RADIOLOGICAL ANATOMY OF THE LUMBAR PEDICLES IN MALAY POPULATION USING REFORMATTED COMPUTED TOMOGRAPHY IMAGES.

BY

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ABSTRAK

Tajuk: Anatomi radiology tulang "lumbar pedicle" dalam populasi kaum Melayu menggunakan gambar "Computer Tomografi" yang di "ubah format".

Latar belakang: Ukuran tulang "lumbar pedicle" yang normal penting apabila pembedahan dan rawatan tulang belakang tulang belakang .Satu daripada alat pembedahan yang digunakan untuk pembedahan tualng belakang ialah "skru pedicle".Penggunaan "skru pedicle" semakin kerap digunakan dan pengetahuan mengenai "morfologi lumbar pedicle" penting apabila "skru pedicle" dimasukkan ke dalam tulang belakang pesakit semasa pembedahan.

Tujuan: Mendapat data asas morfologi "lumbar pedicle" dari L1 to L5 dalam populasi kaum Melayu di Hospital HUSM.

Kaedah : 126 pesakit (74 orang dewasa dan 52 golongan pediatrik) di masukkan dalam kajian "cross-sectional retrospective". Gambar "Computer Tomograpfi" yang sedia ada untuk pesakit yang mengidap penyakit barah dan menjalani "staging" atau "pathologi abdomen" yang lain diperolehi dari Jabatn Radiologi, Hospital Universiti Sains Malaysia". " Gambar "axial Computer Tomografi" tulang "lumbar L1-L5" diperolehi

menggunakan "General Elektrik CT scanner".(GE Medical Systems) , plana axial ketebalan 5mm.Workstation 4.0 Ultra 60 digunakan untuk mendapatkan "soft copy"dari gambar Computer Tomografi . Ukuran diameter "transverse pedicle luaran" , ketebalan "medial cortex" panjang pedicle,sudut transverse pedicle dan sudut pedicle saggital diukur.

Keputusan:

Tiada perbezaan statistik bagi"mean transverse pedicle luaran" L1-L5 ,ketebalan "medial cortex" panjang pedicle,transverse dan sudut pedicle saggital yang diukur dari L1-L5 dalam golongan pediatrik.

Terdapat perbezaan statistik yang besar bagi"mean transverse pedicle luaran" L3-L5 ,ketebalan "cortex medial L1-L2", ketebalan cortex lateral L5 tetapi tiada besar perbezaan dari segi mean transverse diameter luaran L1-L5" panjang pedicle,transverse dalaman L1-L5 dan sudut saggital pedicle diukur dari L1-L5 dalam golongan dewasa.

Terdapat banyak perbezaan statistic diantara kaum lelaki dan perempuan dewasa khasnya mean transverse pedicle luar" L1-L5 dan mean transverse pedicle dalaman L1-L5, ketebalan "medial cortex"L1-L2 , panjang pedicle,transverse tetapi tiada banyak perbezaan diantara kaum lelaki dan perempuan pada L3-5 dalam ketebalan cortex medial L1-L5 dan sudut pedicle saggital.

Dalam L1-L5,diametrr tranvesre luaran dan dalaman lebih besar pada kaum lelaki daripada perempuan dalam golongan pediatrik. Terdapat banyak perbezaan statistic pada L1-L3 diameter transverse luaran dan dalaman,corteks lateral L2 dan sudut tranverse pedicle L3-L5 tetapi tiada berbezan yang banyak diantara lelaki dan perempuan dalm cortex medial , cortex lateral (kecuali L2) , panjang pedicle dan sudut transverse pedicle (keculai L3) dan sudut pedicle saggital (keculi L3-L5).

Perbezaan yang besar pada pedicle tranverse luaran dan dalaman, panjang pedicle diantara golongan pediatrik dan dewasa dalam kaum lelaki pada L1-L5. pedicle corteks medial , sudut transverse pedicle dan saggital (L1-L5) dalam kaum lelaki.

Tiada perbezaan statistic yang banyak diantara golongan pediatrik dan perempuan dewasa pada L1-L5.

Kesimpulan:
"Trend" ukuran adalah sama berbanding orang Barat dan populasi kaum 'Asia yang lain.Ukuranukuran kajian ini lebih kurang sama dengan data orang Asia.Ukuran nyata berbanding orang Barat adalah lebih kecil. Tiada perbezaan besar dalam golongan pediatrik dan dewasa kecuali sudut transverse luaran.
Terdapat perbezaan besar diantara kaum lelaki dan perempuan yang dewasa pada L1-L5.Perbezaan yang diukur dari transverse luaran dan dalaman golongan pediatrik juga menunjukkan perbezaan besar.

ABSTRACT

Topic: Radiological anatomy of the lumbar pedicles in malay population using reformatted computed tomography images

Overview: The normal measurements of the lumbar pedicles well provide crucial information for spinal instrumentation, spinal management and useful guidelines for the use of devices. One of the spinal instrumentation used through the pedicle is pedicle screw as a fixation device for posterior spinal instrumentation. The use of pedicle screw had become increasingly popular in the recent years. For proper implant placement, an accurate knowledge of the pedicle morphology is of utmost importance for the safe placement of pedicle screw. Improper implant placement will lead to devastating neurological consequences to the patient.

Objectives: The main objective of this study was to obtain a database for the morphometry of lumbar pedicles from L1 to L5 of the normal Malay population treated in Hospital USM.

Methodology: hundred twenty six (126) patients (74 adults and 52 pediatrics) were included in this cross-sectional retrospective study. Archived Computed Tomography (CT) images of abdomen performed for those patients diagnosed of cancer for the purpose of staging or for other abdominal pathologies were obtained from the Radiology Department of Hospital Universiti Sains Malaysia. Axial CT scan images of lumbar vertebrae (L1 to L5) were obtained using a General Electric CT scanner (GE Medical

Systems) with axial plane with slice thickness of 5 mm. Workstation 4.0 Ultra 60 was used to retrieve soft copy of CT images. Distance of transverse outer pedicle diameter, transverse inner pedicle diameter, medial cortical thickness, lateral cortical thickness, pedicle length, transverse and sagittal pedicle angles were measured.

Results:

There was no significant statistical difference of mean transverse outer pedicle diameter, transverse inner pedicle diameter, medial cortical thickness, lateral cortical thickness, pedicle length, transverse pedicle angle and sagittal pedicle angle between the right and left pedicles from L1 to L5 in pediatric group.

There was significant statistical difference of mean transverse outer diameter at level L3-L5, transverse inner diameter at L5, medial cortex at level L1 and L2, lateral cortex L5, however there was no significant statistical difference of mean transverse outer diameter at L1-L2, transverse inner diameter at L1-L4.pedicle length, transverse pedicle angle and sagittal angle between right and left pedicles in adults group.

There was a significant difference between male and female of adult's group transverse pedicle angle in all levels in transverse outer and inner diameter, lateral cortical thickness, pedicle length and L1-L2 in medial cortical thickness. However no significant difference between male and female at L3-L5 in medial cortical thickness and all levels of transverse pedicle angle.

In all levels, transverse outer and inner diameter were greater in male compare to female in pediatric group and there were significant statistical differences at L1- L3 of transverse outer and inner diameter, lateral cortical thickness at L2, transverse pedicle angle at L3-L5, however there were no significant statistical differences between male and female in medial cortical thickness, lateral cortical thickness except L2,pedicle length, transverse pedicle angle except L3 and sagittal angle except L3-L5.

A significant statistical difference in transverse outer, inner diameter and pedicle length between pediatrics and adult in male all at levels ,medial cortical thickness, lateral cortical thickness ,transverse pedicle angle and sagittal angle at almost all levels in male. No significant statistical difference between pediatrics and adult in female group at almost all levels in transverse outer and inner diameter, medial and lateral cortical thickness, pedicle length, sagittal angle.

Conclusion:

The trends of our measurements were same as the western and other Asian population. However our measurements were close to other Asian and smaller compare to westerns. Almost there were no significant differences between right and left in pediatric group and also the adult group except the transverse outer diameter in adult group. There were significant differences between male and female in almost all levels, however these differences were noted in outer and inner diameter in pediatric group.

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INTRODUCTION

1-0 Introduction:

The pedicles of lumbar vertebrae become an important rout in the management vertebral pathology such as fractures or metastasis in orthopedic surgery or vertebroplasty, biopsy in intervention radiology. The normal measurements of the lumbar pedicles well provide crucial information for spinal instrumentation, spinal management and useful guidelines for the use of devices. One of the spinal instrumentation used through the pedicle is pedicle screw as a fixation device for posterior spinal instrumentation. The use of pedicle screw had become increasingly popular in the recent years. For proper implant placement, an accurate knowledge of the pedicle morphology is of utmost importance for the safe placement of pedicle screw. Improper implant placement will lead to devastating neurological consequences to the patient.

Currently, spiral CT is a frequently used technique that gives accurate estimates of bone morphology. CT scanning is commonly accepted as a reliable method for the evaluation of pedicle morphometry. Software applied to reformat the transverse view provides a good radiological anatomy of the small parts in human body such as lumbar pedicle.

Most of the previous studies on the morphology of vertebrae in the lumbar and thoracic pedicle were done on Caucasian population. Some of these were based on direct cadaveric measurements (Zindrick et al, 2000; Ebrahemi *et a*l, 1997), another on radiological measurements (Senaran *et* al, 2002; Zindrick et al 1986; Thomas *et al* 1992) and some on combined cadaveric and radiological parameters (Robertson and Stewart, 2000).

There have been few such studies on Asian populations. The studies of Cheung *et al.*, (1994), Hou *et al.*, (1993), Chadha *et al*, (2003) and Kim *et al*, (1994) had conclusively shown that there is a significant difference in the diameter of pedicle of lower thoracic and lumbar vertebra between Caucasian and Asian population. Extensive work has been published on the pedicle morphology of the adult and adolescent thoracolumbar spine. Less is known about the pedicle morphology of children.

There is insufficient data on the morphology of the pedicles in pediatric patients. Pedicle screw insertion in the pediatric age group was investigated in by Senaran *et al* 2002 and Ferree *et al*, 1992.

In study done by Ferree *et al*, (1992), the images were obtained in the soft tissue window and the external cortex diameters were measured instead of the internal diameters, which are crucial for the screw placement. (Senaran *et al* 2002).There is no similar study done in Malaysia so far regarding the morphology of lumbar pedicle which include pediatric and adult. Lumbar spinal surgery in Malaysia is performed based on the data of Caucasian population.

Therefore a complete database of the morphology of the lumbar vertebrae particularly the dimensions lumbar pedicle is much needed to ensure a safe and successful spinal intervention radiology and spinal surgery in Malaysia. The results would also provide information for improvement in the design of pedicle screws suitable for the local population.

LITERATURE REVIEW

2. Literature Review

2.1 Anatomy of Pedicle

Pedicle is a cylindrical shaped anatomic bridge between dorsal spinal elements and vertebral body. It is a complex three dimensional structure composed of a thin shell of cortical bone surrounding a core of cancellous bone which made up 62-79% of surface area of pedicle (Kothe, *et al*, 1996). It traverses the 3 spinal columns and is the strongest part of the vertebra (Halliday, 1999).

The pedicle, a roughly "tubular" bone comprised of cancellous matrix surrounded by a cortical shell, couples the anterior and posterior vertebral columns, from the corpus to the facets, bridging two structural regions that transmit loads to the adjacent levels in the spinal column. This unique anatomy of the pedicles provides an excellent implantation site for reconstructive spinal surgeries. Trabeculae in the pedicle had greater thickness and number and had less spacing in the network. Moreover, the cancellous bone in the vertebral body was anisotropic and consisted of mainly rod-like trabeculae whereas trabeculae in pedicle were more isotropic and plate-like. This suggests that, as in the literature, pedicle screw fixation, because of better fixation strength within the pedicle, compares favorably with anterior screw fixation where the screws are inserted transversely through the vertebral body (Inceoglu *et al.*, 2005)

Pedicle size, length and angulation varies throughout the spinal column. The transverse pedicle width is narrower than the sagittal pedicle width (pedicle height) throughout the spinal column except in the lower lumbar spine (Benzel, 1995 A).

The description of the pedicle usually includes information about pedicle height and width, and the orientation of the pedicle axis in the transverse and sagittal planes. Despite different methods of measurements, including computed tomography (CT) scan, calipers, or three dimensional morphometry, all authors agree that there is a high interindividual variability in pedicle dimensions (Kothe *et al*, 1996).

2.2 Characteristics of Lumbar Pedicle

The spinal cord is close to the pedicle 0.2-0.3 cm medially. It is separated by the dura and the cerebrospinal fluid (C.S.F). Below L1, the medial side of the pedicle is close to the cauda equina and the vertical segment of the roots. The nerve root lies very near, just below the pedicle. This is the most dangerous place when drilling. Elsewhere, laterally and above the surroundings, drilling is less dangerous. The lumbar roots only occupy one third of the foramen intervertebrae in its anterior and upper part (Raymond Roy *et al*, 1986).

Ebraheim *et al*, 1997 have defined the anatomic relationship between the lumbar pedicle and the adjacent neural structures. They found that the lateral aspect of the dural sac contacts directly with the medial wall of the pedicle and no epidural sac can be found between the dural sac and the pedicle. Therefore an improper medial placement of a pedicle screw will carry a greater risk of injury to the dural sac and spinal cord.

Mitra *et al.*, 2002 studied the vertebral pedicles at L1–L5 in 20 cadavers by direct roentgenographic and computerized tomographic scan methods. They found that the size and shape of the vertebral pedicle vary between different races. Morphometric studies have been conducted in white and nonwhite populations (e.g., Chinese, Koreans).

Transverse diameter was largest at L5 (16.19 mm) and smallest at L1 (7.05 mm). The transverse angle was largest at L5 (29°) and smallest at L1 (9°). The pedicles were directed cranially in the sagittal plane at all lumber levels except L5.The sagittal angle was largest at L5 (29°) and smallest at L1 (9°). Chord length was largest at L2 (47.5 mm) and smallest at L1 (46.01 mm). The values of linear measurements were smaller in females at all levels.

Another cross-sectional study was conducted by Senaran *et al.*, 2002 in Ankara-Turkey to investigate the pediatric pedicle morphology with the help of modern Computed tomography technology. A total of 21 patient's ages 5 to 10 years underwent standard spiral computed tomography of the abdomen. The patients were grouped according to age: Group 1 (5 to 8 years of age) and Group 2 (9 to 10 years of age). Images were reformatted, and multiplanar reconstructions were used to attain images of lumbar pedicles on sagittal, coronal, and transverse planes. The measurements included the inner and outer pedicle diameters on the transverse plane, the pedicle angle on both the transverse and sagittal planes, and pedicle length. The smallest pedicle length was 24 mm for Group 1 and 25 mm for Group 2. When the average values were considered, the smallest length was at L5 and the longest at L3. The transverse pedicle diameters gradually increased from L1 to L5 in both groups, except L2 in Group 2, which had a diameter minimally smaller than that of L1. The L1 pedicles had the smallest diameter (2.3mm for Group 1 and 3mm for Group 2), whereas the L5 pedicles had the largest diameter (6.17 mm for Group 1 and 8.72 mm for Group 2).In the transverse plane, the pedicle angle increased from L1 to L5 in both groups. In the sagittal plane, the angulations followed an opposite trend. They found that the inner transverse diameter of the lumbar pedicle, particularly in young children, is smaller than previously reported. Insertion of screws currently available commercially screws seems to be safe in the L4–L5 pedicles of children ages 5 to 8 years, and in the L3–L5 pedicles of older children.

Custom-made screws might be considered for upper levels for safe application. The major difference between the Senaran *et al*, 2002 study and the previous study Zindrick *et al*, (2002) on the pediatric population was in the transverse pedicle width. The average transverse pedicle width of the lumbar spine was smaller in comparable age groups of both previous studies. This probably was the result of to the different landmarks used for measurement. Zindrick *et al* found that the average values of extracortical pedicle width were 10.2 mm for L5 and 4.9 mm for L1 in children between 6 and 8 years old.

Extracortical pedicle diameters were given in Ferree's et al study 1992, and the average diameter of L4, L5, and S1 was given as 1 cm by the time the child reached 7 years of age.

Zindrick *et al*, 2000 collected and analyzed the pedicle morphology from C1 to L5 in the age range of 3 to 19 years using a computerized video analysis system. Each vertebral pedicle was measured in the axial and sagittal planes.

The measurements included the minimum pedicle width, the pedicle angle, the distance to anterior cortex, and anteroposterior and interpedicular spinal canal diameters. They found wide variation in pedicle morphology between specimens at each vertebral level was found in the young population.

In general, compared with the average adult data, a younger spine demonstrated a near uniform reduction in the linear pedicle dimensions at each vertebral level. Pedicles from the lower lumbar vertebrae attained dimensions acceptable for standard screw sizes at an earlier age than in the thoracic vertebrae. In the immature spine, the distance to anterior cortex increases with age. This distance increases approximately 70% between ages 3 to 5 years and adulthood.

A quantitative 3 dimensional study of the anatomy of cervical, thoracic and lumbar vertebrae of Chinese Singaporeans was carried out by Tan *et al*, 2004. They studied 220 vertebrae form 10 cadavers. Measurements were taken with the aid of a 3 dimensional digitizer. The following parameters were obtained: linear, angular and area dimensions of the vertebral body, spinal canal, and pedicle, spinous and transverse processes. Compared to Caucasian data, all the dimensions were found to be smaller. Pedicle width and length were smaller by 25.7% and 22.1% respectively. They concluded that the use of transpedicle screw may not be feasible in view of much smaller pedicle width in a large part of the thoracic spine.

No significant difference in the lumbar pedicle morphology between male and female was noted and no demonstrable changes in pedicle morphology with age. However significant differences between lumbar pedicles of Asians and whites.

Asian lumbar pedicles had a larger pedicle inclination angle (transverse angle) from L1 to L4 (Cheung *et al* 1994).

The cross-sectional morphology of the bodies and pedicles of L3, L4, and L5 was studied using transaxial computed tomographic (CT) sections in a series of 213 vertebrae. This revealed that the pedicles of L5 arise more laterally from the body than in L3. Further more, the lateral surfaces of the L5 body are inclined obliquely.

Unlike those of L3, L4 is transitional between L3 and L5, more closely resemble to the former. This morphology explains the fact, in which the lateral outlines of the pedicles and the lateral borders of evident that pathologic changes of the lateral borders of the body of L5 may be invisible also (Schaik *et al* 1985).

2.3 Advantages of Transpedicular Fixation

The use of screw as an internal fixation device for spinal fusion surgery began in the 1940s with the introduction of transfacet screw fixation in the lumbosacral spine for lumbosacral fusion (King *et al*, 1944). However pseudoarthrosis rates were unacceptably high with this method of fixation (Pennal *et al.*, 1964).

Boucher et al 1959 modified the technique by using longer screw that crossed the facet joint into the pedicle and body. Boucher et al 1959 credited as the first to use pedicle screws (Whitecloud *et al.*, 1989). The psuedoarthrosis rate for this technique was 14 to 17 % (Pennal *et al*, 1964); (Graham *et al*, 1979). Transpedicular screw fixation has since become a widely accepted procedure for the post stabilization of lumbosacral spine.

Harrington and Dickson first used pedicle screws inserted to L5 attached to a distraction rod via heavy stainless steel wire for the reduction and stabilization of spondylolisthesis. Roy-Camille et al 1986 was the first to use pedicle screws connected to dorsal plate in the year 1963. He used this system in lumbar and thoracic spine for fixation of vertebral metastases, resection of vertebral tumours and total spondylolectomies. The universal spinal instrumentation which used both screws and hooks connected to rods or plates was introduced by Cotrel and Duboussset in the year 1988 (Cotrel *et al.*, 1988).

Followings are the advantages of transpedicular fixation:

1. A single screw provides stability in 5 planes of motion (Asher, 1996).
2. With transverse connection to the contralateral side, stability is achieved in all 6 planes of motion (Asher, 1996).
3. Rigidity of transpedicular fixation allows for incorporation of fewer normal motion segments, thus preserving maximum motion at the abnormal level (Magerl, 1984); (Louis, 1986); (Roy-Camille *et al*, 1986); (Steffee *et al.*, 1986).

4. Pedicle is the strongest point of attachment to the spine; therefore significant forces can be applied to the spine without failure of the bone-metal junction (Halliday, 1999).
5. Able to apply multidirectional corrective forces (Halliday, 1999).
6. Do not require intact dorsal elements, thus can be used after traumatic disruption of laminae, spinous processes or facets (Halliday, 1999).
7. Avoid placement of instrumentation in the spinal canal, in contrast with sublaminar wires and hooks (Halliday, 1999).
8. Postoperative bracing required less often than with other methods (Halliday, 1999).
9. Higher rates of spinal fusion (Zdeblick, 1994).

2.4 Disadvantages of Transpedicular Fixation (Halliday, 1999).

Followings are the disadvantages of transpedicular fixation:

1. Steep learning curve.
2. Caudal or medial penetration can result in dural tear and neural injury.
3. Extensive tissue dissection to provide for required exposure of entry points.
4. Lengthy operation with significant blood loss.
5. Required use of image intensifier intraoperatively.
6. Costly surgery.
7. Rigid fixation can accelerate adjacent motion segment degeneration.
8. Relatively contraindicated in osteoporosis.

2.5 Pedicle Screw Characteristics and Selection of Screw Size

Most pedicle screws have cancellous thread pattern, with two predominant type; self-tapping and non-self-tapping (Halliday, 1999). The outer diameters of the most commonly used pedicle screws ranged from 4.5 mm to 7 mm (Krag *et al*, 1988b; Zucherman *et al*, 1988; Esses and Bednar, 1989; Steffee *et al*, 1989).

Screw strength is proportional to cube of core (minor) diameter (Benzel, 1995 B). The larger the core diameter, the greater the resistance to screw bending or breakage. Screw pullout resistance is proportional to the outer screw diameter, thread depth and pitch (Benzel, 1995 B). Most investigators of pedicle screw systems recommended selecting the largest fully threaded screw that can be safely accommodated by a pedicle.

Screw lengths range from 30 to 55 mm with 5 mm increments. Chord length of the pedicle determines the screw length to be used. It was shown by Krag *et al* 1988a and Zindrick *et al*, 1991 to be an important determinant of the strength of the screw in resisting being pulled out. Measurement of this length on scanned images ensures the selection of an optimum screw length for transpedicular fixation (Vaccaro *et al.*, 1995a).

2.6 Complications of Transpedicular Fixation

Complication rates are as high as 25% (Halliday, 1999). According to a cohort study by Garfin, 1994 complications are usually misplaced screws (1.2 to 28.8%), implant failure (7%), pedicle fractures (1%), vertebral body penetration (less than 0.5%) and neurological deficit (less than 0.5%).

Ohlin *et al.*, 1994 reported 40% radiographic failure rate after surgery. Most of them were screw loosening, angulation and fracture. Implant removal was required in 15% of cases within a year after operation.

i) Misplaced screws

This is the most frequent complication of transpedicular fixation. The rate ranges from 1.2 to 28.8% in different series; (Roy-Camille *et al.*, 1986); (Gertzbein and Robbins, 1990); (Krag et al, 1991); (West *et al.*, 1991). Caudally misplaced screw risk injury to dura mater and nerve root (West *et al.*, 1991).

Medially misplaced screw will carry a greater risk of injury to the dural sac and spinal cord (West *et al.*, 1991); (Ebraheim *et al.*, 1997b). Laterally misplaced screw risks injury to segmental vessels and poor screw purchase (West *et al.*, 1991).

ii) Nerve Root and Spinal Cord Injury

The rate of neurological injury ranges from 2.5 to 7.5% of cases (Esses *et al.*, 1991). They result from misplaced screw, migration of screw into spinal canal or traction injury during correction of a deformity (Esses *et al.*, 1991). In most cases, the radiculopathy improves after removal or repositioning of the misplaced screw (Ohlin *et al.*, 1994).

iii) Pedicle Fracture

Transverse pedicle width is the limiting factor which determines the largest screw that can be used in transpedicular screw fixation (Vaccaro *et al*, 1995). A discrepancy between pedicle width and screw diameter can lead to expansion or even fracture of the pedicle wall and cut out of screw thread (Misenhimer *et al.*, 1989). It is a common clinical finding that most of the pedicle fractures related to pedicle screws occur at the lateral wall of the pedicle (Sjostrom *et al.*, 1993).

In a CT analysis of the thoracolumbar spine (T11-L3) after removal of pedicle screws Sjostrom *et al.*, 1993 found significant pedicle changes compared with the CT scans that were obtained before screw insertion. They showed that the width of the pedicle increased in 65% of the pedicles, and in 29% there was a fracture of the lateral pedicle wall (Sjostrom *et al.*, 1993). Whereas study by Misenhimer *et al*, 1989 showed that 72% of pedicle fractures occur laterally and only 28% medially. This could be explained by the findings of Kothe *et al*, 1996 which showed that the medial wall is between two and three times thicker than the lateral wall. This fact should be considered by the surgeon, particularly when a screw is inserted in a pedicle that is only slightly larger than the screw diameter (Kothe *et al*, 1996).

2.7 Computed Tomographic Measurement of Pedicle Dimensions.

Krag *et al.*,1988 and Bernard and Seibert, 1992 confirmed the extreme accuracy of measurements of pedicle diameters, chord length, pedicle length, and vertebral body length that had been obtained from CT scans. As a result of volume averaging, analysis of a transverse CT image of the convex pedicle may result in a slight underestimation of the transverse diameter of the pedicle, which would provide a margin of safety in the selection of pedicle screws (Vaccaro *et al.*, 1995b). The calibration standard of each machine should be known to ensure accurate interpretation of the scanned images (Berry *et al.*, 1987).

The use of CT scan for the study of pedicle vertebrae was supported by a study done by Vaccaro *et al.*, 1995a on the morphometry of middle and lower thoracic vertebrae from T4 to T12 using CT scans of 19 thoracic spines in living adult patients who had no vertebral abnormalities. The study was done with a Quick Scanner (model 9800; General Electric, Milwaukee, Wisconsin) with a slice thickness of 5 millimeters at 4 millimeter interval.

The morphometric data revealed wide variations in the dimensions of the pedicles. Vaccaro *et al.*, 1995a recommended the use of accurate preoperative imaging with transaxial CT scans to define three important variables: the angle of insertion of the pedicle into the vertebral body, the transverse diameter of the pedicle and the chord length.

2.8 Asian Studies on Lumbar Pedicle Morphometry

The first cadaveric study in Asia regarding the thoracolumbar pedicle was done by Hou *et al.*, 1993 in Beijing, China. They did a study on 40 thoracolumbar spinal columns from T9 to L5. All pedicle width except T11 was significantly smaller than the white population as measured by Zindrick *et al.*, 1987.

Pedicle length parallel to midline was also significantly different compared to Zindrick's data. They recommended that care should be taken in these regions to ensure that the pedicle screw diameter is appropriately chosen in accordance to the pedicle size of different populations particularly for the smaller sized Asian group. This is followed by several other studies in Korea, India and Singapore regarding the morphometry of lumbar spine.

The first CT osteometry of Asian was done in Hong Kong by Cheung *et al.*, 1994 for lumbar pedicle morphometry. The study was done using CT scans of 100 adult Chinese patients, age range from 18 to 60, underwent examination for spinal problems, predominantly low back pain. The CT images were obtained from a General Electric CT9800 Scanner system (General Electric Inc., Waukesha, WI).

They reported significant differences between lumbar pedicles of Asians and whites. Asian lumbar pedicles had a larger pedicle inclination angle (transverse angle) from L1 to L4. Only L2 would be able to take a pedicle screw of 6 mm in diameter and approximately 30% of Chinese patients would have a L2 pedicle endosteal diameter of less than 4mm. However the weakness in their study is that the CT scans were predominantly taken from patients with low back pain. Therefore this selected group of patients may have had pedicle morphology that was different from the underlying population. There were no demonstrable changes in pedicle morphology with age in their study.

The Korean study (Kim *et al.*, 1994) defined the morphometry of the thoracic and lumbar pedicle of the Korean population. The pedicle measurements were obtained from 73 dried human spinal columns (42 male and 31 female).The age of their subjects were between 19-70 years old. Significant statistical differences were found between the transverse diameter of the pedicles of Westerners and Koreans. Their result suggested that using a 6 millimeter screw can violate the cortex of the pedicles in a significant number of levels in the Korean population.

Chadha *et al.*, 2003 did another CT scan study in India regarding the morphology of lower thoracic (T9 to T12) and lumbar vertebrae of patients from Indian subcontinent. CT scans of 31 patients with no obvious spinal deformity were analysed. The CT images were scanned using a Siemens Somatom AR Star (Erlangen, Germany).

The parameters recorded were transverse pedicle isthmus width, transverse pedicle angle, and depth to anterior cortex along the midline axis and the pedicle axis. Significant differences exist between the pedicles of Indian and white populations. A diameter of less than 5 mm was most common at T9 (46.15 %) followed by T10 (12.5%).

In the lumbar region, the widest pedicle was at L5, with a mean of 13.47 mm (range, 10.4–16.2 mm), and narrowest at L1, with a mean of 6.69 mm (range, 4.6– 9.2 mm). The mean transverse pedicle isthmus width at L1 was less than that at T12, which is similar to the findings reported by Hou *et al.*, 1993 and Kim *et al.*, 1994 in their studies on Asian pedicles. The percentage of vertebrae less than 6 mm was 76.92% at T9, followed by T11

(33.33%), L1 (33.33%), T10 (25.00%), T12 (25.00%), L2 (20%), and L3 (5.56%). Most of the lower lumbar vertebrae had wide enough pedicles. However, if only T9 to L2 are considered, then 11.43% of these had a diameter of less than 5 mm and 33.33% had a diameter of less than 6 mm.

For transverse pedicle angle, the shallowest angle was 8.78° at L1 (range, 0–18°). At T11 and T12, the mean transverse pedicle angles were laterally faced, being -2.97° and -3°, spectively, similar to the observations of Kim *et al.*, 1994 in Korean patients.

The shortest pedicle length was seen at L5, with a mean of 37.06mm (range, 26.8–53.0 mm), and the longest was seen at L2, with a mean of 43.96 mm (range, 31.9–52.5 mm).

Their result suggested that using a 6 mm diameter pedicle screws may not safe in the lower thoracic and upper lumbar regions of patients from the Indian subcontinent. This observation is important because most fractures occur at the thoracolumbar region and surgical stabilization at this level using transpedicular screws of 6 mm or more may be hazardous (Chadha *et al.*, 2003). However the weakness of their study is that only 4 out of the 31 patients had a normal spine, 10 had fracture, 6 had tuberculosis of the spine, 6 had tumour, 4 had degenerative spine or disc prolapse and 1 had spondylolisthesis.

A study regarding the CT scan evaluation of odontoid of Malaysian population was done in Hospital Universiti Sains Malaysia in 2004 by Yusof et al (unpublished reference). They found that there were 48.2% of patients who had odontoid diameters of less than 9.0 mm at least at one level of measurements, therefore not suitable for two 3.5 mm cortical screws fixation for odontoid fracture (Yusof, 2004).

Another study regarding the CT evaluation of cervicle pedicles of Malaysian population was done in Hospital Universiti Sains Malaysia by Yusof *et al.*, 2006. The study was done using axial CT images of 40 patients. This study had concluded that transverse cervical pedicle diameters in the Malaysian population were significantly smaller as compared to Caucasian population. Pedicle diameters were smaller in female patients compared to men at all levels and significantly smaller at C5 and C7 levels. It was found that between 4.2% and 54.2% of pedicles at different levels in male patients and 6.7% to 73.3% in female patients cannot be fixed transpedicularly using 3.5 mm screws if the minimum transverse diameter required is 5.0 mm. CT scan evaluation is recommended before any cervical transpedicular fixation is attempted (Yusof *et al.*, 2006).

2.9 Comparison Studies of Lumbar Pedicle Morphology between Male and Female Population

Hou *et al.*, 1993 examined the differences of male and female morphology of the lower thoracic and lumbar vertebrae in Chinese population. In this study they compared 25 male and 15 female cadaveric specimens of thoracolumbar spinal columns from T9 to L5 obtained from the Anatomy Department of the fourth Military Medical Institute in Xian city, China. Measurement was performed using Vernier calipers with a precision of 0.1 mm.

Transverse pedicle diameter of thoracic spine was significantly larger in male specimens at T9, T10 and T12; T9. Sagittal pedicle diameter of thoracic spine was significantly larger in male specimens at T12 only. There was no significant difference in chord length of the thoracic pedicles between the genders.

At the lumbar spine they found that there were no statistical differences between sexes in the pedicle transverse diameter. The pedicle transverse diameter was (7.2mm, SD1.3mm) in male and (6.6mm, SD1.0mm) in female at level of L1.

At L2 level (7.6mm, SD1.2mm) in male and (7.1mm, SD1.5mm) in female. At L3 level (9.4mm, SD1.6mm) in male, (9.0mm, SD1.8mm) in female. At L4 (10.8mm, SD 1.4mm) in male and (10.2mm, SD2.2mm) in female. At level of L5 (12.8mm, SD2.7mm) in male and (13.0mm, SD 2.7mm) in female.

In pedicle length they found that there is significant difference at L1 between male and female, however was no significant difference between male and female from L2-L5.

Another study which examined the difference of male and female morphology in the thoracic and lumbar spine done in the Korean population by Kim *et al.*, 1994.

Seventy three dried human spinal columns (42 male and 31 female) were obtained for study from the Department of Anatomy at Yonsei University College of Medicine, Korea.

The age at the time of death was between 19 to 70 years old (average 40.4 years old). Measurements of transverse pedicle diameter were taken from T1 to L5 using Vernier calipers. The accuracy of their measurement was 0.1 mm. Significant difference between male and female specimens was seen at T10, L3 and L5 level (male, 6.3mm, SD 1.2 mm; 9.9 mm, SD 1.5mm, 18.9mm, SD 2.5mm respectively and female, 5.7 mm, SD 0.8 mm, 8.9mm, SD 3.0mm, 17.6mm, SD2.0 mm respectively).

The widest transverse diameter was seen at L5 in both male and female (average, 18.4 mm). The narrowest transverse diameter of the pedicles was seen at T4 in both male and female (average, 4.1 mm). Their results suggest that using a 6 millimeter screw can violate the cortex of the pedicles in a significant number of thoracic and lumbar levels in the Korean population.

Review of other previous studies of thoracic and lumbar pedicle morphology in the Caucasian population (Zindrick *et al* 1987; Ebraheim *et al* 1997; and Cinotti *et al.*, 1999) and Asian population (Chadha *et al* 2003; Datir *et al* 2004; and Tan *et al* 2004) showed no significant difference of pedicle morphology between the genders.

OBJECTIVES

3.OBJECTIVE

1) To obtain a database for the morphometry of lumbar pedicles from L1 to L5 of the normal Malay population treated in Hospital USM.

2) To compare the means of pedicle morphometry between right and left pedicle.

3) To compare the means of pedicle morphometry between male and female patients.

4) To compare the means of pedicle morphometry between adult and children groups.

3.1 Study Hypothesis.

1. There is significant difference of mean pedicle parameters between the right and left pedicle at each level of the lumbar vertebrae.

2. There is significant difference of mean pedicle parameters between male and female at each level of lumbar vertebrae.

3. There is significant difference of mean pedicle parameters between adult age group and child age group at each level of lumbar vertebrae.

METHODOLOGY

4. Methodology

4.1 Study Design

The study was a cross sectional study on Malay patients who were treated in Hospital Universiti Sains Malaysia. The study was done in the CT scan room of Department of Radiology, Hospital Universiti Sains Malaysia. The time frame of this study was 4 years starting from January 2002 till 31st December 2005.

4.2 Sample Size

Level of significance: α =0.05.

Confidence interval: 95%.

Power of study: 80%.

A) The sample size for obtaining a database for the local Malay population was calculated using single mean formula.

$$n = \frac{(1.96 \times ó)^2}{(\blacktriangle)^2}$$

For adult group:

SD (ó) for adult = 0.9.

Precision ($\blacktriangle$) = 0.3.

Sample size for adult was 35 patients.

For pediatric group:

SD (ó) for children = 5.

Precision ($\blacktriangle$) = 2.

Sample size for children was 25 patients.

B) The sample size for obtaining differences between right and left, male and female, adult and pediatrics groups was calculating using PS software (paired t.test):

For adult:

SD = 0.9

Precision (▲) = 0.3

Sample size = 73 patients

For children:

SD = 5

Precision (▲) = 2

Sample size = 51 patients.

*Finally; the largest sample size for each group was taken:

Adult group = 73 patients.

Children group = 51 patients.

The standard deviation of adult group of 0.9 mm was taken from lateral isthmus cortical thickness measurement at the level of L5 from previous study by Li et al 2004. A sample size of 73 patients was needed to obtain a power of study of 80%.

The standard deviation of pediatric group of 5 mm was taken from pedicle length measurement at the level of L3 from previous study by Senaran et al 2002.

A sample size of 51patients was needed to obtain a power of study of 80%.

4.3 Material and Method

4.3.1 Study Sample

Archived Computed Tomography (CT) images of abdomen performed for patients diagnosed of cancer for the purpose of staging or for other abdominal pathologies were obtained from the Radiology Department of Hospital Universiti Sains Malaysia.

CT scan room registration book was used to select study samples. Stratification was done by first dividing the subjects into male and female groups. From each group, CT abdomen images of both male and female patients were selected randomly based on the criteria listed below.

Inclusion criteria:

A) 1-Children (represent the immature spine) from 9-17 years.

2-Adults (represent the mature spine) from 18-60 years

B) -Sex: Both male and female.

C) -Race: Malay as patient refers (From the folder or IC).

D) -Patients referred to Radiology department for a CT abdomen (5mm slice thickness) for reasons other than vertebral pathology.

Exclusion criteria:

Any spinal deformity or pathology (congenital, idiopathic, infective, traumatic and spine metastasis).

4.3.2 CT Image Selection

Axial CT scan images of lumbar vertebrae (L1 to L5) were obtained using a General Electric CT scanner (GE Medical Systems) with axial plane with slice thickness of 5 mm and bone window (UH 2000-350).

Workstation 4.0 Ultra 60 was used to retrieve soft copy of CT images.

Volume analysis of the images was performed using Spine Protocol. Images were then reviewed and analysed using reformatted images.

Axial view was selected in reference to coronal reformatted images. The axial images which demonstrate the narrowest transverse outer pedicle diameter perpendicular to the longitudinal axis of pedicle was chosen for measurement. Sagittal view was chosen to measure the sagittal angles.

4.3.3 Method of Measurement

Function tools of Workstation 4.0 Ultra 60 software programme were used to measure the required parameters. All measurements were performed in two dimensional projection of the axial view of each vertebra level and sagittal view was applied for sagittal angle measurement.

Distance of transverse outer pedicle diameter, transverse inner pedicle diameter, medial cortical thickness, lateral cortical thickness and pedicle length were measured using Distance Measurement Tool which has a precision of 0.1 millimeters. Transverse and sagittal pedicle angles were measured with Angle Measurement Tool which has a precision of 0.1 degree.

All measurements were performed by the same investigator to ensure consistent results.

Three measurements were taken for each parameter and all the data obtained were entered into SPSS 12.0 spreadsheet.

The preset calibration of the Workstation 4.0 Ultra 60 software programme was predetermined by the manufacturer. No manual calibration done for this study.

4.3.4 Measurements Taken For Each Vertebra Level

A) Transverse outer pedicle diameters at the isthmus of the pedicle; the transverse outer pedicle diameter was defined as a line perpendicular to and bisecting the narrowest diameter of the pedicle. (Include medial and lateral cortex) (Nojiri 2005).

B) Transverse inner pedicle diameters at the isthmus of the pedicle. Same as above but with exclusion of medial and lateral cortex.

C) Medial cortical thickness; measured at the isthmus of the pedicle.

D) Lateral cortical thickness; measured at the isthmus of the pedicle.

E) Pedicle length; the pedicle length was determined as the distance from the posterior aspect of the laminar cortex to the anterior aspect of the cortex of the vertebral body along the pedicle axis (Nojiri 2005).

F) Transverse pedicle angle; the angle formed between a line through the pedicle axis and a line of the vertebral midline in the axial plane was defined as the transverse angle (Nojiri 2005).

G) The sagittal pedicle angle; the angle formed between the superior margin of the vertebral body and a line through the pedicle axis in the sagittal plane was defined as the sagittal angle (Nojiri 2005).

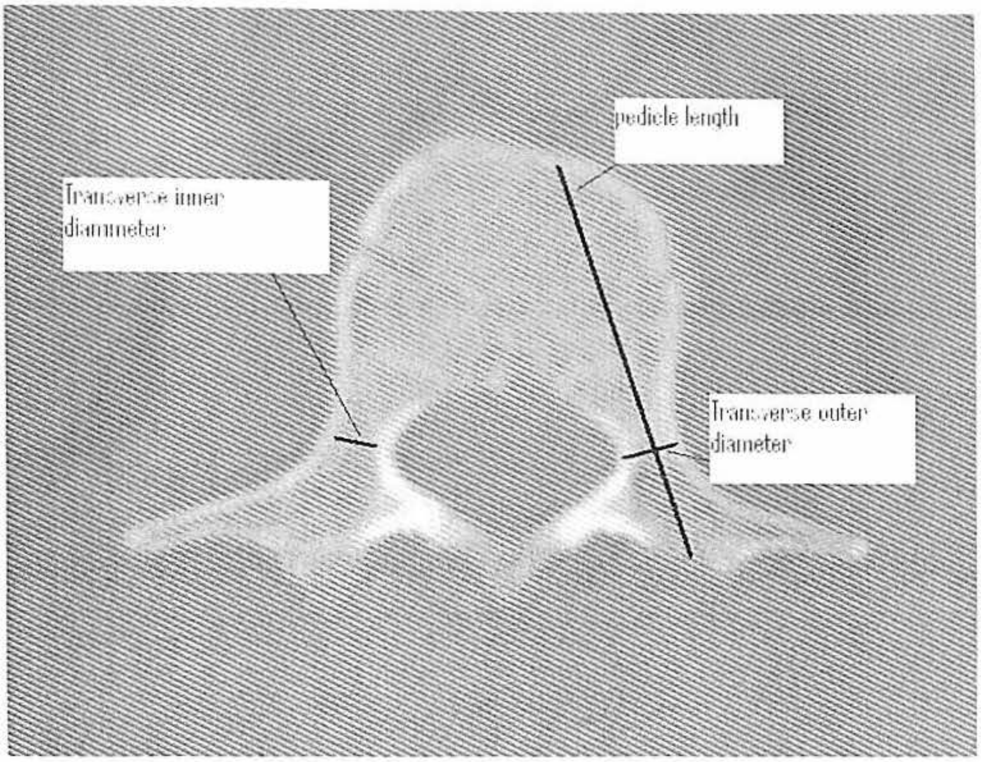

Figure A: showing pedicle length, transverse outer and inner diameter.