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Morphometric assessment of the lumbar pedicle isthmus by reformatted CT: variations according to age and gender

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SUMMARY

This work aims to determine the morphometric characteristics of the lumbar pedicle isthmus with surgical relevance to transpedicular procedures using reformatted computed tomography (CT) and to determine the possible variations in the diameters between genders and age groups. Observational, cross-sectional, descriptive and comparative anatomical studies were carried out. We analyzed 200 CT studies of Mexican patients of known age and gender. The images were analyzed using specialized software for reformatting that could determine cortical and endosteal diameters and cortical thickness at the level of the pedicle isthmus. The mean and standard deviation for each measurement parameter were determined, and a parametric correlation test was performed to compare the variations between the age groups of the same gender. Significant differences in the pedicle diameters between men and women were evident for most of the age groups (p <0.05). The cortical and endosteal pedicle width showed an increase from L1 to L5; the reverse was observed for cortical and endosteal pedicle height. No significant differences were evident with respect to age in the horizontal and vertical diameters for most of the generated study groups. The lateral cortical bone had the lowest scores of the study. The mean values of the morphometric characteristics of the pedicle isthmus obtained in this study will be helpful to conclusively define the pedicle dimensions and to improve the transpedicular approach to the lumbar spine.

Key words: Reformatted CT – Morphometry – Lumbar pedicle – Age – Gender – Isthmus

INTRODUCTION

The pedicles of the lumbar vertebrae are important surgical access points for the management of congenital, traumatic, degenerative, and neoplastic vertebral pathology (Fujimoto et al., 2012). They also represent surgical approach points in

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transpedicular procedures such as vertebral body biopsies, vertebroplasty, pediculoplasties and instrumentation with transpedicular screws (Gailloud et al., 2002). 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 (Guven et al., 1993; Boos and Webb, 1997).

The morphometric characteristics of the vertebral pedicle are valuable for preoperative procedure planning and in the design and manufacture of pedicle screws (Olmos et al., 2002). Knowledge of such morphometric characteristics is important for the surgeon to prevent injuries to the pedicle cortex, meninges, nerve roots, joint facets, viscera or adjacent vascular structures due to misplacement or improper orientation of the screws (Okutan et al., 2004; Femenias-Roselló et al., 2009)

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, the measurement of dry vertebrae, radiography, fluoroscopy, three-dimensional reconstruction, magnetic resonance imaging and computed tomography (CT) (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; Kang et al., 2011). These 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) (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; Kang et al., 2011). In Mexico, some studies have been carried out regarding the morphometric characteristics of lumbar pedicles using conventional computed tomography (Urrutia-Vega et al., 2009).

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 (Li et al., 2004). Studies of bone samples entail a high risk of technical errors in measurement due to the difficulty in establishing this site. Standardizing the measurements is also difficult due to the complex morphology of the pedicle (Li et al., 2004). Studies of plain radiographs and fluoroscopy offer the possibility of magnifying the structures, notwithstanding the disadvantage of being dependent on the technique for obtaining images.

Previous studies have resorted to the use of axial slices in computed tomography to determine the cortical and endosteal pedicle widths of lumbar pedicles. However, recently, it has been established that due to the oval morphology of the lumbar pedicle in the coronal section and to the normal vertebral pedicle inclination in relation to the horizontal plane, the pedicle width results obtained from these studies may not match the actual minimum pedicle diameter and may lead to inadequate identification of the morphometric features of the pedicle (Li et al., 2004; Mohammed et al., 2010). For this reason, the horizontal and vertical diameters of the vertebral pedicle isthmus should be obtained from coronal reconstructions (Li et al., 2004).

Reformatting CT images to correct the normal inclination of the pedicle with regard to the horizontal plane clearly differentiates the cortical and cancellous bone and enables multiple multiplanar reconstructions with minimum distances between cuts.

The aim of this study was to determine by reformatted computed tomography the morphometric characteristics of the lumbar vertebral pedicle isthmus and to analyze the variation in diameters according to gender and age.

MATERIALS AND METHODS

This was an observational, cross-sectional, descriptive, and comparative study. The study included 200 computerized tomographic images (1000 vertebrae, 2000 pedicles) of Mexican patients older than 18 years, randomly selected from the registry of the Department of Radiology, in whom a CT scan of the abdomen was performed for any medical indication (excluding those with a non-degenerative bone disease) during the period between August 2012 and March 2013. The CT scans were independently evaluated by two radiologists to rule out scans that showed a congenital deformity, infection, trauma, tuberculosis or tumors (primary or secondary) of the spine.

The population consisted of 100 men and 100 women with an age range between 18 and 72 years. Four study groups were generated based on age and gender: males under 50 years (n = 50), males aged 50 years or more (n = 50), women younger than 50 years (n = 50), and women aged 50 years or more (n = 50).

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, and syndromes of malabsorption because these conditions can alter the size or composition of the vertebral pedicle.

The equipment used for image acquisition was a 64-slice LightSpeed VCT (General Electric, Milwaukee, WI). A continuous scan was performed with a thickness of 2.5 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 0.625 mm using the "Bone Plus" algorithm. The reconstructed images were transmitted to Advantage Workstations AW 4.4 (General Electric, Milwaukee, WI) with a linear accuracy of 0.01 mm. The calibration of the workstation was predetermined by the manufacturer.

The method used for conducting pedicle isthmus morphometry was previously described by Li et al. (2004), Chen et al. (2010), Zhuang et al. (2011) and Zhuang et al. (2012). Slices were made at the level of the longitudinal axis of the pedicle on axial sections and a multiplanar reformation of the original axial images was achieved using Volume Analysis Voxtool 3.0.4 (General Electric) software for optimal sagittal slices of the pedicles. From these sagittal images, slices parallel to the longitudinal axis of the pedicle were made with a thickness of 0.625 millimeters to reform the image and to obtain a cross-sectional view of the pedicle at this level (cross section at the level of the pedicle axis). Then, a perpendicular slice to the longitudinal axis of the pedicle was drawn in the narrowest portion of the vertebral pedicle, generating a coronal reconstruction at this level, which was defined as the pedicle isthmus (Fig. 1).

The bone window was applied, and the contrast of the images was modified to clearly delineate the cortex from the cancellous bone. The following measurements were obtained bilaterally for each of the lumbar vertebral levels (L1-L5) from the 200 scans: horizontal diameters (cortical pedicle width and endosteal pedicle width), vertical diameters (cortical pedicle height and endosteal pedicle height), and the thickness of the medial, lateral, upper and lower cortices using Voxtool 3.0.4 Volume Analysis software (General Electric) (Fig. 2). Each measurement was obtained twice by the same observer and was recorded in a database.

Statistical analysis

The statistical analysis was performed using Microsoft Excel 2013 for Windows XP. For each of the four groups, the mean and the standard devia-

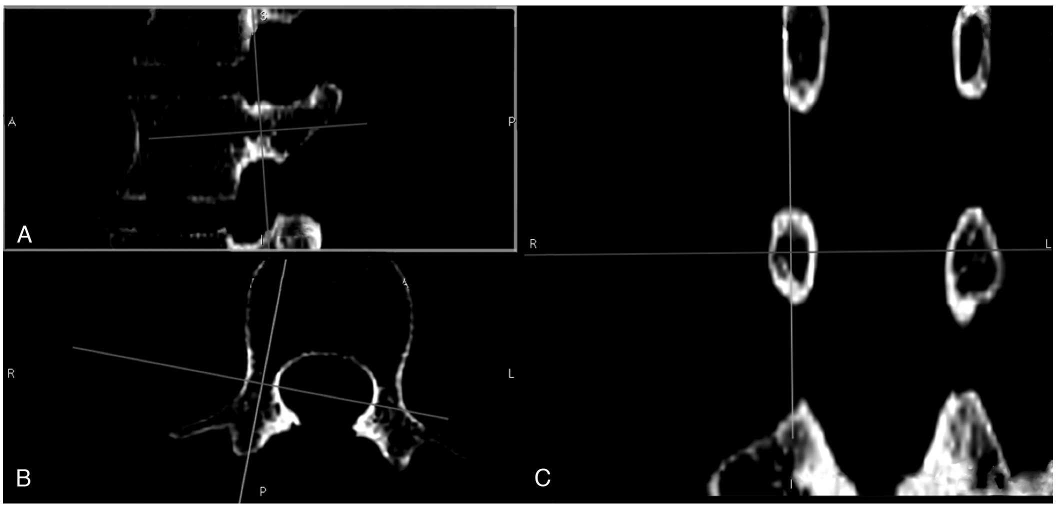

Fig. 1. Technique for obtaining the pedicle isthmus coronal section for performing morphometry. **(A)** The original images were reformatted to obtain an optimal sagittal section. **(B)** A slice was made parallel to and another perpendicular to the longitudinal axis of the pedicle in the cross section obtained from a sagittal reconstruction at the level of the narrowest section of the vertebral pedicle. **(C)** Coronal section at the level of the pedicle isthmus.

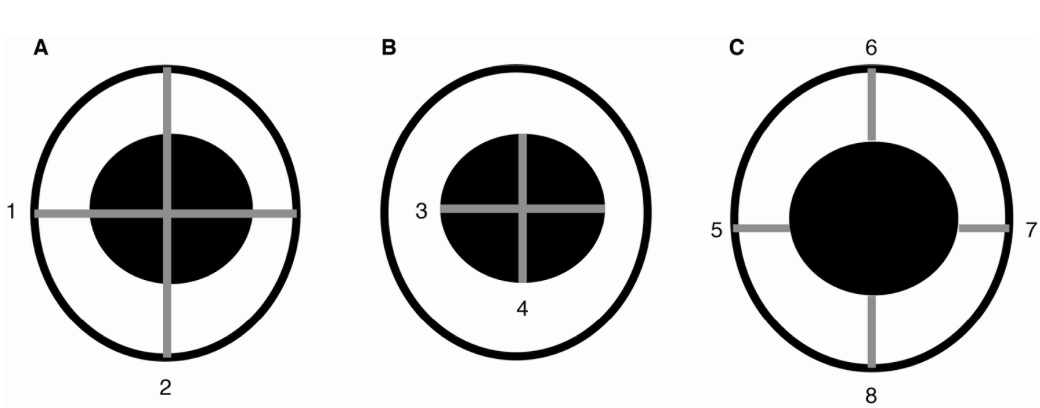

Fig. 2. Morphometric parameters evaluated. **(A)** Cortical pedicle width (1) and endosteal pedicle height (2). **(B)** Endosteal pedicle width (3) and endosteal pedicle height (4). **(C)** inner (5), superior (6), external (7) and inferior (8) cortical bone.

tion for each parameter measured were determined independently. A two-tailed Student's *t* test was used to determine the significance of the differences between each measured parameter between men and women for each vertebral level and the corresponding age group, interpreting a *P* level less than 0.05 as significant. Similarly, parametric correlation tests were performed using the two-tailed Student´s *t* test to compare the mean results for each measurement parameter for the different age groups of the same gender (< 50 vs. ≥ 50) for each vertebral level, interpreting a *P* value less than 0.05 as significant. All results were tabulated in tables.

The ability to replicate measurements is essential for any morphometric study. For this reason, tests for determining intraobserver and interobserver errors were conducted. Each measurement was obtained a second time two weeks later by the first author. The differences between the two sets of measurements were used to calculate a percentage of intraobserver error using a paired Student´s *t* test to estimate the significance of these results. Finally, to evaluate interobserver error, a random subsample consisting of 50 specimens was selected and later reviewed by the first and second author after a period of two weeks. The sample consisted of 25 CT scans each of male and female patients; the same procedure was used for the determination of the morphometric parameters. These data were entered into a computer database, and a paired Student´s *t* test was performed to compare the two sets of measurements.

Ethical considerations

The manuscript submitted does not contain information about medical device(s) or drug(s). No funds were received in support of this work. This research was evaluated and approved by the local Research Ethics Committee under the registration number AH12-006.

RESULTS

A total of 200 scans were analyzed. The mean age of the total sample was 40.4 ± 18.6 years. The group of men under 50 averaged 30.2 ± 8.6 years, men aged 50 years or more had a mean age of 67.4 ± 12.4 years, women under 50 years had a mean age of 35.2 ± 9.6 years, and women aged 50 years or more had a mean age of 61.40 ± 10.6 years.

Intraobserver and interobserver correlation

Paired *t* tests revealed low intraobserver variability (*P* > 0.05 in all cases). Interobserver variability was examined by comparing two sets of measurements obtained by the authors. The results of the paired *t* test indicated that this method of measurement could be reproduced by someone who has not used this method before (*P* > 0.05 in all cases).

Horizontal diameters (pedicular cortical and endosteal width)

A progressive increase in cortical and endosteal pedicle width from L1 to L5 for both age groups in both genders (Table 1) was demonstrated.

In women, the cortical pedicle had a minimum width of 6.22 ± 1.21 mm in L1 in the age group under 50 years and a maximum width of 13.97 ± 2.54 mm at L5 in the age group over 50 years. The endosteal pedicle had a minimum width of 3.83 ± 0.98 mm in L1 in the age group over 50 years and a maximum width of 11.08 ± 2.53 mm at L5 in the age group over 50 years (Table 1).

In men, the cortical pedicle had a minimum width of 8.08 ± 1.19 mm at L1 for the group older than 50 years and a maximum width of 16.34 ± 2.16 mm at L5 in the group younger than 50

Vertebra level	Cortical pedicle width (<50)			Cortical pedicle width (≥50)			Endosteal pedicle width (<50)		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
L1	9.24 ±1.52	6.62 ±1.21	<0.001	8.08 ±1.19	6.66 ±1 .18	<0.001	6.30 ±1.55	3.84 ±1.02	<0.001
L2	9.62 ±1.31	6.91 ±1.34	0,001	8.31 ±1.08	7.05 ±1. 19	0,004	6.63 ±0.99	4.20 ±1.16	0,001
L3	10.26 ±1.24	8.02 ±2.29	0,001	10.15 ±1.49	8.75 ±1.56	0,01	6.90 ±1.04	5.35 ±1.60	0,005
L4	11.86 ±1.73	10.10 ±1.75	0,01	11.71 ±2.19	10.24 ±2.07	0,05	8.34 ±1.85	6.93 ±1.84	0,01
L5	16.34 ±2.16	13.95 ±3.27	0,03	14.86 ±2.53	13.97 ±2.54	0,04	12.07 ±2.18	10.50 ±3.61	0,04

Vertebra level	Endosteal pedicle width (≥50)			Cortical pedicle height (<50)			Cortical pedicle height (≥50)		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
L1	5.45 ±1.29	3.83 ±0.98	<0.001	16.93 ±0.62	16.22 ±1.16	0,05	16.51 ±1.63	15.17 ±1.30	0,01
L2	6.46 ±1.13	4.33 ±1.30	0,01	15.17 ±1.70	14.22 ±1 .24	0,04	16.19 ±1.22	14.66 ±1.37	0,02
L3	7.30 ±1.48	5.89 ±1.71	0,02	15.08 ±1.55	13.97 ±1 .02	0,04	14.94 ±1.04	14.01 ±2.15	0,04
L4	8.67 ±2.06	7.05 ±2.00	0,03	14.23 ±0.98	12.96 ±1 .01	0,003	13.83 ±2.38	12.17 ±3.36	0,03
L5	12.05 ±2.69	11.08 ±2.53	0,04	14.22 ±1.19	11.12 ±1.56	0,01	13.71 ±3.73	11.59 ±1.74	0,03

Vertebra level	Endosteal pedicle height (<50)			Endosteal pedicle height (≥50)		
	Men	Women	*p*	Men	Women	*p*
L1	10.69 ±1.56	9.14 ±1.79	0,02	10.95 ±1.86	9.48 ±1 .20	0,01
L2	8.72 ±1.81	7.62 ±1.79	0,03	9.92 ±0.54	8.68 ±0.93	0,04
L3	8.67 ±1.74	7.17 ±1.50	0,02	9.25 ±1.09	8.19 ±1.33	0,02
L4	8.43 ±1.38	7.13±0.89	0,02	8.92 ±2.19	7.90 ±0.81	0,05
L5	8.12 ±2.04	7.10 ±2.03	0,02	9.93 ±3.75	7.02 ±1.22	0,005

Table 1. Morphometry of the lumbar vertebral pedicle.

Table 2. Comparison of vertebral pedicle morphometry of the two age groups in men and women. **M**, men and **W**, women.

Vertebra level	Cortical pedicle width (M)			Cortical pedicle width (W)			Endosteal pedicle width (M)		
	<50	≥50	p	<50	≥50	p	<50	≥50	p
L1	9.24 ±1.52	8.08 ±1.19	NS (0.07)	6.62 ±1.21	6.66 ±1.18	NS (0.42)	6.30 ±1.55	5.45 ±1.29	NS (0.13)
L2	9.62 ±1.31	8.31 ±1.08	NS (0.50)	6.91 ±1.34	7.05 ±1.19	NS (0.76)	6.63 ±0.99	6.46 ±1.13	NS (0.68)
L3	10.26 ±1.24	10.15 ±1.49	NS (0.85)	8.02 ±2.29	8.75 ±1.56	NS (0.32)	6.90 ±1.04	7.30 ±1.48	NS (0.41)
L4	11.86 ±1.73	11.71 ±2.19	NS (0.84)	10.10 ±1.75	10.24 ±2.07	NS (0.85)	8.34 ±1.85	8.67 ±2.06	NS (0.66)
L5	16.34 ±2.16	14.86 ±2.53	NS (0.19)	13.95 ±3.27	13.97 ±2.54	NS (0.24)	12.07 ±2.18	12.05 ±2.69	NS (0.55)

Vertebra level	Endosteal pedicle width (W)			Cortical pedicle height (M)			Cortical pedicle height (W)		
	<50	≥50	p	<50	≥50	p	<50	≥50	p
L1	3.84 ±1.02	3.83 ±0.98	NS (0.99)	16.93 ±0.62	16.51 ±1.63	NS (0.36)	16.22 ±1.16	15.17 ±1.30	NS (0.08)
L2	4.20 ±1.16	4.33 ±1.30	NS (0.77)	15.17 ±1.70	16.19 ±1.22	NS (0.96)	14.22 ±1.24	14.66 ±1.37	NS (0.38)
L3	5.35 ±1.60	5.89 ±1.71	NS (0.39)	15.08 ±1.55	14.94 ±1.04	NS (0.50)	13.97 ±1.02	14.01 ±2.15	NS (0.035)
L4	6.93 ±1.84	7.05 ±2.00	NS (0.87)	14.23 ±0.98	13.83 ±2.38	NS (0.56)	12.96 ±1.01	12.17 ±3.36	NS (0.77)
L5	10.50 ±3.61	11.08 ±2.53	NS (0.39)	14.22 ±1.19	13.71 ±3.73	NS (0.16)	11.12 ±1.56	11.59 ±1.74	NS (0.39)

Vertebra level	Endosteal pedicle height (M)			Endosteal pedicle height (W)		
	<50	≥50	p	<50	≥50	p
L1	10.69 ±1.56	10.95 ±1.86	NS (0.68)	9.14 ±1.79	9.48 ±1.20	NS (0.53)
L2	8.72 ±1.81	9.92 ±0.54	NS (0.57)	7.62 ±1.79	8.68 ±0.93	0,04
L3	8.67 ±1.74	9.25 ±1.09	NS (0.75)	7.17 ±1.50	8.19 ±1.33	0,01
L4	8.43 ±1.38	8.92 ±2.19	0,05	7.13 ±0.89	7.90 ±0.81	0,02
L5	8.12 ±2.04	9.93 ±3.75	0,04	7.10 ±2.03	7.02 ±1.22	NS (0.85)

years. The endosteal pedicle had a minimum width of 5.45 ± 1.29 mm in L1 in the age group over 50 years and a maximum width of 12.07 ± 1.18 mm at L5 in the age group less than 50 years (Table 1).

The mean cortical and endosteal pedicle widths showed significant differences (*P* <0.05) when the means obtained for men and women were compared for all lumbar vertebral levels (Table 1). The morphometric variations of cortical and endosteal pedicle width according to age demonstrated no significant differences (*P* > 0.05) for all the vertebral levels studied when compared with the means between the groups younger and older than 50 years within the same gender (Table 2).

Vertical diameters (cortical and endosteal pedicle height)

A progressive decrease in the cortical and endosteal pedicle height from L1 to L5 for both age groups in both genders was observed (Table 1). In women, the cortical pedicle had a minimum height of 11.12 ± 1.56 mm at L5 in the age group below 50 years and a maximum height of 16.22 ± 1.16 mm at L1 in the age group above 50 years. Endosteal pedicles had a minimum height of 7.02 ± 1.22 mm at L5 in the age group over 50 years and a maximum height of 9.48 ± 1.20 mm at L1 in the age group over 50 years (Table 1).

In men, the cortical pedicle had a minimum height of 13.71 ± 3.73 mm at L5 in the age group over 50 years and a maximum height of 16.93 ± 0.62 mm at L1 in the age group under 50 years. The endosteal pedicle had a minimum height of 8.12 ± 2.04 mm at L5 in the age group under 50 years and a maximum height of 10.95 ± 1.86 mm at L1 in the age group over 50 years (Table 1).

The cortical and endosteal pedicle heights showed significant differences (*P* <0.05) when compared with the means obtained for men and women for all lumbar vertebral levels studied (Table 1). Morphometric variations of cortical and endosteal pedicle height according to age showed no significant differences (*P* > 0.05) for most of the vertebral levels studied when compared with the means obtained from the groups below and above 50 years within the same gender. Exceptions were observed for the endosteal pedicle height at the level of L4 and L5 for men and of L2, L3 and L4 for women (Table 2).

Cortical thickness

The upper and lower cortical pedicle isthmi are thicker than the internal and external cortices. The thickness of the upper and lower cortical bone exceeded 2 mm in all cases, whereas the medial and lateral cortical bone thicknesses were generally less than 2 mm with the exception of L5, in which the medial and lateral cortical values exceeded 2 mm. The results obtained for the lateral cortical bone were the lowest in the study. A characteristic pattern of growth in the thickness of any of the cortical bones was not found, although a general tendency to increase in size as the vertebral level descends was observed (Table 3).

Regarding the differences in the mean values of cortical thickness between men and women, non-significant differences were observed in most of the comparison groups (Table 3). The exceptions were found when comparing the upper cortical bone of L4 in the group younger than 50 years and the inferior cortical bone of L1 in the group older than 50 years. Morphometric variations of cortical bone thickness with regard to age showed no significant differences (*P* > 0.05) for most of the vertebral levels studied. The exceptions are shown in Table 4.

DISCUSSION

The pedicle screw to be used should ideally be placed along the axis of the pedicle, incorporating as much space in the transverse and sagittal diameters of the vertebral pedicle as possible (Weinstein et al., 1992). This research represents the second study on morphometric characteristics of the lumbar vertebral pedicle isthmus through reformatted CT; however, this study has a larger sample size and a more rigorous statistical methodology".

The horizontal diameters (cortical and endosteal pedicle width) are the parameters most commonly assessed in morphometric studies of the vertebral pedicle. The mean values obtained in this study support the results of other publications with regard to the patterns of behavior and the general morphometric characteristics of the lumbar pedicle (Table 5) (Olsewski et al., 1990; Amonoo-Kuofi, 1995; Wolf et al., 2001; Olmos et al., 2002;

Vertebra level	Internal cortical thickness (<50)			Internal cortical thickness (≥50)			External cortical thickness (<50)		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
L1	1.59 ±0.29	1.66 ±0.26	NS (0.43)	1.57 ±0.30	1.44 ±0.39	NS (0.32)	1.33 ±0.37	1.47 ±0.36	NS (0.37)
L2	1.70 ±0.34	1.60 ±0.29	NS (0.40)	1.69 ±0.44	1.48 ±0.46	NS (0.19)	1.48 ±0.42	1.44 ±0.25	NS (0.74)
L3	1.51 ±0.32	1.68 ±0.32	NS (0.12)	1.59 ±0.38	1.53 ±0.28	NS (0.59)	1.60 ±0.56	1.75 ±0.59	NS (0.51)
L4	1.84 ±0.65	1.96 ±0.31	NS (0.20)	1.95 ±0.59	1.65 ±0.35	NS (0.09)	1.79 ±0.79	1.64 ±0.34	NS (0.56)
L5	2.78 ±1.12	2.38 ±0.70	NS (0.30)	2.24 ±0.51	2.21 ±0.56	NS (0.91)	2.00 ±0.71	1.94 ±0.54	NS (0.81)

Vertebra level	External cortical thickness (≥50)			Superior cortical thickness (<50)			Superior cortical thickness (≥50)		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
L1	1.32 ±0.23	1.29 ±0.21	NS (0.76)	2.95 ±1.00	3.59 ±1.47	NS (0.18)	2.81 ±0.99	2.82 ±0.74	NS (0.97)
L2	1.45 ±0.27	1.43 ±0.45	NS (0.84)	3.29 ±1.05	3.09 ±0.77	NS (0.59)	2.86 ±0.50	3.13 ±1.14	NS (0.42)
L3	1.61 ±0.45	1.56 ±0.47	NS (0.76)	3.48 ±1.18	3.54 ±1.07	NS (0.90)	3.14 ±0.51	3.49 ±1.58	NS (0.42)
L4	1.40 ±0.33	1.49 ±0.55	NS (0.60)	3.90 ±1.03	3.03 ±0.68	0,01	2.57 ±0.65	2.99 ±0.75	NS (0.11)
L5	2.04 ±0.51	2.26 ±0.69	NS (0.32)	3.12 ±1.13	2.87 ±1.05	NS (0.56)	2.24 ±0.47	2.55 ±0.99	NS (0.29)

Vertebra level	Inferior cortical thickness (<50)			Inferior cortical thickness (≥50)		
	Men	Women	*p*	Men	Women	*p*
L1	3.27 ±0.75	3.49 ±1.08	NS (0.52)	3.16 ±0.65	2.46 ±0.75	0,01
L2	3.52 ±0.60	3.60 ±1.13	NS (0.81)	3.27 ±0.71	2.73 ±0.77	0,05
L3	3.22 ±0.65	3.29 ±0.59	NS (0.79)	2.76 ±0.58	2.63 ±0.84	NS (0.63)
L4	2.78 ±0.69	2.59 ±0.78±	NS (0.51)	2.29 ±0.37	2.36 ±0.79	NS (0.78)
L5	2.07 ±0.74	2.20 ±0.63	NS (0.65)	2.12 ±0.63	1.84 ±0.61	NS (0.22)

Table 3. Morphometry of cortical bone thickness of the lumbar vertebral pedicle.

Kadioglu et al., 2003; Singel et al., 2004; Li et al., 2004 Nojiri et al., 2005; Lien et al., 2007; Urrutia-Vega et al., 2009; Acharya et al., 2010; Maaly et al., 2010; Kang et al., 2011).

The vertical diameters (cortical and endosteal pedicle height) are the measurement parameters holding less interest for the surgeon. Their values are always higher than the horizontal diameter and therefore do not interfere with the decision involving a pedicle screw (Maillot and Wolfram- Gabel, 1993). However, the results of this study are consistent with the results obtained in previous studies (Maillot and Wolfram-Gabel, 1993; Li et al., 2004). The cortical pedicle height is generally considered to be approximately 15 millimeters, and its values decrease from L1 to L5 (Maillot and Wolfram-Gabel, 1993), data that were confirmed by this study.

Zindrick et al. (1987) recorded the highest number of measurements of the lumbar pedicle with a total of 2,905 pedicles measured by CT, establishing their study as the basis of subsequent morphometric studies. Sjostrom et al. (1993) maintained, according to the data obtained in their study, that lumbar pedicle screws with a diameter greater than 65% of the cortical diameter deform the pedicle in 85% of cases. Misenhimer et al. (1989) established that plastic deformation of the pedicle occurs before fracture when the pedicle screw used is larger than the endosteal pedicle width or when the screw exceeds 80% of the cortical pedicle width. Cheung et al. (1994) also determined that the endosteal pedicle width represents the most valuable morphometric parameter for adequate preoperative selection of the pedicle screw. Li et al. (2004) recommends using the endosteal pedicle width plus one millimeter as the maximum limit of the pedicle screw to be used.

The overall mean endosteal pedicle width in this study was 64.5 ± 7.4% greater than the cortical pedicle width. This fact should be considered by the spine surgeon prior to the selection of a pedicle screw, particularly in situations where it is not possible to determine the morphometric characteristics of the vertebral pedicle preoperatively by computed tomography.

Regarding sexual dimorphism in the horizontal and vertical diameters of the lumbar pedicles, the results of this study support the conclusions reached by previous studies in other populations, showing significant differences in these parameters exist for all lumbar vertebral levels be-

Vertebra level	Internal cortical thickness (M)			Internal cortical thickness (W)			External cortical thickness (M)		
	<50	≥50	*p*	<50	≥50	*p*	<50	≥50	*p*
L1	1.59 ±0.29	1.57 ±0.30	NS (0.32)	1.66 ±0.26	1.44 ±0.39	NS (0.10)	1.33 ±0.37	1.32 ±0.23	NS (0.88)
L2	1.70 ±0.34	1.69 ±0.44	NS (0.93)	1.60 ±0.29	1.48 ±0.46	NS (0.42)	1.48 ±0.42	1.45 ±0.27	NS (0.83)
L3	1.51 ±0.32	1.59 ±0.38	NS (0.55)	1.68 ±0.32	1.53 ±0.28	NS (0.10)	1.60 ±0.56	1.61 ±0.45	NS (0.95)
L4	1.84 ±0.65	1.95 ±0.59	NS (0.66)	1.96 ±0.31	1.65 ±0.35	NS (0.07)	1.79 ±0.79	1.40 ±0.33	NS (0.11)
L5	2.78 ±1.12	2.24 ±0.51	NS (0.12)	2.38 ±0.70	2.21 ±0.56	NS (0.47)	2.00 ±0.71	2.04 ±0.51	NS (0.87)

Vertebra level	External cortical thickness (W)			Superior cortical thickness (M)			Superior cortical thickness (W)		
	<50	≥50	*p*	<50	≥50	*p*	<50	≥50	*p*
L1	1.47 ±0.36	1.29 ±0.21	NS (0.11)	2.95 ±1.00	2.81 ±0.99	NS (0.71)	3.59 ±1.47	2.82 ±0.74	0,05
L2	1.44 ±0.25	1.43 ±0.45	NS (0.95)	3.29 ±1.05	2.86 ±0.50	NS (0.19)	3.09 ±0.77	3.13 ±1.14	NS (0.91)
L3	1.75 ±0.59	1.56 ±0.47	NS (0.33)	3.48 ±1.18	3.14 ±0.51	NS (0.33)	3.54 ±1.07	3.49 ±1.58	NS (0.93)
L4	1.64 ±0.34	1.49 ±0.55	NS (0.40)	3.90 ±1.03	2.57 ±0.65	<0.001	3.03 ±0.68	2.99 ±0.75	NS (0.89)
L5	1.94 ±0.54	2.26 ±0.69	NS (0.18)	3.12 ±1.13	2.24 ±0.47	0,01	2.87 ±1.05	2.55 ±0.99	NS (0.40)

Vertebra level	Inferior cortical thickness (M)			Inferior cortical thickness (W)		
	<50	≥50	*p*	<50	≥50	*p*
L1	3.27 ±0.75	3.16 ±0.65	NS (0.69)	3.49 ±1.08	2.46 ±0.75	0,004
L2	3.52 ±0.60	3.27 ±0.71	NS (0.33)	3.60 ±1.13	2.73 ±0.77	0,01
L3	3.22 ±0.65	2.76 ±0.58	0,05	3.29 ±0.59	2.63 ±0.84	0,02
L4	2.78 ±0.69	2.29 ±0.37	0,003	2.59 ±0.78±	2.36 ±0.79	NS (0.43)
L5	2.07 ±0.74	2.12 ±0.63	NS (0.85)	2.20 ±0.63	1.84 ±0.61	NS (0.14)

Table 4. Comparison of the morphometry of cortical thickness of the two age groups in men and women. **M**, men and **W**, women

tween men and women (Amonoo-Kuofi, 1995). In our study, it was observed that the horizontal and vertical diameters of the pedicles in men were significantly higher than those of women in all cases. The study of variations in the vertebral elements with regard to age has been largely confined to the vertebral body and intervertebral discs, with these elements being analyzed from an anthropological point of view and not from their clinical and surgical applicability (Allbrook, 1956). Regarding the vertebral pedicle, there are very few reports in the literature, and its study has been limited to the lumbar and thoracic region (Zindrick et al., 1987; Amonoo-Kuofi, 1995; Mohammed et al., 2010; Morales-Avalos et al., 2014).

With respect to changes of cortical and endosteal pedicle width in the lumbar pedicles with regard to age, our study demonstrated that no significant differences exist in the mean results obtained when comparing the group younger than 50 years with that older than 50 years among any of the groups studied. These results match those obtained by Li et al. (2004) in a study similar to ours, using reformatted CT. This study suggested that the lumbar vertebral pedicle is not part of this bone degeneration, most likely because unlike other bones and vertebral elements, it sustains ongoing activity throughout life in active and passive conditions for the transfer and distribution of forces that cross the spine and for the stabilization and maintenance of postural tone.

The results of our study support the concept proposed by Delfino et al. (2007) that the lumbar vertebral pedicle is a cylinder with a uniform internal structure; however, the analysis of cortical thickness showed that the pedicle is not symmetrical in its constitution.

In both genders, the vertical diameters of the pedicle isthmus are greater than the horizontal diameter for all ages and vertebral levels. The endosteal pedicle width of the pedicle isthmus determines the decision regarding the dimensions of the screw that must be used. The mean values and the behavior patterns of the pedicle isthmus

Table 5. Pedical cortical width (L1 to L5) obtained in studies performed with different world populations. Results are expressed in millimeters ± SD. **CT**, computed tomography. **M**, male. **F**, female

Population (author, year)	Method	L1	L2	L3	L4	L5
Chinese (LÍEN et al., 2007)	Direct	6.4 ±1.6	7.4 ±1.7	9.3 ±1.9	11.6 ±2.1	17.5 ±2 .6
Chinese (LI et al., 2004)	Reformatted CT	7.9 ± 1.4	8.7 ± 1.2	10.2 ± 1.7	11.5 ± 1.2	13.7 ± 2. 3
Spanish (OLMOS et al.,2002)	CT	---	---	8.7 ± 2.2	11.5 ± 2.1	16.3 ±2.5
Turkish (KADIOGLU et al., 2003)	Direct	6.4 ± 2.0	6.6 ± 2.3	8.6 ± 3.8	10.8 ± 3.3	12 .4 ± 2.4
Mexicans (URRUTIA-VEGA et al., 2009)	CT	7.8 ±1.3	8.2 ±1.4	9.5± 1.0	10.7 ±0.6	14.3 ±1.8
Japanese (NOJIRI et al., 2005)	Direct	7.4 ±2.0	7.8 ±1.7	9.1 ± 1.7	10.1 ±1.7	11.1 ± 1.7
Indians (ACHARYA et al., 2010)	Direct	7.2 ± 0.93	7.6 ±0.84	8.9 ± 1.1	11.1 ±1.0	13. 9 ± 1.1
Koreans (KANG et al., 2011)	CT	8.1 ±1.7	8.5 ± 1.5	10.0 ±1.7	11.5 ±2.0	16.5 ±2. 4
Arabs (AMONOO KUOFI, 1995)	Direct	8.7	9.0	10.5	11.1	12.5
Indians (SINGEL et al., 2004)	Direct	8.2 ±6.7	8.5 ±6.5	10.4 ±7.0	13.5 ±7.0	18.2 ±9.7
Americans (OLSEWSKI et al., 1990)	Direct	7.7 ±1.9	7.9 ± 1.9	9.6 ± 2.4	12.5 ± 2.3	18. 4 ± 3.6
Israelites (WOLF et al., 2001)	CT	5.6 ±1.3	7.7 ± 1.5	8.9 ± 1.9	11,4 ± 1.8	13.7 ± 2.2
Egyptians (MAALY et al., 2010)	CT	6.8 ±1.9	8.8 ± 1.4	10.1 ± 1.6	12.9 ± 1.8	18.9 ± 2.1
Mexicans (MORALES-AVALOS *et al*., 2015) This study.	Reformatted CT	9.24 ± 1.50 (M <50) 8.08 1.19 (M >50) 6.62 ±1.21 (F <50) 6.66 ±1.18 (F >50)	9.62 ± 1.31 (M <50) 8.31 ±1.08 (M >50) 6.91 ±1.34 (F <50) 7.05 ±1.19 (F >50)	10.26 ± 1.24 (M <50) 10.15 ±1.49 (M >50) 8.02 ±2.29 (F <50) 8.75 ±1.56 (F >50)	11.86 ± 1.73 (M <50) 11.71 ±2.19 (M >50) 10.10 ±1.75 (F <50) 10.24 ±2.07 (F >50)	16.34 ±2.16 (M <50) 14.86 ±2.53 (M >50) 13.95 ±3.27 (F <50) 13.97 ±2.54 (F >50)

obtained in this study will be helpful in determining the behavior of the dimensions of the lumbar vertebral pedicle and in improving the transpedicular approach to the lumbar spine. We consider that not including the weight and size of the participants as a correlation and association variable is an important limitation of our study.

Significant gender differences exist in the horizontal and vertical diameters of the lumbar pedicle isthmus. In the present study, no significant differences in the horizontal and vertical diameters of the lumbar vertebral pedicle isthmus were evident in relation to age for most of the generated groups.

The upper and lower cortical pedicle isthmi are thicker than the medial and lateral cortical bone. The results obtained for the lateral cortical bone were the lowest in the study and therefore the most prone to suffer perforation. No significant differences in age and gender at most vertebral levels for this measured parameter were observed.

Reformatting of CT images represents the best currently available technique for the determination of the morphometric characteristics of the vertebral pedicle.

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