral levels L1,L2 and L3 in the lumbar spine was significantly larger in younger age categories (26 -35 years) than in older age category(>55years) ($p \leq 0.05$) (Table 5). No significant differences were found between the mean pedicle chord length and both categories in L4 and L5 lumbar vertebral levels.

Table 5: Depicted Pair wise (post hoc Bonferroni) comparison of the mean Chord length of younger and older categories of Jazan population. *Statistically significant values (P<0.05)

Vertebral Levels	26-35years **Vs**> 55years p-value
L1	.002*
L2	.000*
L3	.000*
L4	1.000
L5	0.202

Our study has established an equation to predict the correlation coefficient between the Pedicle Chord length(PDAL) and age for Jazan region population of a known age with Correlation significant at($p \leq 0.05$),R2=.138.**Chord length (PDAL) =51.611+(-.044)*age.**(Table 6).Correlation Coefficient between the (PDAL) and age was also depicted in a scatter plot diagram which showed the negative linear relationship between the pedicle chord length (PDAL) and age(Figure. 5).

Table 6: Demonstrated Correlation Coefficient between the Pedicle Chord length(PDAL) and age

	Unstandardized Coefficients		Standardized Coefficients		
Age (Constant)	B	Std. Error	Beta	T	Sig
	-.044 51.611	.008 .336	-.371	-5.629 153.707	.000 .000

stablished equation to predict the Pedicle Chord length(PDAL) for Saudi –Jazan region population of known age. Correlation is significant at($p \leq 0.05$),R^2=.138 .**Chord length (PDAL) =51.611+(-.044)*age.**

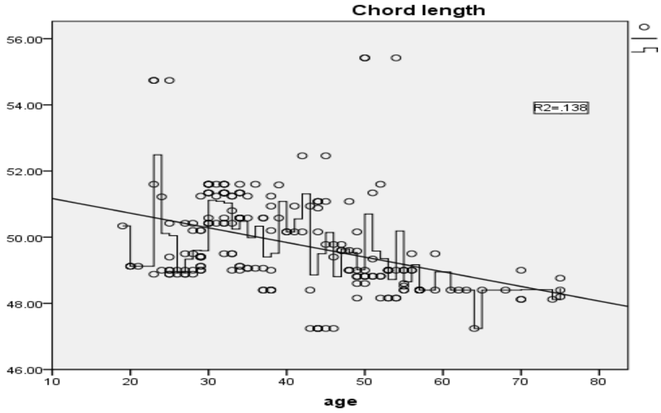

Figure 5:Ascatter plot diagram demonstrated the negative linear relationship between the pedicle chord length (PDAL) and age

The overall result of measurements of the (chord length) (PDAL) of the lumbar vertebral among the 200 participants showed, L1(48.96), increased gradually to L2 (49.71), L3(49.99), then reduced suddenly in L4 (49.63),then increment again in L5 (50.73).,our measurements in (PDAL) were in line with that of other studies. (Figure.6).

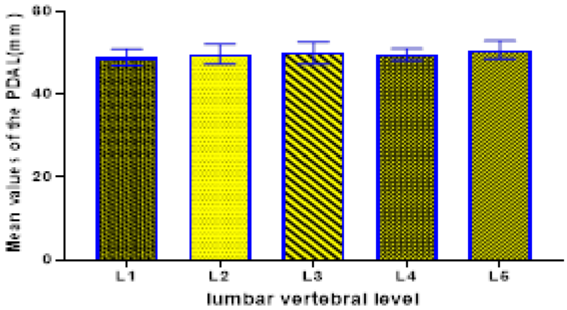

Figure 6: Demonstrated Bar chart showing dimension of (PDAL) mean values (mm) and SD in sample at each lumbar vertebral level between participants.

The results of(PDAL)showed that there were not a greater variation in the mean values of vertebra levels of our study (49.80mm) and others some populations such as; (Ebraheim et al[19] 48.87mm,USA) and India (Acharya et al[26] 47.68mm,India), whereas the greater variation shown between our study and population of (Tan et al[27]41.78mm,Singapore) ((Figure.7).

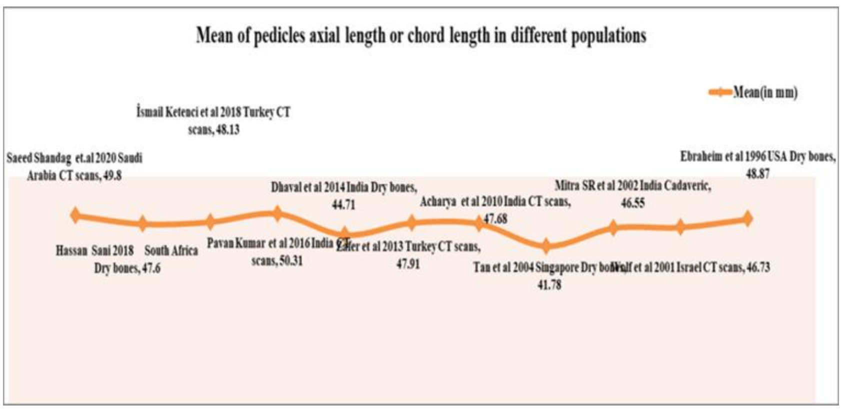

Figure 7: Chord length of lumbar vertebral pedicles obtained in studies performed in different populations.

Transverse pedicle angle (TPA):

Knowledge of transverse pedicle angle is important while placing screws because any inadvertent medial perforation due to wrong placement of the pedicle screw can put the spinal cord at risk or cause vascular injury [21] it's the angle of screw path inclination. The results of the comparison of the mean values of(TPA)at L1to L5 between males and females suggested that no significant difference between males (L118.71^{o} ±1.97,L219.21^{o} ±1.92,L319.94^{o} ±1.76,L4 22.32^{o}±2.28 and L5 25.71^{o} ±3.19) and females (L118.49^{o} ± 2.01,L2 19.20 ^{o} ±1.78,L3 19.90 ^{o} ±1.80,L4 22.44 ^{o} ±2.22 and L526.16^{o}±2.76)respectively. L1 (0.76,p=0.45),L2(0.04,P=0.96),L3(0.19,P=0.85),L4(-0.40,P=0.68)andL5(-1.07,P=0.29) respectively. The pooled data of males and females are listed in (Table 7). The results of the TPA showed gradually increase in the degrees of angles from L1 to L5,the maximum TPA found to be among female at L5=(30.70 $^{o)}$ and minimum (TPA) found in both males and females (13 ^{o}) at L3.The mean (TPA) was slightly larger in males in than in females and the difference was statistically insignificant (p >0.05) (Table 7).The mean (TPA) of the pedicle in males was 21.18^{o} ± 2.40 and in females was 19.24^{o} ± 2.33. The largest mean lumbar transverse pedicle angle was seen at vertebral level L5 in both males (25.71^{o} ±3.19) and females (26.16^{o} ±2.76) and the least was at vertebral level L1 in both males (18.71^{o}±1.97) and females (18.49^{o}±2.01).The largest (TPA) was located at female L5 ((30.70^{o}) and the smallest (TPA) was located at female L1 (18.49^{o}).

Table7: Demonstrated comparison of (TPA)of (L1-L5) between gender using independent sample t-test ,the results are expressed in (degree).

		Male	Female	T-values	Significance
L1	Mean	18.71	18.49	0.76	0.45
	SD	1.97	2.01		
	Maximum	22.90	22.90		
	Minimum	14.70	14.70		
L2	Mean	19.21	19.20	0.04	
	SD	1.92	1.78		0.96
	Maximum	23.50	22.40		
	Minimum	14.70	14.70		
L3	Mean	19.94	19.90	0.19	0.85
	SD	1.76	1.80		
	Maximum	23.70	23.70		
	Minimum	13	13		
L4	Mean	22.32	22.44		0.68
	SD	2.28	2.22	-0.40	
	Maximum	26.60	26.60		
	Minimum	18	18.50		
L5	Mean	25.71	26.16		0.29
	SD	3.19	2.76	-1.07	
	Maximum	30	30.70		
	Minimum	14	14		

First lumbar vertebra (L1)Second lumbar vertebra (L2)Third lumbar vertebra (L3)Fourth lumbar vertebra (L4) Fifth lumbar vertebra (L5) ,SD=standard deviation,. P>0.05 statistically insignificant between female and male at the lumbar level. The results of the post-hoc, Bonferroni-corrected pairwise analysis convinced that the mean (TPA) at all vertebral levels L1-L5 in the lumbar spine was significantly larger in older age categories(> 55) than in younger age category(26-35) (p≤ 0.05) (Table.8)

Table 8: Pair wise (post hoc Bonferroni) comparison of the mean transverse pedicle angle of younger and older categories of Jazan population. *P<0.05 statistically significant differences

Vertebral Levels	26-35years Vs> 55years p- value
L1	.002*
L2	.000*
L3	.000*
L4	.006*
L5	.000*

Our study has established an equation to predict the correlation coefficient between the Transverse pedicle angle(TPA) and age for Jazan region population of a known age with Correlation significant at($p \leq 0.05$),R^2=.002. **Transverse pedicle angle(TPA)=19.249+.005*age.** (Table 9).Correlation Coefficient between the (PDAL) and age was also convinced in a scatter plot diagram which depicted the positive linear relationship between the transverse pedicle angle (TPA) and age.(Figure.9).

Table 9: Correlation Coefficient between the Transverse pedicle angle(TPA) and age

	Unstandardized Coefficients		Standardized Coefficients		
Age (Constant)	B	Std. Error	Beta	T	Sig
	.005 19.249	.009 .369	.042	.591 52.226	.555 .000

Established equation to predict the transverse pedicle angle (TPA) for Saudi –Jazan region population of known age. Correlation is significant at($p \leq 0.05$),R^2=.002**.transverse pedicle angle(TPA)=19.249+.005*age.**

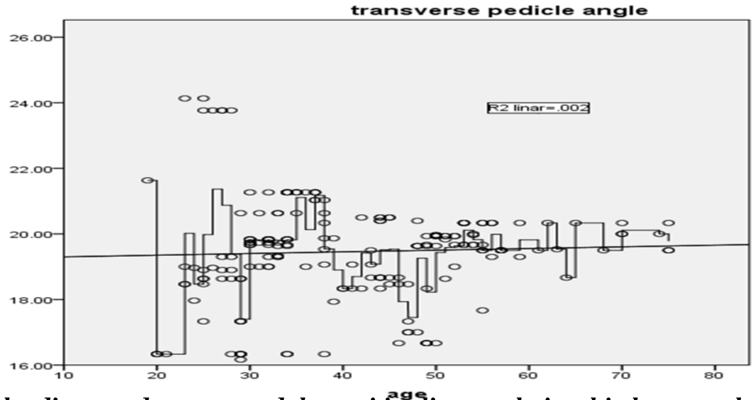

Figure 8: Ascatter plot diagram demonstrated the positive linear relationship between the transverse pedicle angle (TPA) and age.

The overall result of the mean values of the (TPA) of the lumbar vertebrae among the 200 participants showed gradually increase from ,L1(18.59°), L2 (19.20°), L3(19.92°),L4 (22.38°) and L5 (25.93°). (Figure.9)

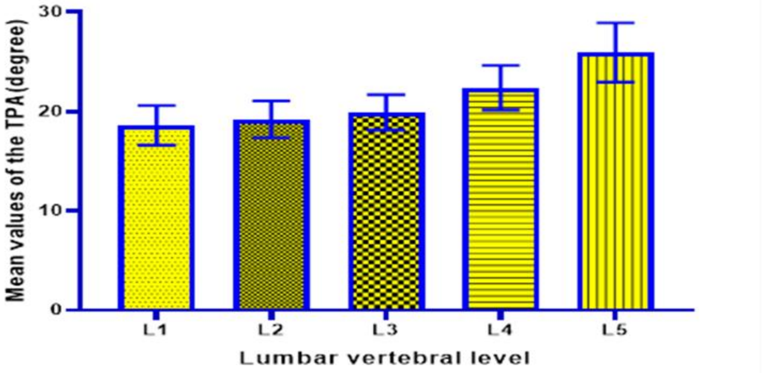

Figure 9: Bar chart showing dimension of (TPA) mean values in (degrees) and SD in sample at each lumbar vertebral level between participants

When the result of our study mean values for the (TPA) in(degrees) compared with other populations in the world the results depicted that the mean value of our study of the (TPA) (21.21°) was totally different with some populations such as; USA(28.82 °),Israel(12.42 °),India(11.24 °),Taiwan(13.73 °) ,Pakistan(16.6 °) whereas there was no greater variation shown between our study and some populations of Burkina Faso (21.58 °) and Black South Africans (24.18°)(Figure.10).

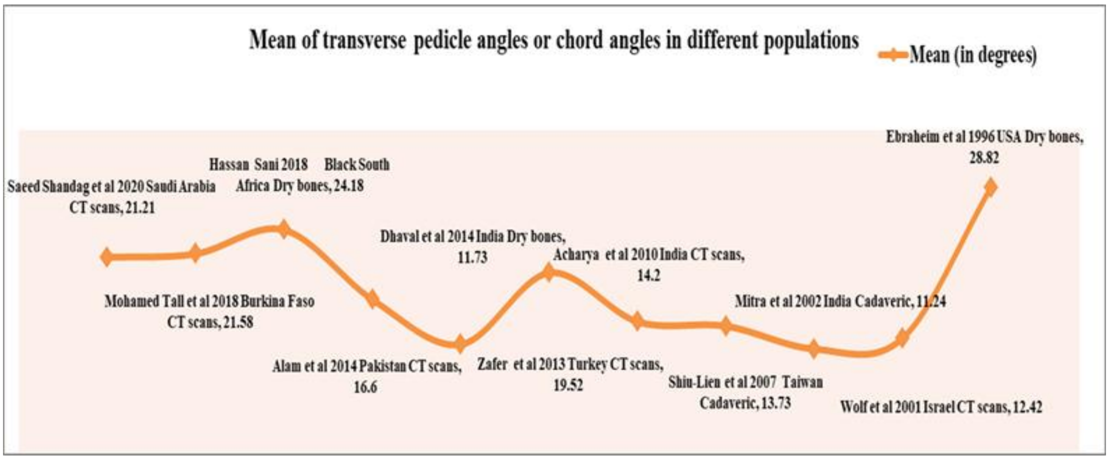

Figure 10. Demonstrated transverse pedicles angle of lumbar vertebral pedicles obtained from studies performed in different populations.

IV. DISCUSSION

The pedicle width range for typical lumbar vertebrae has been mentioned previously [23] as 4- 17 mm, and as 5 - 17 mm[17], and as 4.5- 20 mm[24], compared to (4.25mm -15.60mm) in the current study. The average diameter of our study pedicle width is 8.43mm; hence 5.5 to 7.5 mm screw would be safiest with the Jazan population. A lumbar pedicle with a width of 8.43 mm will easily accommodate a 7.5 mm screw, especially if the pediculation is done under fluoroscopy or computed tomography scan guidance.

The total number of participants' average for (PDAL) in our study is (49.80mm). One previous study [17] had found that the range of (PDAL) chord length for typical lumbar vertebrae among the USA population was (38 - 58 mm) as opposed to (48.83 -50.80mm) in our study.

Screws ranging in length from 41 to 42 mm look to be safe at all lumbar vertebral levels, as the minimum mean chord length was 48.83 mm. Important study[19] convinced that the transverse pedicle angle ranged between (20 - 40^{o}) for typical lumbar vertebrae, whereas the current study found (13-30.70^{o}).

The differences in the current study's results and those of previous studies in terms of some of the parameters are primarily due to differences in race, ethnicity, environmental factors, and study methods.

As a conclusion the current study accurately found the morphometric diameters of the lumbar vertebral pedicle among Jazan population, so according to the our results, it can be mentioned that the lumbar transpedicular screw that , use of a 5.5 to 7.5 mm screw width and of 41 to 42 mm length appeared to be suitable and safety for use with our participants at all lumbar levels.

V. CONCLUSION

As a conclusion the our study with high degree of precision had determined the morphometric diameters of the lumbar vertebral pedicle among the Jazan population, it can be Sayed that the lumbar transpedicular screw with a screw width of 5.5 to 7.5 mm and a length of 41 to 42 mm look to be suitable and safest for use with our participants at all lumbar levels.

However, because this is a one-of-a-kind study among the Jazan population, more anatomical imaging studies with a large number of samples are needed to analyze the morphometric diameters of the lumbar vertebral pedicle and other anatomical structures.

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CT metric probe of the lumbar vertebral ratios among Jazan population(KSA)

Saeed Taha Mohamed Ali [1], Fathia Abd El Rahman Mohamed Alamin[2], Caroline Edward Ayad[3]

1 Diagnostic Radiography Technology Department, Jazan University, College of Applied Medical Science, Jazan,KSA
2 Diagnostic Radiography Technology Department, Jazan University, College of Applied Medical Science, Jazan,KSA
3College of Medical Radiological Science, Sudan University of Science and Technology.

Abstract *Measurements of the pedicle width, pedicle height, spinal canal width and vertebral body width are the most popular measurements in vertebra, but reason that made this study interesting ,was the measurement of all lumbar vertebral ratios including spinal canal ratio, pedicle(CT)ratio as well as the unique measurement for the pedicle index. Our study aimed to institute a baseline data by the analysis of the (pedicle index: the ratio of the pedicle width to the pedicle height) (pedicle ratio or CT ratio: the ratio of pedicle width to the vertebral body width) and the (spinal canal ratio: the ratio of the spinal canal width to the to the vertebral body width)at each lumbar vertebral level(L1-L5) among Jazan population using CT scan.*

This study was a prospective and descriptive, using a reviewed CT images for lumbar vertebrae (L1to L5). It consisted of 200adult participants [100males and 100 females] The mean age of the total patients was 41.77 years (range between 19 and 75 years).The three lumbar vertebral ratios were: the ratio of the pedicle width(PDW) to the pedicle height(PDH)), (pedicle ratio or CT ratio: the ratio of pedicle width (PDW) to the vertebral body width (VBW))and the (spinal canal ratio: the ratio of the spinal canal width(SCW)to the to the vertebral body width (VBW).All were measured in millimeter, using statistical analysis. The mean of the lumbar vertebral pedicle index ratios gradually increased from L1 to L5,these ratios were greater in females than males, mean of the CT ratios also demonstrated gradually increasing from L1 to L5and their ratios also greater in females than males whereas the results of the mean of the spinal canal ratios were gradually decreasing from L1 to L5and the spinal canal ratios were greater in males than females.

Lumbar vertebral ratios structural knowledge might be helpful for the clinicians in the images diagnoses and orthopedic surgeon in plan for surgery of lumbar spine anomalies. It acts also as a useful database for Jazan population which can be assisted in the further spinal researches.

Keywords: *ratio; lumbar vertebrae; morphometry, pedicles.*

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I. Introduction

Several studies have been conducted to determine morphometry of lumbar vertebra[1]and [2]as knowledge of high precision of human lumbar vertebra anatomy is necessary not only for the understanding of biomechanical and functional feature of lumbar spine but also for various interventions such as; safe placement of screws in pedicle fracture, correction of deformities or degenerative changes, vertebroplasty, pediculoplasties, discography, discectomy, vertebral biopsy as well as pre surgical planning and designing surgical instruments[3],and with the help of screws, various devices such as rods, plates or wires can be applied to spine for immobilization or fixation [4].Transpedicular fixation has become the most frequently used technique in lumbar spine arthrodesis due to its biomechanical superiority and the observed clinical improvement compared with other available vertebral fusion systems [5]; [6].Most anatomical studies on morphology of lumber pedicle have been reported in white population, Asian patients, American and African with a few report in Arab zone in spite of these anatomical constraints in the lumbar spine. However there are no existed reports about the vertebrae in Saudi population with the exception of that found by[7], [4].

Accurate anatomical descriptions of the shape and orientation of lumbar is also important to distinguish differences in morphometry of vertebrae in men and women and to understand changes in the elderly [8] as incorrect placement of instruments and devices may have serious complications [9].

Most of studies have been carried out using fresh cadaver [10] [11] or osteological collections with the help of vernier caliper. Computerized tomographic(CT) images have been employed more recently to study lumbar vertebrae [1] and[15],and it's used in morphometric analysis of lumbar spine measurements in this study.

Computed tomography (CT) scans, with an established accuracy for evaluating pedicle dimension, are most commonly used as the best radiologic tool for measuring various radiographic pedicle parameters [1], [12]and [13].In comparison with the CT scan, it is well known that plain radiograph is a relatively inaccurate way to evaluate pedicle diameter because of various three dimensional structures with different transverse and sagittal angles of pedicle at each spine level[14].

The aim of the present study was to establish a baseline data by the analysis of the(pedicle index: the ratio of the pedicle width(PDW) to the pedicle height(PDH)), (pedicle ratio or CT ratio: the ratio of pedicle width (PDW) to the vertebral body width (VBW))and the (spinal canal ratio: the ratio of the spinal canal width(SCW)to the to the vertebral body width (VBW)) at each lumbar vertebral level(L1-L5) in Saudi Arabian[Jazan population] using CT scan, to find more accurate estimations of pedicle diameters and indices and the lumbar spinal canal diameters which may help clinicians for interpret and plan for proper treatment of lumbar anomalies such as; spinal canal stenosis. The only report found related to the characteristics of CT ratio or pedicle ratio PWD/VBW done by (Kang.,et al 2011)[14] who hypothesized that CT scan is a trustable radiologic imaging modality to provide precise measurements of PDW and VBW,VBW measured on true anteroposterior radiographs incorporates less measurement error because the shape of the vertebral body has nearly circular profile, and the approximate value of a true PDW could be determined using the VBD as measured on plain radiographs and the mean CT ratio of PDW/VBW at each spine level.

II. Materials & Methods

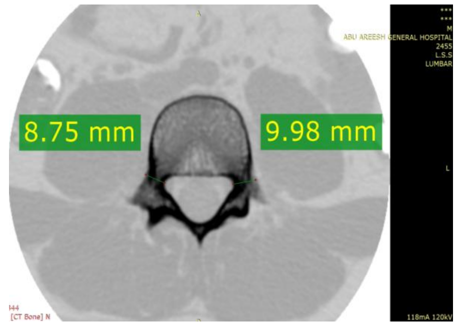
The study was an observational, prospective, descriptive and comparative morphometric study based on a review of CT images by measuring the dimension of the lumbar spine.200 patients[100male and 100female],The mean age of the total patients was 41.77years (range between 19 and 75 years), with the mean age of 100 male being 41.36 years (range 20–75years) and the mean age of 100 female patients being 40.70years (range 19–75 years). The study sample analyzed *two thousand* pedicles, *one thousand* morphometrically normal lumbar vertebral body and canal from (L1to L5) of the*two hundred* patients.The lumbar vertebrae were analyzed prospectively with CT scans, patients were selective randomly according to their fulfilling the inclusion criteria [age above 18] and exclusion criteria [patients with a certain degree of skeletal pathology which was interpreted by their chronic back pain, back pain related to age factor, arthritis prior back surgery, pregnancy and degenerative conditions, spondylolisthesis, retrolithesis, and disk space collapse.]study was performed between March 2016 and April2020. Data were collected from CT units of governmental hospitals in Jazan region after permission verbally from head of the medical imaging departments in the region in a form of lumbar CT or abdominal CT images using USB flash or CD-ROM. No patient data were published also the data was kept in personal computer with personal password. Data were then analyzed using DICOM viewer [RadiAnt DICOM Viewer 4.6.9 (64-bit) reviewed April 14, 2019] however some cases were independently measured and analyzed in the PACS rooms in some hospitals in the region, by *radiologists* to rule out scans that showed symptomatic of the spine because these conditions can alter the size or composition of the vertebral pedicle. All data collected were presented as mean±SD values by using of the (SPSS version 19,SPSS Inc., Chicago,USA))There was official permission to Jazan governmental hospitals to take the data. Patients' height and weight were not considered in this study like that done by others studies.

Measurements of Pedicle index(PI) :

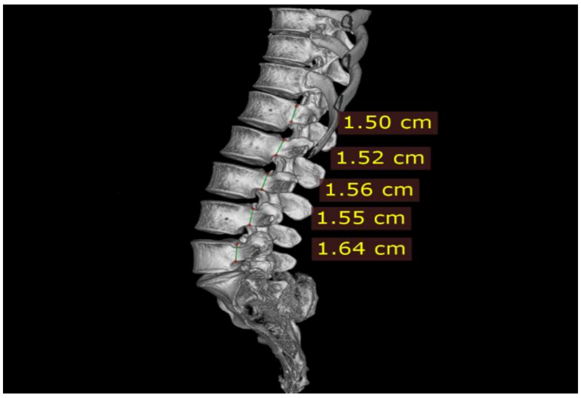
It's the ratio of the pedicle width to the pedicle height at each lumbar vertebral level:

Pedicle index = Pedicle width (PDW)/Pedicle height (PDH)

Pedicle width (PDW)was measured using the CT axial views in the transverse plane, 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, also known as (isthmus), transverse or axial width. As proposed previously [15], the pedicle axis was defined as a line perpendicular to and bisecting the narrowest diameter of the pedicle. Both right and left pedicles width were measured, (Figure1) whereas the Pedicle Height (PDH) was measured from the 3D reconstruction images using the lateral approach in the sagittal plane. This is the maximum diameter of the pedicle It is the vertical distance between superior and inferior border of pedicle at its midpoint isthmus. Both right and left pedicles height were measured. (Figure2).



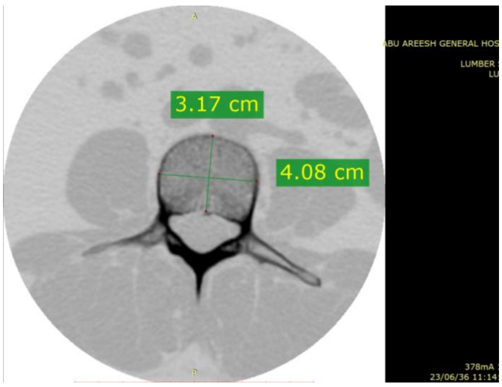
(Figure 1) Demonstrated measurements of the right and left pedicles of the (PDW) using axial MPR images at the level of (L4) *(Zindrick et al.1987[15]method).*



(**Figure2):** demonstrated measurements of the left Pedicle Height (PDH):using 3D reconstruction images.

Measurements of pedicle ratio or (CT ratio):
The ratio of pedicle width (PDW) to the vertebral body width (VBW).

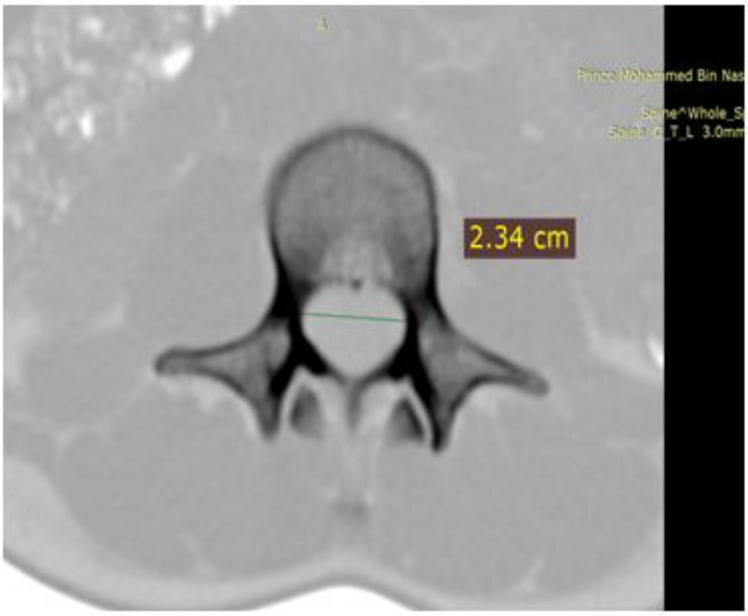
Pedicle ratio (CT ratio) = Pedicle width (PDW)/Vertebral body width (VBW)
For the knowledge of the pedicle width (PDW) measurement see (Figure 1)
Vertebral body width (VBW) was measured using the CT axial views in the transverse plane, vertebral body width measurements, include the distance between the lateral borders of the vertebral body in the transverse plane of the cranial endplate, i.e. it's the widest distance between the lateral borders of the vertebral body. The Transverse diameter of the vertebral body, measured from the external cortex of the right border to the external cortex of the left border**.** *(Urrutia et al.,2009).* (Figure.3)



(Figure.3)Demonstrated measurement of both the Vertebral Body Width (VBW) and the Vertebral Body Depth (VBD) using axial MPR images at the level of (L3) as reported and measured by *(Urrutia et al.,2009)[16].*

Spinal canal ratio: Spinal canal ratio SCW/VBW Mean spinal canal width /Mean vertebral body width.
Spinal canal width (SCW) or (interpedicular diameter)using the axial CT plane, it's the maximum distance between the medial surfaces of the right and left isthmuses of the vertebral pedicles**,** it was measured and *also*

recorded as the transverse diameter of the vertebral foramen width as *described* and measured by *(Jones, Thomson,.1968[17]* Transverse diameter of the spinal canal. Described as the distance that exists between the external cortex of the medial border of both pedicles according to *(Urrutia et al.,2009[16]*.(Figure 4).*For the knowledge of the* vertebral body width(VBW) measurement (Figure 3)



(Figure.4) Demonstrated measurement of the Spinal Canal Width (SCW) or (interpedicular diameter) using axial MPR images at the level of (L3) as reported and measured by *(Jones, Thomson,.1968)[17] and (Urrutia et al.,2009)[16]*

III. RESULTS

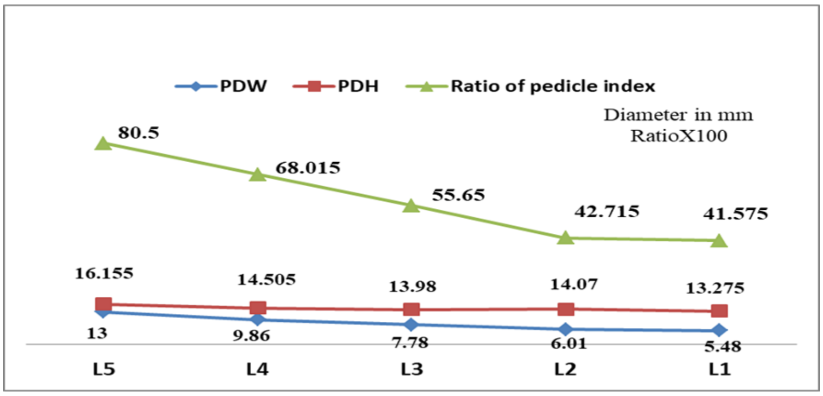
(Table.1): Demonstrated pedicle width &pedicle height (mean ± SD, mm):

Vertebral Level	Pedicle width (PDW)			Pedicle height (PDH)		
	Male	Female	Total	Male	Female	Total
L1	5.56±.95	5.39±.68	5.48±.828	13.36±1.83	13.19 ± 1.86	13.275±1.84
L2	5.98±.653	6.04±.83	6.01±1.74	14.04±1.91	14.1±1.92	14.07±1.95
L3	7.67±.75*	7.89±.65	7.78±2.70	13.98±1.25	13.98± 1.20	13.98±1.225
L4	9.74±.900	9.99±1.17	9.86±1.05	14.57±1.64	14.44±1.50	14.505±1.57
L5	12.99±1.29	13.02±1.05	13.00±1.17	16.19 ±1.41	16.12±1.52	16.155±1.465

* Significant difference of pedicle width diameter between male and female ($P<0.05$)also there was statistically insignificant difference of the pedicle height between female and male at the lumbar level ($P>0.05$)

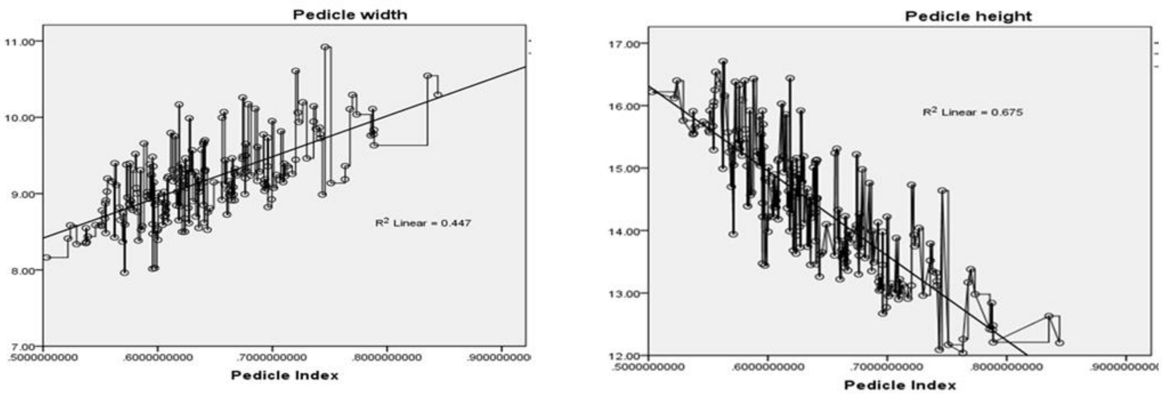
(Table.2): Depicted the ratio of pedicle width to pedicle height (mean ± SD, %):

Vertebral Level	Pedicle index		
	Male	Female	Total
L1	42.29± 4.15	40.86±3.05	41.575±3.6
L2	42.59± 3.22	42.84±3.75	42.715±3.485
L3	54.86± 3.30	56.44±2.81	55.65±3.055
L4	66.85± 3.98	69.18±3.63	68.015±3.805
L5	80.23± 4.54	80.77 ± 4.66	80.5±4.6



(Figure.5) Demonstrated the mean PDW, PDH, and the ratio of (PDW/PDH X 100) L1–L5 are demonstrated on a linear graph

The results found that the pedicle index curve is more similar to both the PDW (r2 = 0.447) curve and the PDH (r2 = 0.675) curve especially at lumbar levels of L1– L3, PDW curve demonstrated positive linear relationship with Pedicle index and PDH curve demonstrated negative linear relationship with Pedicle index(Figure.6).



(Figure.6): demonstrated that the pedicle index curve is more similar to both the PDW (r2 = 0.447) and the PDH (r2 = 0.675) curve , especially at lumbar levels of L1–L3,PDW curve depicted positive linear relationship with Pedicle index and PDH curve depicted negative linear relationship with Pedicle index.

Pedicle ratio (CT ratio) = (PDW)/ (VBW)

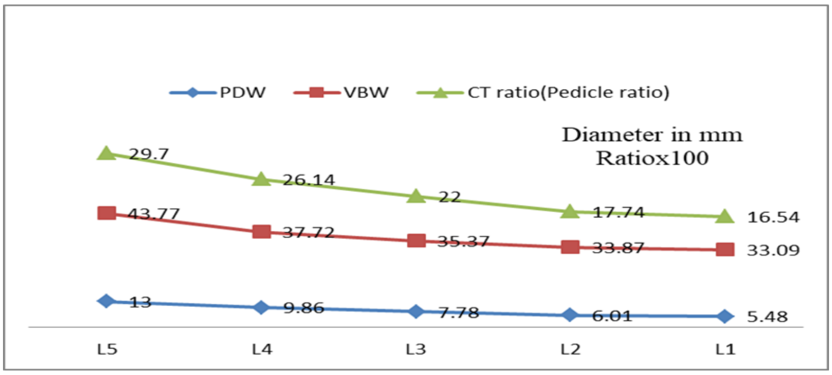
(Table 3): Depicted the Pedicle width& vertebral body width (mean ± SD, mm):

Vertebral Level	Pedicle width (PDW)			Vertebral body width		
	Male	Female	Total	Male	Female	total
L1	5.56±.95	5.39±.68	5.48±.828	33.29±2.80	32.90±2.54	33.09± 4.00
L2	5.98±.653	6.04±.83	6.01±1.74	34.02±2.66	33.72±2.23	33.87± 4.11
L3	7.67±.75*	7.89±.65	7.78±2.70	35.78±2.66	34.97± 2.63	35.37± 4.66
L4	9.74±.900*	9.99±1.17	9.86±1.05	38.11±2.73	37.32±2.20	37.72± 3.88
L5	12.99±1.29	13.02±1.05	13.00±1.17	43.97±3.09	43.57±2.51	43.77± 4.89

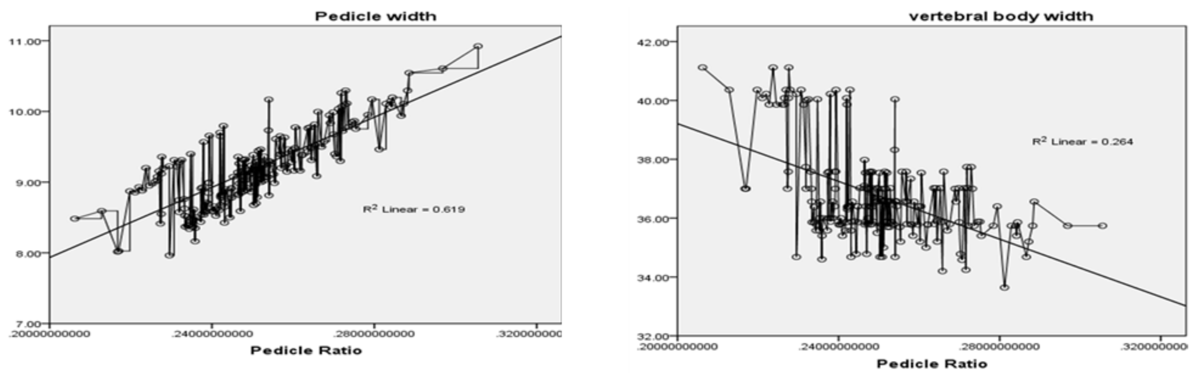
(Table.4)Demonstrated Pedicle ratio or CT ratio of the pedicle width to vertebral body width (mean ± SD, %):

vertebral Level	CT ratio (pedicle ratio)		
	Male	Female	Total
L1	16.70 ± 2.45	16.38 ± 2.07	16.54 ± 4.16
L2	17.58 ± 2.00	17.91 ±2.77	17.74 ± 4.35
L3	21.44 ± 2.13	22.56± 2.81	22.00± 3.88

L4	25.56 ± 2.98	26.77± 2.55	26.14± 3.95
L5	29.54± 2.54	29.88 ± 3.66	29.70± 4.56



(Figure.7): The mean PDW,VBW,and the ratio of (PDW/VBWX100) L1–L5 are demonstrated on a linear graph.



(Figure.8):Demonstrated that the pedicle ratio curve is more similar to the PDW curve (r2 = 0.619) than the VBW (r2 = 0.264) curve, especially at lumbar levels of L1–L2,PDW curve depicted highly positive linear relationship with Pedicle ratio and VBW curve depicted negative linear relationship with Pedicle ratio.

Spinal canal ratio: SCW/VBW

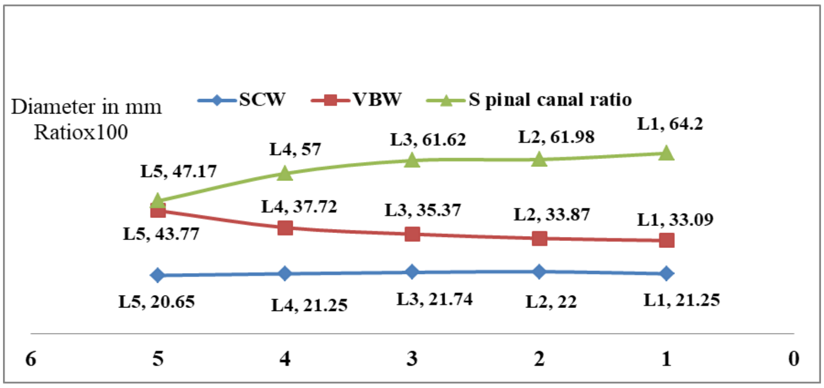
(Table5): Demonstrated the (SCW) and (VBW) (mean ± SD, mm):

Level	Spinal canal width(SCW)			Vertebral body width (VBW)		
	Male	Female	Total	Male	Female	Total
L1	21.36 ±1.24	21.14±1.1	21.25 ± 1.26	33.29±2.80	32.90±2.54	33.09± 4.00
L2	21.21±2.00	20.78±2.4	22.00± 2.2	34.02±2.66	33.72±2.23	33.87± 4.11
L3	22.04±2.90	21.45±2.5	21.74 ± 2.7	35.78±2.66	34.97± 2.63	35.37± 4.66
L4	22.04±2.90	20.96±2.7	21.25 ±2.8	38.11±2.73	37.32±2.20	37.72± 3.88
L5	20.85±2.89	20.45±2.5	20.65 ± 2.70	43.97±3.09	43.57±2.51	43.77± 4.89

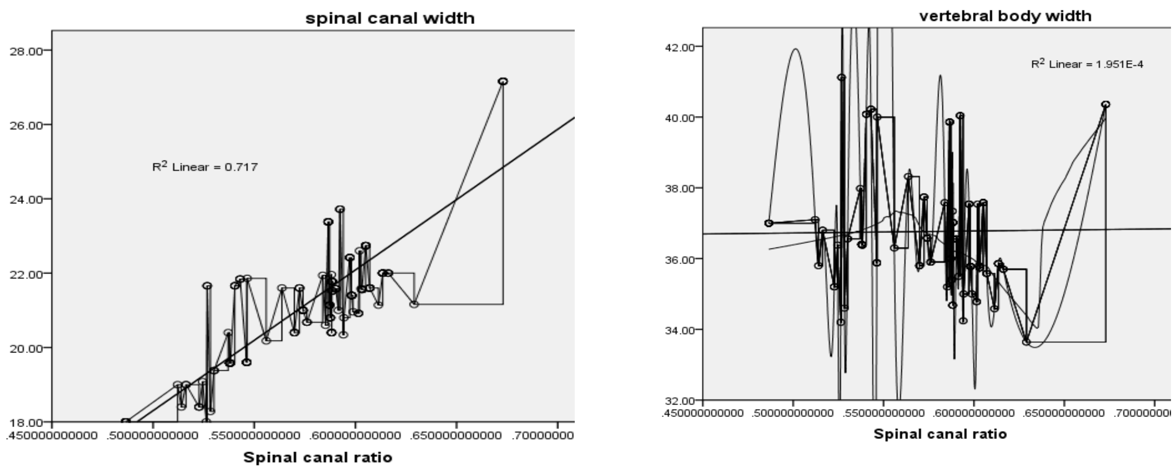
(Table 6): Demonstrated the ratio of the spinal canal at each level (mean ± SD, %):

Level	Spinal canal ratio		
	Male	Female	Total
L1	64.16 ± 2.02	64.25± 3.05	64.20 ± 3.83
L2	62.34 ± 2.33	61.62 ± 3.75	61.98 ± 3.35
L3	61.60 ± 2.78	61.65 ± 2.81	61.62 ± 3.19

L4	57.83± 3.98	56.16± 3.63	57.00 ± 3.94
L5	47.42 ± 4.54	46.93 ± 4.66	47.17 ± 4.6



(Figure.9):The mean SCW,VBW and the ratio of (SCW/VBWX100) L1–L5 are demonstrated on a linear graph.



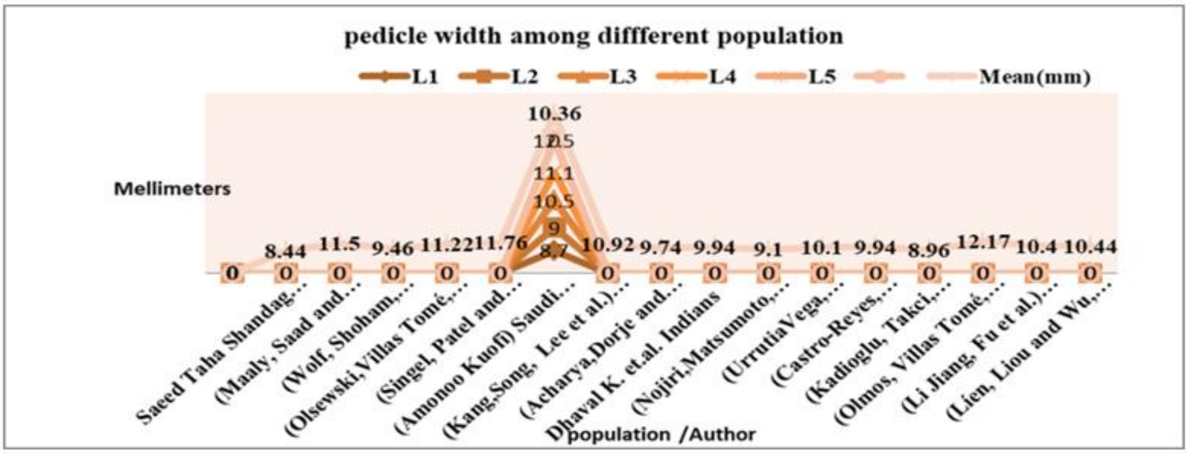
(Figure10):A. The mean SCW, VBW, and the ratio (SCW/VBWx100) for L1–L5 are depicted on a linear graph. B. The Spinal canal ratio curve is more similar to the SCW (r2 = 0.717) curve than the VBW (r2 = 1.951E) curve, along lumbar vertebral levels of L1–L5. SCW curve demonstrated a positive linear relationship with spinal canal ratio and VBW curve depicted no linear relationship with spinal canal ratio.

IV. Discussion

Vertebral column morphology is influenced by various factors such as environmental and mechanical factors of our everyday lifestyle and internally by hormonal, genetic and metabolic factors. These all affect its ability of everyday life to react to the dynamic forces which are much influenced by occupation, locomotion and posture [18].The lumbar pedicle has been the object of many morphometric studies in different populations around the world to determine their true dimensions using direct measurement in cadavers spines [19,20,21,22]and the measurement of dry vertebrae [21,23, 24, 25] plain radiography, fluoroscopy, 3D reconstruction, magnetic resonance imaging and computed tomography (CT) such as; [1,9,12,26,27,14,2,29 ,30 ,31, 32,3,8 ,16 ,33 15] as well as the current study.

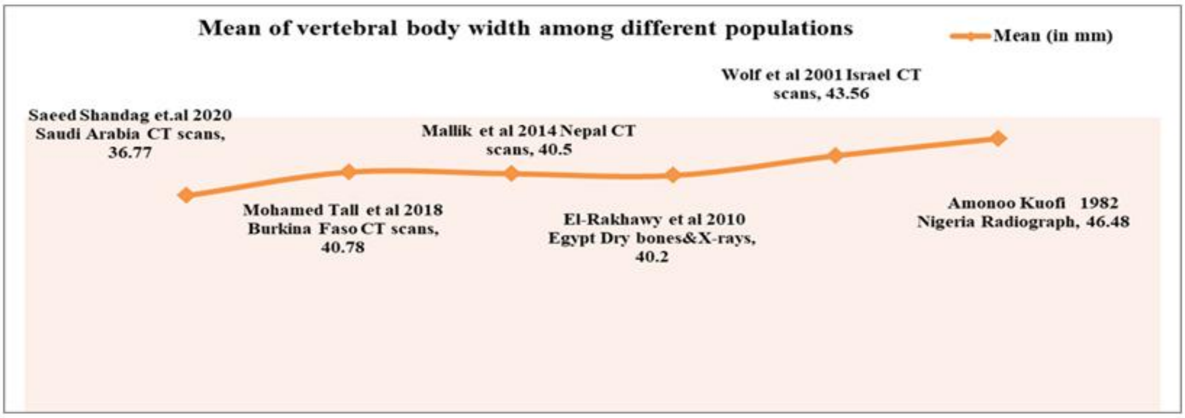
The largest mean lumbar pedicle width was seen at vertebral level L5 in both males (12.99±1.29) and females (13.024±1.047) and the least was at vertebral level L1 in both males (5.56±.948) and females (5.3901±.68104) . The minimum (5.39mm) and maximum (13.023mm) readings for both male and female pedicles width were noted both at (female L1) and (female L5) respectively. In all the vertebral levels, the mean pedicle width was slightly larger in females than in males and the difference was statistically insignificant ($p > 0.05$) except at vertebral level L1 .The result of our study demonstrated that the mean values of pedicle width of L3 in male (7.6 mm) was slightly smaller than that of L3 female (7.88 mm). lumbar vertebrae increased gradually from L1 to L5 in both males and females. The mean (PDW) of the pedicle in males was (8.39 ± 1.23) mm and in females was 8.47 ± 1.17 mm.

The results of pedicle width in our study(Jazan population)compared with different populations are demonstrated in (Figure 11),these studies depicted corresponding with our study in gradually increase in pedicle width from L1 to L5,and there was a great variation between our results with other races and ethnicities at each vertebral level in the mean values, although some populations showed close or slightly close corresponding with our results such as; Turkish [27], Israelites.[33], Indians [9], Chinese [34]. Mexicans [16] and Japanese.[35]The figure result also convinced that there was a great variation in (PDW) between this study and the study of Amoono kaufi in 1995 among Saudi Arabians though both studies were employed in the same country but in different region and the method of each study [4] used the plain radiograph where our study used CT scan as a method of measurement.



(Figure11)The (PDW) of lumbar spine of the present study were compared with the data from previous studies.

Pedicle height also influences pedicle screw selection. However, in all studies, it has been established that the pedicle height is always greater than the pedicle width [21]). Our study agrees with this finding. Some authors claim that pedicle height should not be considered as a morphometric parameter for proper selection of a transpedicular screw [36].The study results convinced that there was no great variation in (PDH) between this study and that of Amoono kaufi in 1995 among Saudi Arabians as both studies were employed in the same country but with different in regions and the method of each study [4] used the plain radiograph where in our study we used CT scan as a method of measurement. One study [4] depicted that the height of pedicles in males and females are maximum at L5 with 20.7mm and 17.5mm respectively, the present study reveals that the height of pedicles is maximum also at L5,with 16.19mm (male)and 16.12mm(female) respectively. Amonoo-Kuofi convinced that there was a cephalocaudal gradient of increase (from L1-L5) of the pedicles (height) in males and females, this later result corresponding with our study. But it is quite intriguing that, some studies showed a gradually decrease in height of pedicles (male & female) from L1-L5., [37] (T1 to L5), [38] (L1 to L5) and [39] (L1 to L5).The Pedicle index (PI) ratio that presented in our study is a unique radiologic measurement. The pedicle index curve is more correlated to both the PDW ($r2 = 0.447$) and the PDH ($r2 = 0.675$) curve, especially at lumbar levels of L1–L3, PDW curve in this ratio depicted positive linear relationship with Pedicle index and PDH curve depicted negative linear relationship with Pedicle index, This indicates that the mean PI ratio can be used as a very important measure for representing properties of pedicle diameters. Moreover, the fact that there is no significant difference between males and females in PI ratios at each spine level means that the PI ratio is a constant measurement along the lumbar spine, regardless of gender. Vertebral body width(VBW) represents a very important variable as it is playing a big role in the measurements of the spinal canal ratio and pedicle ratio or (CT ratio).The mean values of the (VBW) of the lumbar vertebrae for our participants showed gradually increase from(L1 to L5) ,L1(33.09), L2 (33.87), L3(35.37),then increased in L4 (37.72) and L5 (43.77). When these mean value in(mm) have been compared with other different races and ethnicities in the world (Figure12)the results demonstrated that there were greater variation in the mean values of vertebra levels of our study (36.77mm) and others such as; Nigeria (46.48mm) , Israel(43.56),Burkina Faso (40.78mm),Nepal (40.40mm) and Egypt(40.20mm).

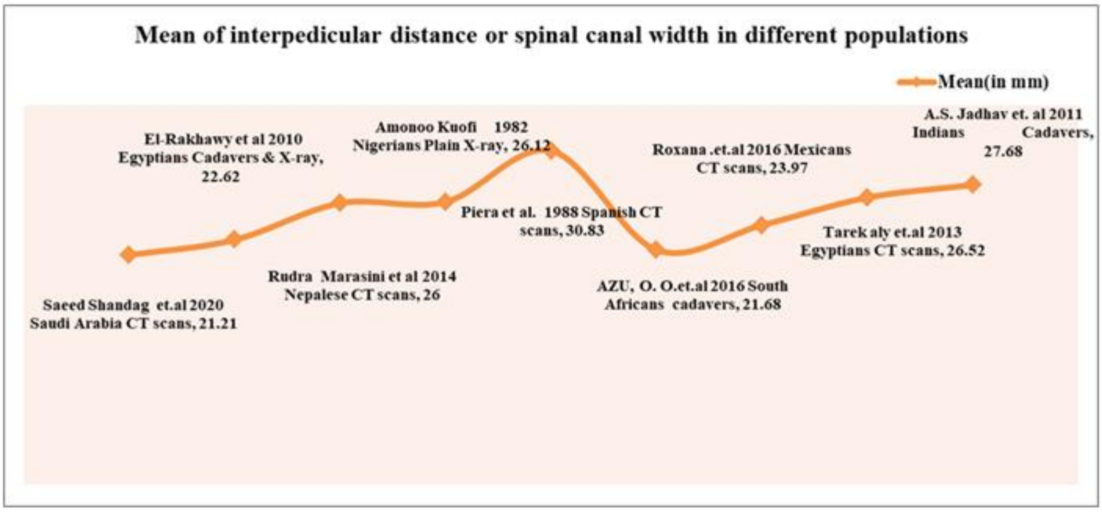


(Figure12)The (VBW) of the lumbar vertebrae of the present study compared with the data from previous studies.

The CT ratio(Pedicle ratio) is a unique radiologic ratio measurement that first performed [14].(Figure 7) this linear graph figure demonstrated the mean values of PDW and VBW and the ratio of (PDW/VBWX100) for each level (L1–L5) there was a correlation between the mean of PDW , the mean of VBW, whereas (Figure 8) had observed that the ratio curve is more similar to the PDW curve ($r2 = 0.619$) than the VBW ($r2 = 0.264$) curve, especially at lumbar levels of L1–L2,PDW curve showed highly positive linear relationship with Pedicle ratio and VBW curve showed negative linear relationship with Pedicle ratio. The above data for CT ratios might be useful backup data for developmental anatomic study particularly if future studies show it to be highly reliable in multiple racial and ethnic groups and over a large range of body sizes.

Spinal canal width (SCW) represents a very important role in the measurement of the spinal canal ratio in order to detect spinal stenosis. Spinal stenosis, is a rising phenomenon due to aging of the population, and has been diagnosed increasingly in the last two decades [40]). This disease is most typically due to degenerative changes [41]).(SCW) is a reliable index for the assessment of the size of the canal [42].Measurements of the (SCW) may be a preliminary, but useful aid in the diagnosis of the lumbar canal stenosis syndrome [43].There is not enough evidence to conclude that male scores (21.36 ±1.24,21.21±2.00,22.04±2.90 and 20.85±2.89) are any different from female scores (21.14±1.11,20.78±2.14,21.45±2.15,20.96±2.37 and 20.45±2.55), $t(198)$ = (L1=1.34, P =0.18), (L2= 1.48, P= 0.14),(L3= 1.36,P=0.11), (L4= 1.79,P=0.08)and(L5= 1.05,P=.0.30) respectively. The largest mean lumbar (SCW) was seen at vertebral level L3 in both males (22.04±2.90) and females (21.45±2.15) and the least was at vertebral level L5 in both males (20.85±2.89) and females (20.45±2.55).The mean SCW was larger in males than in females and the difference was statistically insignificant ($p > 0.05$).The mean SCW of the pedicle in males was 21.42 ± 2.40 mm and in females was 20.96 ± 2.06 mm.

Overall measurements of the (SCW) of the lumbar vertebral among Jazan population showed between the levels, L1(21.247mm), reduced in L2 to(20.997mm),then increased in L3(21.8190mm),then reduced gradually at L4 (21.3055mm),L5(20.6520mm)our measurements in (SCW) are totally not in line with that of other studies.(neither increase gradually from(L1-L5) nor decrease).Comparing with other different races and ethnicities in the world the mean of our result (21.21mm) was in close relation with some population(Figure13 though the difference in methods used between our study and others such as; south Africans(21.68mm) [44], Egyptians (22.62mm) [40]and Mexicans [45] (23.97mm).There was a large variation between our (SCW) mean value and some populations such as; Spanish [46] (30.83mm) and Nigerians.[43] (26.12mm).



(Figure13) The (SCW) of the lumbar vertebrae of the present study compared with the data from previous studies.

the result of the spinal canal ratio.(Table:6) at each lumbar vertebral level demonstrated that in the total ratio there was gradually decreasing from L1 (mean ± SD 64.20 ± 3.83%),L2 (mean ± SD 61.98 ± 3.35%),L3(mean ± SD 61.62 ± 3.19 %),L4(mean ± SD 57.00 ± 3.94%) and L5(mean ± SD 47.17 ± 4.6 %).The tables also demonstrated that spinal canal ratio were greater in males than in females at each lumbar level with exception of (L1 and L3) which were greater in females for a little bit. lowest (spinal canal ratio) was observed at L5 (mean ± SD 46.93 ± 4.66 %) and the highest ratio was at L1 (mean± SD 64.25± 3.05 %),both the smallest and largest pedicle ratios were observed among females. Our study also demonstrated that the ratio between the width of spinal canal and lumbar vertebral body is 0.6 at L1, L2 and L3 but it becomes 0.5 at L4 and 0.4 at L5, this signifies that in L4 andL5 levels the vertebral bodies are larger than the canal ,so the spinal canals are thus susceptible to stenosis.

V. Conclusion

In the measurements of *pedicle index ratio,* our study convinced that there was gradually increasing from L1 to L5 in the pedicle index ratio and the result among gender explained that pedicle index ratio were greater in females than males at each lumbar level with exception of L1 which was greater in males, and the pedicle index curve is more similar to both the PDH curve and the PDW curve, especially at lumbar levels of L1–L3.This study also demonstrated that *CT ratio or pedicle ratio* is gradually increasing from L1 to L5.Pedicle ratio were greater in females than males at each lumbar level with exception of L1 which was greater in males for a little bit. The result of the *spinal canal ratio* demonstrated that in the total ratio there was gradually decreasing from L1 to L5 and the spinal canal ratio were greater in males than in females at each lumbar level with exception of (L1 and L3) which were greater in females for a little bit. The vertebral ratio was not found constant at any vertebral level in both sexes. Based on the study results, it can be stated that measurements of lumbar vertebral ratios are useful for use as it provides precisions measurements of vertebral parameters to represent the characteristics of the lumbar vertebra. Furthermore, that CT metric scan is used as a trustable radiologic imaging modality as it yields precise measurements of the vertebral parameters particularly the PDW. The anatomical knowledge of the lumbar vertebral ratios may be helpful for the clinicians in the images interpretation and preparing plan for treatment of lumbar spine anomalies. It represents also greater a baseline data for Jazan population which can be assisted in the further research activities.

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