Clinical Anatomy 27:441–450 (2014)

ORIGINAL COMMUNICATION

Age- and Gender-Related Variations in Morphometric Characteristics of Thoracic Spine Pedicle: A Study of 4,800 Pedicles

RODOLFO MORALES-AVALOS,[1] JORGE LEYVA-VILLEGAS,[1] GABRIELA SÁNCHEZ-MEJORADA,[2] MARCELA CÁRDENAS-SERNA,[1] FÉLIX VÍLCHEZ-CAVAZOS,[3] ÁNGEL MARTÍNEZ-PONCE DE LEÓN,[4] GUILLERMO ELIZONDO-RIOJAS,[5] JORGE MARTÍNEZ-GARCÍA,[5] OSCAR DE LA GARZA-CASTRO,[1] RODRIGO ELIZONDO-OMAÑA,[1*] AND SANTOS GUZMÁN-LÓPEZ[1]

[1]*Department of Human Anatomy, Faculty of Medicine, Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México*

[2]*Laboratory of Physical Anthropology, Department of Human Anatomy, Faculty of Medicine, Universidad Nacional Autónoma de México, D.F, México*

[3]*Orthopedics and Traumatology Service, University Hospital "Dr. José Eleuterio González", Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México*

[4]*Neurosurgery Service, University Hospital "Dr. José Eleuterio González", Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México*

[5]*Department of Radiology, University Hospital "Dr. José Eleuterio González", Universidad Autónoma de Nuevo León, Monterrey, Nuevo León, México*

Transpedicular spinal fusion is the most commonly used fixation technique for the surgical treatment of vertebral disorders. However, the instrumentation of the thoracic spine using this technique continues to be controversial. The objective of the present study was to determine the morphometric characteristics of the thoracic pedicle and to establish how these characteristics vary with gender and age. Two hundred thoracic spines (4800 thoracic pedicles) from individuals of known gender and age were analyzed (in accordance with the order of vertebrae). The spines were divided into six groups according to age and gender. The horizontal and vertical diameters of the thoracic pedicle were determined for each piece. The mean and standard deviation of each variable were determined, and differences between age groups for each gender were evaluated using parametric correlation tests. The pedicle diameters of men and women differed significantly for most groups ($P < 0.05$). The horizontal diameters decreased from T1 to T5 and increased up to T12. The vertical diameter followed a cephalocaudal pattern of development from T1-T12. The pedicle diameters decreased with increasing age in women, while the opposite trend was observed in men. In men, the dimensions of the thoracic spine pedicle increase with increasing age; in women, they decrease. These differences should be taken into account when selecting the appropriate pedicle screw. Clin. Anat. 27:441–450, 2014.

**Correspondence to:* Rodrigo Elizondo-Omaña, Department of Human Anatomy, Universidad Autónoma de Nuevo Leon, Ave. Madero y Dr. Aguirre Pequeño s/n, Col. Mitras Centro, Monterrey 64460, Mexico. E-mail: rod_omana@yahoo.com

Received 19 September 2013; Revised 11 November 2013; Accepted 15 November 2013

Published online 21 December 2013 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/ca.22359

Key words: morphometry; variation; pedicle; spine; thoracic; age; gender; Mexico

INTRODUCTION

Currently, one surgical treatment option for spinal pathology is transpedicular instrumentation. This is the most commonly used fixation technique in any spinal region for treating degenerative, infectious, neoplastic, congenital, and traumatic vertebral disorders. The procedure consists of introducing screws through a point at the union of the transverse and the superior articular processes, the trajectory traversing the pedicle until it reaches the vertebral body, thus providing stability and internal fixation to the vertebral segment involved (Fujimoto et al., 2012; Morales-Avalos et al., 2012).

Among the advantages of transpedicular spinal fusion are the stability of the vertebral segments involved; biomechanical superiority over other spinal fusion systems; fewer postoperative complications; short length of hospital stay; and satisfactory clinical results (Kothe et al., 1996; Tan et al., 2004; Lien et al., 2007; Wang et al., 2010; Chan et al., 2011; Beck et al., 2012; Cui et al., 2012; Lu et al., 2012).

In general, the morphometric characteristics of the thoracic spine, and especially of the pedicle, determine the size of the pedicle screws and the manner, direction, and ideal angle of their introduction. It is important to understand these characteristics if the surgeon is to avoid lesions caused by incorrect placement or orientation. Such lesions could involve the pedicle cortex, pleura, spinal cord, meninges, nerve roots, articular facets, viscera, or adjacent vascular structures (Esses et al., 1993; Faraj and Webb, 1997; Di-Silvestre et al., 2007; Li et al., 2010).

Placement of the pedicle screws in the thoracic region remains a controversial issue; pedicle screws are used less frequently in the thoracic region than in the lumbar and cervical regions. This difference can be attributed to the complexity of the procedure resulting from the anatomical, biomechanical, and technical characteristics of the thoracic region: physiological kyphosis; variations in the dimensions, orientation, angle, and shape of the vertebral pedicle; the patient's gender, age, and ethnicity; the small safety space between the medial wall of the pedicle and the dura mater (1.0–1.5 mm); and the difficulty of obtaining useful fluoroscopic images at some vertebral levels (Panjabi et al., 1997; Liljengvist et al., 2000; Changkun et al., 2009). Collectively, these anatomical and technical issues explain the high incidence of pedicle perforations and fractures, medullary canal invasion, and injury to neurovascular structures or neighboring viscera when screws are introduced into the thoracic region. Prior studies have documented a 7–40% incidence of poor screw placement in this region (Chaynes et al., 2001).

The general morphometric characteristics of the thoracic spine pedicle have been widely studied (Zindrick et al., 1987; Islam et al., 1994; McCormack et al., 1995), and some authors have considered the differences between genders (Amonoo-Kuofi, 1995; Mughir et al., 2010). However, to date, no thoracic spine studies have examined variations in pedicle dimensions with respect to age and gender for any population. Age and gender are variables of special importance for the correct selection of an appropriate pedicle screw.

The objective of this study was to determine the morphometric characteristics of the thoracic spine pedicle in the Mexican population. Variations with gender, age, and vertebral level were analyzed in order to aid the development of thoracic transpedicular spinal fusion surgery.

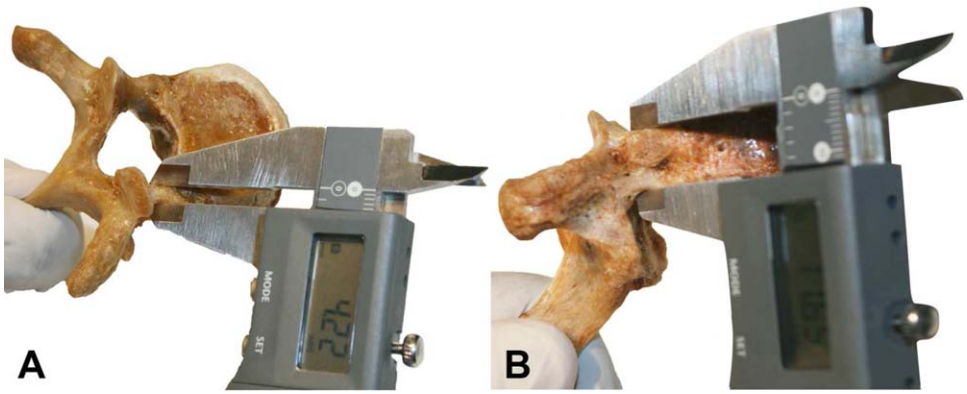

Fig. 1. Technique for measuring the horizontal (**A**) and vertical (**B**) diameters of the thoracic spine pedicle at the level of the pedicle isthmus. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 1. Distribution of the Thoracic Columns used in the Study into Groups According to Gender and Age

Distribution by gender and age			
Age range (years)	Female (*n*)	Male (*n*)	Total (*n*)
18–39	30	45	75
40–59	25	40	65
≥ 60	30	30	60
Total	85	115	200

MATERIALS AND METHODS

This is an observational, cross-sectional, descriptive, and comparative study. Two hundred dry thoracic columns, T1 to T12 (2,400 vertebra, 4,800 pedicles) from the Mexican population, belonging to the osteological collection of the Human Anatomy Department of the School of Medicine at the Autonomous University of Nuevo Leon (UANL, its initials in Spanish) and the National Autonomous University of Mexico (UNAM, its initials in Spanish), were used. Pieces with structural damage or signs of any disease or evident abnormality were excluded. Also excluded were pieces from patients with a recorded medical history of growth disorders, systemic bone disease, chronic renal disease, thoracic spine surgery, or malabsorption syndrome, because these conditions could contribute to altering the dimensions of the vertebral pedicle.

For each piece studied, the horizontal (outer pedicle width) and vertical (outer pedicle height) diameters were determined bilaterally at the level of the pedicle isthmus (the narrowest portion of the vertebral pedicle) (Fig. 1).

The pieces were initially divided according to gender and then subdivided into three age groups with the following ranges: 18 to 39 years, 40 to 59 years, and over 60 years (Table 1). This division was based on the patterns of degenerative changes of the spine with age and the most frequent indications for transpedicular vertebral instrumentation of the thoracic spine.

Data for each of the studied pieces were obtained using a Ted Pella digital caliper with a precision of 0.01 mm. All measurements were recorded in millimeters. The data obtained were classified into three categories for analysis:

1. General and intersegmental observations. The patterns of growth and decline that the thoracic spine levels followed in terms of the horizontal and vertical diameters, means, and minimum and maximum values for each study group.
2. Gender differences. The differences between men and women in the means of the horizontal and vertical diameters for each age group and at each vertebral level.
3. Age-related differences. Differences among age groups in the means of the horizontal and vertical diameters for the same gender and vertebral level.

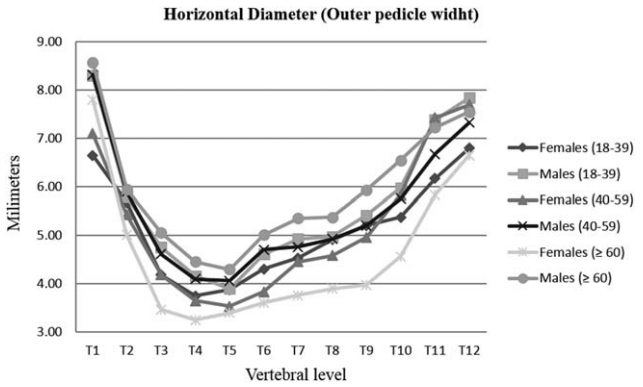

Fig. 2. Horizontal diameter growth patterns of the thoracic spine pedicles in the different study groups.

Ethical Considerations

The protocol was approved by the local Health Research Committee with registration no. AH07–012.

Statistical Analysis

The statistical analysis was conducted using Microsoft Excel® 2013 software for Windows XP. For each of the six groups, the mean and standard deviation were determined independently for each variable. The two-tailed Student's *t*-test was used to determine the significance of the differences between the average diameters (horizontal and vertical, independently) of the vertebral pedicles in men and women for each vertebral level and age group. A *P* value of <0.05 was considered significant. In the same manner, a one-tailed analysis of variance (ANOVA) combined with multiple two-tailed Student's *t*-tests were conducted to compare different age groups within the same gender (18–39 years vs. 40–59 years, 18–39 years vs. $\geq$60 years, 40–59 years vs. $\geq$60 years) for each vertebral level. A *P* value <0.05 was considered significant. All results were summarized in graphs and tables.

RESULTS

The morphometric characteristics of the vertebral pedicle and their differences with gender and age are presented in three sections: general and intersegmental observations, differences between genders, and differences among age groups.

General and Intersegmental Differences

Horizontal diameters (outer pedicle width). The horizontal diameter of the thoracic spine pedicle decreased from T1 to T5, and there was a caudad increase in width from T6 to T12, for all age groups and both genders. The $\geq$60-year male group demonstrated the highest values and the $\geq$60-year female group demonstrated the lowest for all vertebral levels (Fig. 2).

TABLE 2. Morphometry of the Horizontal Diameters of the Thoracic Spine Pedicle According to Gender, Age, and Vertebral Level

Horizontal diameters (outer pedicle width) T1–T12				
Vertebral level	Age range (year)	Female Mean ± SD	Male Mean ± S.D.	Female vs. Male *P*
T1	18–39	6.64 ± 1.15	8.29 ± 0.92	<0.001
	40–59	7.09 ± 0.85	8.31 ± 0.94	<0.001
	≥60	7.80 ± 0.69	8.56 ± 0.91	<0.001
T2	18–39	5.67 ± 0.96	5.79 ± 0.93	NS (0.45)
	40–59	5.42 ± 1.23	5.89 ± 0.99	0.02
	≥60	5.01 ± 0.85	5.94 ± 1.20	<0.001
T3	18–39	4.18 ± 0.73	4.75 ± 0.90	<0.001
	40–59	4.18 ±1.26	4.61 ± 0.86	0.02
	≥60	3.46 ± 0.66	5.05 ± 1.15	<0.001
T4	18–39	3.74 ± 0.81	4.16 ± 0.81	0.002
	40–59	3.64 ± 0.84	4.09 ± 0.79	0.005
	≥60	3.24 ± 0.63	4.45 ± 0.85	<0.001
T5	18–39	3.87 ± 0.74	3.89 ± 0.52	NS (0.85)
	40–59	3.53 ± 1.24	4.06 ± 0.83	0.006
	≥60	3.39 ± 1.55	4.29 ± 1.54	0.001
T6	18–39	4.30 ± 1.19	4.61 ± 1.24	NS (0.13)
	40–59	3.83 ± 0.74	4.70 ± 1.28	<0.001
	≥60	3.60 ± 0.55	5.01 ± 1.08	<0.001
T7	18–39	4.53 ± 0.91	4.92 ± 1.02	0.01
	40–59	4.45 ± 1.57	4.76 ± 0.99	NS (0.18)
	≥60	3.76 ± 0.86	5.35 ± 1.07	<0.001
T8	18–39	4.91 ± 1.19	4.97 ± 0.54	NS (0.68)
	40–59	4.58 ± 0.96	4.92 ± 0.67	0.04
	≥60	3.89 ± 0.66	5.37 ± 0.82	<0.001
T9	18–39	5.20 ± 1.09	5.41 ± 1.05	NS (0.24)
	40–59	4.96 ± 0.91	5.20 ± 0.77	NS (0.14)
	≥60	3.97 ± 0.73	5.93 ± 1.71	<0.001
T10	18–39	5.37 ± 1.06	5.97 ± 0.91	<0.001
	40–59	5.83 ± 1.13	5.75 ± 0.97	NS (0.67)
	≥60	4.56 ± 1.09	6.54 ± 1.87	<0.001
T11	18–39	6.16 ± 0.91	7.38 ± 0.86	<0.001
	40–59	7.42 ± 1.09	6.67 ± 1.03	<0.001
	≥60	5.83 ± 1.29	7.22 ± 1.03	<0.001
T12	18–39	6.79 ± 1.04	7.83 ± 1.11	<0.001
	40–59	7.89 ± 1.05	7.32 ± 0.99	0.05
	≥60	6.64 ± 0.97	7.54 ± 0.77	<0.001

NS: Nonsignificant *P* value. Student's *t*-test. All values are expressed in millimeters.

In women, the minimum outer horizontal diameter result was 3.24 mm ± 0.63 for T4 in the ≥60-year group, and the maximum was 7.89 mm ± 1.05 in T12 in the 40- to 59-year group. In men, the minimum horizontal diameter was 3.89 mm ± 0.52 in T5 for the 18- to 39-year group, and the maximum was 8.56 mm ± 0.91 in T1 for the ≥60-year group (Table 2).

Vertical diameters (outer pedicle height). There was a gradual growth pattern from T1 to T3. Posterior to this, the average values varied slightly between the T4 and T7 levels and there was a progressive and evident increase from T8 to T12 for all age groups and both genders. The highest values were obtained in the 18- to 39-year and ≥60-year groups in men, and in the ≥60-year group in women (Fig. 3).

In women, the minimum outer pedicle height was 7.39 mm ± 0.85 in T1 in the ≥60-year group, and the maximum vertical diameter was 15.46 mm ± 0.64 in T12 in the 40- to 59-year group. In men, the minimal vertical diameter was 8.94 mm ± 1.20 in T5 for the 40- to 59-year group, and the maximum was 17.08 mm ± 1.80 for the ≥60-year group (Table 3).

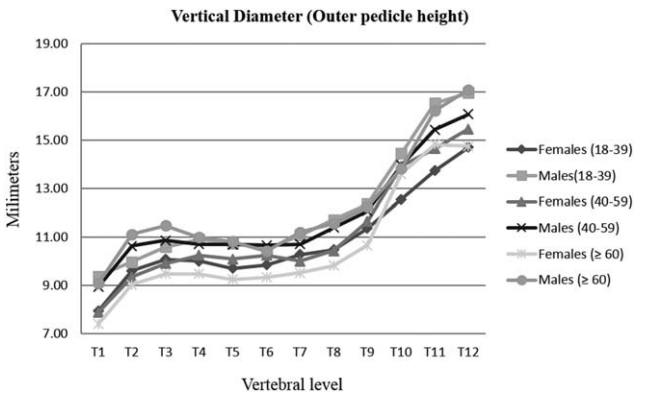

Fig. 3. Vertical diameter growth patterns of the thoracic spine pedicles in the different study groups.

TABLE 3. Morphometry of the Vertical Diameters of the Thoracic Spine Pedicle According to Gender, Age, and Vertebral Level

Vertical diameters (outer pedicle height) T1–T12				
Vertebral level	Age range (yearr)	Female Mean ± SD	Male Mean ± SD	Female vs. Male *P*
T1	18–39	7.94 ± 1.23	9.38 ± 1.29	<0.001
	40–59	7.87 ± 1.23	8.94 ± 1.20	<0.001
	≥60	7.39 ± 0.85	9.08 ± 1.24	<0.001
T2	18–39	9.61 ± 1.33	9.98 ± 2.73	NS (0.33)
	40–59	9.34 ± 0.70	10.63 ± 1.25	<0.001
	≥60	9.03 ± 1.17	11.12 ± 1.81	<0.001
T3	18–39	10.07 ± 1.04	10.59 ± 2.36	NS (0.11)
	40–59	9.90 ± 1.03	10.86 ± 1.45	<0.001
	≥60	9.48 ± 1.38	11.47 ± 1.50	<0.001
T4	18–39	10.00 ± 1.25	10.90 ± 0.98	<0.001
	40–59	10.24 ± 0.84	10.70 ± 1.02	0.01
	≥60	9.47 ± 0.82	10.99 ± 1.31	<0.001
T5	18–39	9.71 ± 1.08	10.75 ± 1.14	<0.001
	40–59	10.09 ± 0.65	10.69 ± 1.05	0.001
	≥60	9.24 ± 1.18	10.82 ± 1.05	<0.001
T6	18–39	9.85 ± 1.07	10.51 ± 1.29	0.001
	40–59	10.25 ± 0.45	10.66 ± 0.88	0.005
	≥60	9.33 ± 1.11	10.42 ± 2.07	0.001
T7	18–39	10.28 ± 1.48	11.08 ± 1.23	<0.001
	40–59	10.01 ± 1.25	10.70 ± 0.94	<0.001
	≥60	9.52 ± 0.84	11.20 ± 1.20	<0.001
T8	18–39	10.48 ± 1.06	11.71 ± 1.12	<0.001
	40–59	10.43 ± 1.96	11.39 ± 0.70	<0.001
	≥60	9.82 ± 0.93	11.56 ± 1.51	<0.001
T9	18–39	11.36 ± 1.23	12.36 ± 1.08	<0.001
	40–59	11.65 ± 0.73	12.07 ± 0.93	0.01
	≥60	10.66 ± 0.81	12.25 ± 1.27	<0.001
T10	18–39	12.55 ± 1.57	14.44 ± 1.54	<0.001
	40–59	13.91 ± 1.04	13.96 ± 1.91	NS (0.88)
	≥60	13.60 ± 1.40	13.83 ± 2.12	NS (0.65)
T11	18–39	13.73 ± 3.04	16.53 ± 0.97	<0.001
	40–59	14.64 ± 1.27	15.43 ± 1.98	0.02
	≥60	14.82 ± 1.45	16.22 ± 1.63	<0.001
T12	18–39	14.70 ± 1.61	16.95 ± 1.52	<0.001
	40–59	15.46 ± 0.64	16.07 ± 1.05	<0.001
	≥60	14.75 ± 1.42	17.08 ± 1.80	<0.001

NS: Nonsignificant *P* value. Student's *t*-test. All values are expressed in millimeters.

Gender Differences

The average results of the horizontal and vertical diameters of the pedicles revealed significant differences ($P < 0.05$) between men and women for most of the thoracic spine levels studied.

Horizontal diameters (outer pedicle width). The values found for men were significantly greater than those for women in most groups, with the exception of the 40- to 59-year group for T10, T11, and T12, where the values for women were higher. In most cases the differences in average values between men and women were statistically insignificant, e.g. when we compared the 18- to 39-year groups (Table 2).

Vertical diameters (outer pedicle height). The values for men were greater than those for women at all vertebral levels and in all age groups. These differences were statistically significant ($P < 0.05$) for most groups compared (T1, T4-T9, T11, T12; Table 3).

Differences with Respect to Age

There were significant differences among age groups at the same vertebral level and in the same gender. In general, there were more cases among women in which the morphometric characteristics of the pedicle differed significantly among age groups for the same vertebral level.

Horizontal diameters (outer pedicle width). In women, the 18- to 39-year and the 40- to 59-year groups differed significantly at T1, T5, T6, T10, T11, and T12. The values for the 18- to 39-year group were significantly higher than those for the ≥60-year group in most cases, the exceptions being T11 and T12. The values for the 40- to 59-year group were significantly higher than those for the ≥60-year group in all cases studied ($P < 0.05$). These results suggest a decrease in the horizontal diameter of the thoracic spine pedicle with increasing age in women (Table 4).

In men, the T1 and T2 vertebrae exhibited no significant differences with age. Also, the 18- to 39-year

TABLE 4. Comparison of Age Groups Within the Same Gender for each Vertebral Level (Horizontal Diameters)

Horizontal diameters (outer pedicle width) T1–T12			
Vertebral level	Comparison groups	Female, *P*-value	Male, *P*-value
T1	18–39 vs. 40–59	0.03	NS (0.88)
	18–39 vs. ≥60	<0.001	NS (0.09)
	40–59 vs. ≥60	<0.001	NS (0.13)
T2	18–39 vs. 40–59	NS (0.27)	NS (0.47)
	18–39 vs. ≥60	<0.001	NS (0.39)
	40–59 vs. ≥60	0.05	NS (0.80)
T3	18–39 vs. 40–59	NS (0.99)	NS (0.31)
	18–39 vs. ≥60	<0.001	NS (0.08)
	40–59 vs. ≥60	<0.001	0.01
T4	18–39 vs. 40–59	NS (0.53)	NS (0.57)
	18–39 vs. ≥60	<0.001	0.04
	40–59 vs. ≥60	0.01	0.01
T5	18–39 vs. 40–59	0.05	NS (0.10)
	18–39 vs. ≥60	0.03	0.003
	40–59 vs. ≥60	0.05	NS (0.18)
T6	18–39 vs. 40–59	0.002	NS (0.65)
	18–39 vs. ≥60	<0.001	0.05
	40–59 vs. ≥60	<0.001	NS (0.14)
T7	18–39 vs. 40–59	NS (0.75)	NS (0.31)
	18–39 vs. ≥60	<0.001	0.01
	40–59 vs. ≥60	0.007	<0.001
T8	18–39 vs. 40–59	NS (0.18)	NS (0.61)
	18–39 vs. ≥60	<0.001	<0.001
	40–59 vs. ≥60	<0.001	<0.001
T9	18–39 vs. 40–59	NS (0.24)	NS (0.13)
	18–39 vs. ≥60	<0.001	0.02
	40–59 vs. ≥60	<0.001	0.001
T10	18–39 vs. 40–59	0.04	NS (0.13)
	18–39 vs. ≥60	<0.001	0.01
	40–59 vs. ≥60	<0.001	0.002
T11	18–39 vs. 40–59	<0.001	<0.001
	18––39 vs. ≥60	NS (0.12)	NS (0.33)
	40–59 vs. ≥60	<0.001	0.003
T12	18–39 vs. 40–59	<0.001	0.002
	18–39 vs. ≥60	NS (0.44)	NS (0.10)
	40–59 vs. ≥60	<0.001	NS (0.18)

NS: Nonsignificant *P* value. Student's *t*-test.

and 40- to 59-year groups differed only at T11 and T12, while the values for the ≥60-year group were significantly greater than those for the 18- to 39-year group for T4 to T10. The 40- to 59-year and ≥60-year groups differed significantly at T3, T4, and T7 to T11. Even so, in men, the average values of the different age groups overlapped widely, and the highest values were those for the ≥60-year-old group. These results suggest an increase in the horizontal diameter of the thoracic spine pedicle in men as age increases (Table 4).

Vertical diameters (outer pedicle height). In women, the differences between the 18- to 39-year and the 40- to 59-year groups were insignificant at the vertebral levels T1-T4 and T7-T9. The values for the 18- to 39-year group were significantly higher than those for the ≥60-year group at most vertebral levels, the exception being T12, where the difference was insignificant. There were significant differences between the 40- to 59-year and ≥60-year group at eight of the 12 vertebral levels studied (T1, T4, T5, T6, T7, T8, T9, T12). The highest average results were observed in the 40- to 59-year group. These data suggest that the vertical diameters of the thoracic spine pedicles in women remain constant between 18 and 59 years of age, after which they begin to decrease.

In men, T4, T5, and T6 did not differ significantly with age. The results for the remaining vertebral levels varied, predominantly with no significant differences among vertebral levels or age groups. These data suggest that the vertical diameters of the thoracic spine pedicles in men do not change significantly as age increases (Table 5).

DISCUSSION

General and Intersegmental Observations

The pedicle is the strongest portion of the vertebra. Consequently, spine instrumentation through this route is biomechanically superior to other available posterior instrumentation systems (Fig. 4) (Yu et al., 2011).

TABLE 5. Comparison of Age Groups Within the Same Gender for Each Vertebral Level (Vertical Diameters)

Vertical diameters (outer pedicle height) T1–T12			
Vertebral level	Comparison groups	Female, *P* value	Male, *P* value
T1	18–39 vs. 40–59	NS (0.77)	0.02
	18–39 vs. ≥60	0.008	NS (0.17)
	40–59 vs. ≥60	0.02	NS (0.53)
T2	18–39 vs. 40–59	NS (0.25)	0.05
	18–39 vs. ≥60	0.01	0.008
	40–59 vs. ≥60	NS (0.12)	NS (0.07)
T3	18–39 vs. 40–59	NS (0.42)	NS (0.38)
	18–39 vs. ≥60	0.01	0.01
	40–59 vs. ≥60	NS (0.09)	0.02
T4	18–39 vs. 40–59	NS (0.27)	NS (0.20)
	18–39 vs. ≥60	0.01	NS (0.65)
	40–59 vs. ≥60	<0.001	NS (0.17)
T5	18–39 vs. 40–59	0.04	NS (0.71)
	18–39 vs. ≥60	0.03	NS (0.70)
	40–59 vs. ≥60	<0.001	NS (0.47)
T6	18–39 vs. 40–59	0.02	NS (0.34)
	18–39 vs. ≥60	0.01	NS (0.72)
	40–59 vs. ≥60	<0.001	NS (0.36)
T7	18–39 vs. 40–59	NS (0.32)	0.04
	18–39 vs. ≥60	0.001	NS (0.57)
	40–59 vs. ≥60	0.02	0.009
T8	18–39 vs. 40–59	NS (0.86)	0.03
	18–39 vs. ≥60	<0.001	NS (0.51)
	40–59 vs. ≥60	0.05	NS (0.39)
T9	18–39 vs. 40–59	NS (0.17)	0.05
	18–39 vs. ≥60	<0.001	NS (0.63)
	40–59 vs. ≥60	<0.001	NS (0.36)
T10	18–39 vs. 40–59	<0.001	NS (0.07)
	18–39 vs. ≥60	<0.001	0.05
	40–59 vs. ≥60	NS (0.36)	NS (0.73)
T11	18–39 vs. 40–59	0.05	<0.001
	18–39 vs. ≥60	0.02	NS (0.14)
	40–59 vs. ≥60	NS (0.54)	0.01
T12	18–39 vs. 40–59	0.004	<0.001
	18–39 vs. ≥60	NS (0.86)	NS (0.66)
	40–59 vs. ≥60	0.003	<0.001

NS: Nonsignificant *P* value. Student's *t*-test.

The horizontal diameters are the most commonly studied variables in morphometric studies of the vertebral pedicle. The average values of the different horizontal diameters (outer pedicle width) are consistent with those of other populations with respect to the patterns of behavior and the general morphometric characteristics of the thoracic spine pedicle (Zindrick et al., 1987; Islam et al., 1994; McCormack et al., 1995; Vaccaro et al., 1995a,b; Islam et al., 1996; Ebraheim et al., 1997; Ugur et al., 2001; Datir and Mitra, 2004; Christodolou et al., 2005; Nojiri et al., 2005; ; Catan et al., 2007; Jun-Hak et al., 2009; Yong et al., 2009; Chen et al., 2010; Acharya et al., 2011; Singh et al., 2011; Zhuang et al., 2011, 2012; Cui et al., 2012).

The patterns observed in the dimensions of the thoracic pedicle and its lowest diameters suggest that the mid-thoracic spine (T4-T8) comprises the most critical points, particularly at T4 and T5, since its horizontal diameter does not allow pedicle screws of conventional size to be placed. Other fixation systems, such as the transarticular or costrotransverse approach to the thoracic spine, should therefore be considered for these levels. For levels T6 and T7, it is possible to use 3.5 or 4 mm screws. Instrumentation for the other thoracic spine levels could be performed using transpedicular screws of conventional diameter (4.5 mm or larger).

The T1 and T2 vertebrae have horizontal and vertical diameters very similar to those of C7 and L1, respectively. T1 and T2 are therefore known as transition vertebrae and are responsible for transmitting force from and towards the cervical and lumbar spines, respectively.

As in other morphometric studies of the thoracic spine pedicle, the vertical diameters (outer pedicle height) grew gradually from T1 to T3; at lower levels, the average values remained relatively stable from T4 to T7, with a progressive and evident increase from T8 to T12 for all age groups and both genders (Zindrick et al., 1987; Islam et al., 1994; McCormack et al., 1995; Vaccaro et al., 1995a,b; Islam et al., 1996; Ebraheim et al., 1997; Ugur et al., 2001; Datir and Mitra, 2004; Christodolou et al., 2005; Nojiri

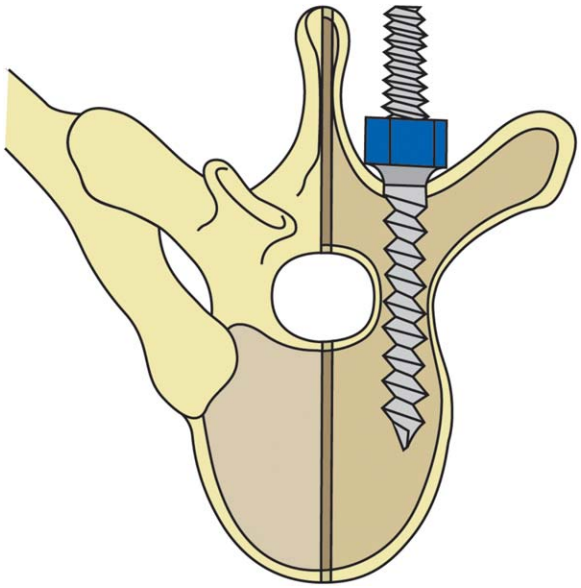

Fig. 4. Representative diagram of the transpedicular instrumentation applied to a thoracic spine. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

et al., 2005; Catan et al., 2007; Jun-Hak et al., 2009; Yong et al., 2009; Chen et al., 2010; Acharya et al., 2011; Singh et al., 2011; Zhuang et al., 2011, 2012; Cui et al., 2012). The vertical diameter is larger than the horizontal for all age groups and vertebral levels in both males and females. The horizontal diameter determines the screw size to be used at different vertebral levels.

Variations with respect to gender. Sexual dimorphism in the horizontal and vertical diameters of the thoracic pedicles was confirmed by this study: as in studies on other populations, the spine pedicle dimensions at most thoracic vertebral levels differed significantly between men and women (Amonoo-Kuofi, 1995). This fact should be considered by the spinal surgeon before the pedicle screw is selected, particularly when the morphometric characteristics of the vertebral pedicle cannot be determined preoperatively by computerized tomography.

In our study, the horizontal and vertical diameters of the vertebral pedicle were significantly greater in men than women. Most of the comparisons in which these differences were insignificant were among the 18–39 year age group. This could be related to the osteoblastic regeneration and remodeling promoted by estrogen in women during this period, which leads to the maintenance of bones stable in structure and composition; also, men and women in this age group perform very similar types and levels of physical activity, which could contribute to the insignificance of the pedicle differences.

Variations with respect to age. Studies of age-related variations of the vertebral elements have largely been limited to the vertebral body and intervertebral discs (Allbrook, 1956; Ericksen, 1976, 1978a,b; Oda et al., 1988; Amonoo-Kuofi, 1991; Gocmen-Mas et al., 2010); in those studies, the vertebral elements were analyzed from an anthropological perspective rather than focusing on clinical or surgical applications. The literature contains very few reports about the vertebral pedicle, and those are limited to the lumbar region (Amonoo-Kuofi, 1995; Mughir et al., 2010).

Amonoo-Kuofi (1991) studied structural changes in the different elements of the spine during growth and found them to be characterized by alternating phases of growth and decrease in dimensions. Oda et al. (1988) concluded that there are regeneration and remodeling cycles in the osseous component of the spine in response to the mechanical demands and the degree of physical activity performed. Those authors established that weight loading and mechanical factors appear important in the morphological and functional adaptations of the spine to the changes associated with growth. They also demonstrated age-related differences in the vertebral pedicle's capacity to expand; the capacity was greater in the pediatric population and decreased with growth. This is why the incidence of pedicle fractures is lower in the pediatric population and higher among adults (Shaikh et al., 2012).

The variations in the vertebral pedicle with respect to age have been studied by Amonoo-Kuofi (1995) and Mughir (2010). Their studies were limited to the lumbar region, where they found significant age-related variations in the horizontal and vertical diameters in the study groups (Amonoo-Kuofi, 1995; Mughir et al., 2010). Such variations in the morphometric characteristics of the thoracic spine pedicle have not been studied for any population to date, but information about them is very important because of the tendency to use the transpedicular approach in the thoracic region of the spine.

Our study demonstrated that the growth of the thoracic spine pedicle from younger to older age was not simply linear; rather, increasing age is associated with a diameter increase in some groups and a decrease in others. These differences could be related to physiological and endocrine changes, nutritional factors, the amount and intensity of physical activity performed by individuals at different stages of life, and osteodegenerative factors.

Traditionally, it has been thought that vertebral pedicle dimensions decrease with increasing age (McLain et al., 2012). This might be only partially true because in many studies no gender distinction is made, the age of the cadaveric specimens is not known precisely, and the distribution and organization of study groups are inappropriate.

The pattern observed in males corresponded to increased horizontal diameters of the thoracic spine pedicles with increasing age. Men lose bone mass as they age because of the progressive decrease in testosterone synthesis, which leads to a decrease in the peripheral conversion (aromatization) of testosterone to estradiol, initiating a loss of bone mass and density similar to that in women. On average, this decrease tends to begin 10 to 15 years after the age of onset in women because of bone physiology differences, which include a greater uptake and storage of calcium in the bones of men during the second and third decades of life, leading to a greater bone density than in women.

Male bone diameters are greater, so their resistance is higher; and men do not experience a sudden decrease in the production of sex steroids as women do (Guggenbuhl, 2009; Gielen et al., 2010). Even so, it seems that the thoracic spine pedicle in men is not involved in these bone changes, probably because unlike other bones and vertebral elements, it is continuously involved throughout life in active and passive situations for transferring and distributing the forces that travel the spine and in stabilizing and maintaining postural tone.

In women, the dimensions of the thoracic spine pedicle decreased from the younger to older age groups; the lowest values corresponded to the >60-year group. These changes could be attributed to the sudden loss of protection of the bone by estrogen, leading to increased osteoclastic activity and thus accelerated bone mass loss. This is reflected in the decrease of spongy bone and thinning of cortical bone and decreased calcium absorption, which are likely to surpass the maintenance capacity of the vertebral pedicle mass in women and bring about a decrease in its dimensions and an increased incidence of osteoporosis and degenerative diseases of the spine.

CONCLUSIONS

There are significant differences in the dimensions of the thoracic spine pedicle between men and women. In men, the dimensions increase with age; in women, they decrease with age. These differences should be taken into account when selecting the appropriate pedicle screw. The vertical diameter is greater than the horizontal diameter for all age groups and vertebral levels in both genders. Thus, the horizontal diameter guides the choice of screw dimensions to be used for the different vertebral levels. The average values and behavior patterns of the spine obtained in this study will help to improve the transpedicular approach to the thoracic spine.

Knowing that age and gender differences in the morphometric characteristics of vertebral thoracic pedicles are significant, preoperative reformatted CT scan evaluation of each individual patient must become routine for an appropriate selection of pedicle screws.

This study reveals the patterns of variation in the thoracic spine pedicle with respect to gender and age in Mexican specimens. However, because of the limited sample size, we suggest conducting further studies. It is also necessary to conduct similar studies on other populations and ethnicities to verify these patterns of variability in the thoracic region.

ACKNOWLEDGMENTS

The authors express their appreciation to the anthropologist Guillermo Torres, curator of the osteological collection of the Physical Anthropology Laboratory, and to Dr. Manuel Arteaga, Chief of the Human Anatomy Department, School of Medicine, UNAM, for their valuable advice, support, and technical help in conducting this study, and to designer Jaime Alberto Cisneros Ríos for his help in preparing the graphic material presented in this study.

REFERENCES

Acharya S, Dorje T, Srivastava A. 2010. Lower dorsal and lumbar pedicle morphometry in an Indian population. A study of four hundred fifty vertebrae. Spine 35:378–384.

Allbrook DB. 1956. Changes in lumbar vertebral body height with age. Am J Phys Anthropol 14:35–39.

Amonoo-Kuofi HS. 1991. Morphometric changes in the heights and anteroposterior diameters of the lumbar intervertebral discs with age. J Anat 175:159–168.

Amonoo-Kuofi HS. 1995. Age-Related variations in the horizontal and vertical diameters of the pedicles of the lumbar spine. J Anat 186:321–328.

Beck M, Rotter R, Gradl G, Herlyn P, Krober M, Mittlmeier T, Gierer P. 2012. Reliability and consequences of intraoperative 3D imaging to control positions of thoracic pedicle screws. Arch Orthop Trauma Surg 14:169–173.

Catan H, Buluc L, Anik Y, Ayyildiz E, Sarlak AY. 2007. Pedicle morphology of the thoracic spine in preadolescent idiopathic scoliosis: Magnetic resonance supported analysis. Eur Spine J 16:1203–1208.

Chan CYW, Kwam MK, Saw LB. 2011. Thoracic pedicle screw insertion in Asian cadaveric specimen: Does radiological pedicle profile affect outcome. Surg Radiol Anat 33:19–25.

Changkun Z, Qishan H, Yuezheng H, Xiangyang W, Wei C. 2009. Computed tomographic morphometry of thoracic pedicles: Safety pedicle parameter measurement of the Chinese immature thoracic spine. Int Orthop 33:1663–1668.

Chaynes P, Sol JC, Vaysse P, Becue J, Lagarrigue J. 2001. Vertebral pedicle anatomy in relation to pedicle screw fixation: A cadaver study. Surg Radiol Anat 23:85–90.

Chen Y, Zeng J, Guan J. 2010. Reformatted computed tomographic evaluation of the thoracic pedicle in a Chinese population for the surgical application of transpedicular screw placement. Surg Radiol Anat 32:463–468.

Christodolou AG, Apostolou T, Ploumis A, Terzidis I, Hantzokos I, Pournaras J. 2005. Pedicle dimensions of the thoracic and lumbar vertebrae in the Greek population. Clin Anat 18:404–408.

Cui G, Kota W, Hosogane N, Tsuji T, Ishii K, Nakamura M, Toyama Y, Chiba K, Lenke LG, Matsumoto M. 2012. Morphologic evaluation of the thoracic vertebrae for safe free-hand pedicle screw placement in adolescent idiopathic scoliosis: A CT-based anatomical study. Surg Radiol Anat 34:209–216.

Datir SP, Mitra SR. 2004. Morphometric study of the thoracic vertebral pedicle in an Indian population. Spine 29:1174–1181.

Di-Silvestre M, Parisini P, Lolli F, Bakaloudis G. 2007. Complications of thoracic pedicle screws in scoliosis treatment. Spine 32:1655–1661.

Ebraheim NA, Xu R, Ahmad M, Yeasting RA. 1997. Projection of the thoracic pedicle and its morphometric analysis. Spine 22:233–238.

Ericksen MF. 1976. Some aspects of aging in the lumbar spine. Am J Phys Anthropol 45:575–580.

Ericksen MF. 1978a. Aging in the lumbar spine II. L1 and L2. Am J Phys Anthropol 48:241–246.

Ericksen MF. 1978b. Aging in the lumbar spine III. L5. Am J Phys Anthropol 48:247–250.

Esses SI, Sachs BL, Dreyzin V. 1993. Complications associated with the technique of pedicle screw fixation. Spine 18:2231–2239.

Faraj AA, Webb JK. 1997. Early complications of spinal pedicle screw. Eur Spine J 6:324–326.

Fujimoto T, Sei A, Taniwaki T, Okada T, Yakushiji T, Mizuta H. 2012. Pedicle screw diameter selection for safe insertion in the thoracic spine. Eur J Orthop Surg Traumatol 22:351–356.

Gielen E, Vanderschueren D, Callewaert F, Boonen S. 2011. Osteoporosis in men. Best Pract Res Clin Endocrinol Metab 25:321–335.

Gocmen-Mas N, Karabekir H, Ertekin T, Ediezer M, Canan Y, Izzet-Duyar I. 2010. Evaluation of lumbar vertebral body and disc: A stereological morphometric study. Int J Morphol 28:841–847.

Guggenbuhl P. 2009. Osteoporosis in males and females: Is there a really difference? Joint Bone Spine 76:595–601.

Islam C, Sakul BU, Guzel MB. 1994. Real minimal diameter of the lower thoracic and lumbar vertebral pedicles. Clin Anat 7:271–274.

Islam C, Guzel MB, Sakul BU. 1996. Clinical importance of the minimal cancellous diameter of lower thoracic and lumbar vertebral pedicles. Clin Anat 9:151–154.

Jun-Hak K, Gyeong-Mi C, In-Bok C, Sung-Ki A, Joon-Ho S, Hyun-Chul C. 2009. Pedicular and extrapedicular morphometric analysis in the Korean population: Computed tomographic assessment relevance to pedicle and extrapedicle screw fixation in the thoracic spine. J Korean Neurosurg Soc 46:181–188.

Kothe R, O'Holeran JD, Liu W, Panjabi MM. 1996. Internal architecture of the thoracic pedicle. An anatomic study. Spine 21:264–270.

Li G, Guohua L, Passias P, et al. 2010. Complications associated with thoracic pedicle screws in spinal deformity. Eur Spine J 19:1576–1584.

Lien SB, Liou NH, Wu SS. 2007. Analysis of anatomic morphometry of the pedicles and the safe zone for through-pedicle procedures in the thoracic and lumbar spine. Eur Spine J 16:1215–1222.

Liljengvist UR, Link TM, Halm HF. 2000. Morphometric analysis of thoracic and lumbar vertebrae in idiopathic scoliosis. Spine 25: 1247–1253.

Lu S, Zhang YJ, Wang Z, Shi JH, Chen YB, Xu XM, Xu YQ. 2012. Accuracy and efficacy of thoracic pedicle screws in scoliosis with patient-specific drill template. Med Biol Eng Comput 50:751–758.

McCormack BM, Benzel EC, Adams MS, Baldwin NG, Rupp FW, Maher DJ. 1995. Anatomy of the thoracic pedicle. Neurosurgery 37: 303–308.

McLain RF, Ferrara L, Kabins M. 2002. Pedicle morphometry in the upper thoracic spine. Limits to safe screw placement in older patients. Spine 27:2467–2471.

Morales-Avalos R, Elizondo-Omaña RE, Vílchez-Cavazos F, Martínez-Ponce de León AR, Elizondo-Riojas G, Delgado-Brito M, Cortes-González P, Guzmán-Avilan RI, Pinales-Razo R, de la Garza-Castro O, Guzmán-López S. 2012. Vertebral fixation with a transpedicular approach. Importance of anatomical and imaging studies. Acta Ortop Mex 26:402–411.

Mughir AMA, Yusof M, Abdullah S, Ahmad S. 2010. Morphological comparison between adolescent and adult lumbar pedicle using computerized tomography scanning. Surg Radiol Anat 32:587–592.

Nojiri K, Matsumoto M, Chiba K, Toyama Y. 2005. Morphometric analysis of the thoracic and lumbar spine in Japanese on the use of pedicle screws. Surg Radiol Anat 27:123–128.

Oda J, Tanaka H, Tsuzuki N. 1988. Intervertebral disc changes with aging human cervical vertebra. Neonate to eighty years. Spine 13:1205–1211.

Panjabi MM, O'Holleran JD, Crisco JJ, Kothe R. 1997. Complexity of the thoracic spine pedicle anatomy. Eur Spine J 6:19–24.

Shaikh KA, Bennett GM, White IK, Buliis CL, Fulkerson DH. 2012. Computed-tomography-based anatomical study to assees feasibility of pedicle screw placement in the lumbar and lower thoracic pediatric spine. Childs Nerv Syst 10:1007–1012.

Singh R, Srivastva SK, Prasath CSV, Rohilla RK, Siwach R, Magu NK. 2011. Morphometric measurements of cadaveric thoracic spine in Indian population and its clinical implications. Asian Spine J 5: 20–34.

Tan SH, Teo EC, Chua HQ. 2004. Quantitative three-dimensional anatomy of cervical, thoracic and lumbar vertebrae of Chinese Singaporeans. Eur Spine J 13:137–146.

Ugur HC, Attar A, Uz A, Tekdemir I, Egemen N, Genc Y. 2001. Thoracic pedicle: Surgical anatomic evaluation and relations. J Spinal Disord 14:39–45.

Vaccaro AR, Rizzolo SJ, Allardyce TJ, Ramsey M, Salvo J, Balderston RA, Cotler JM. 1995a. Placement of pedicle screws in the thoracic spine. Part 1: Morphometric analysis of the thoracic vertebrae. J Bone Joint Surg 77:1193–1199.

Vaccaro AR, Rizzolo SJ, Balderston RA, Allardyce TJ, Garfin SR, Dolinskas C, An HS. 1995b. Placement of pedicle screws in the thoracic spine. Part 2: An anatomical and radiographic assessment. J Bone Joint Surg. 77:1200–1206.

Wang VY, Chin CT, Lu DC, Smith JS, Chou D. 2010. Free-hand thoracic pedicle screws placed by neurosurgery residents: A CT analysis. Eur Spine J 19:821–827.

Yong SC, Young JK, Hyeong-Joong Y, Young-Joon K. 2009. Pedicle morphometry for thoracic screw fixation in ethnic Koreans: Radiological assessment using computed tomographic myelography. J Korean Neurosurg Soc 46:317–321.

Yu Y, Xie N, Song S, Zhang W, Guo Q, Ni B, Luo J. 2011. A biomechanical comparison of a novel thoracic screw fixation method: Transarticular screw fixation vs. traditional pedicle screw fixation. Neurosurgery 69:141–145.

Zhuang Z, Chen Y, Han H, Cai S, Wang X, Qi W, Kong K. 2011. Thoracic pedicle morphometry in different body height populations. A three-dimensional study using reformatted computed tomography. Spine 36:1547–1554.

Zhuang Z, Xie Z, Ding S, Chen Y, Luo J, Wang X, Kong K. 2012. Evaluation of thoracic pedicle morphometry in a Chinese population using 3D reformatted CT. Clin Anat 25:461–467.

Zindrick MR, Wiltse LL, Doornik A, Widell EH, Knight GW, Patwardhan AG, Thomas JC, Rothman SL, Fields BT. 1987. Analysis of the morphometric characteristics of the thoracic and lumbar pedicles. Spine 12:160–166.