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Morphometrics of T11-L5 Vertebrae in Jordanian Population: CT Scan-Based Study

Morfometría de las Vértebras T11-L5 en una Población Jordana: Estudio Basado en Tomografía Computarizada

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SUMMARY: The study will provide information on the morphometrics of the vertebrae, which can be used to guide clinicians on the appropriate size of transpedicular screws to use in spine interventions among the Jordanian population and for comparative studies with other races. A retrospective analysis of normal CT scans of the lumbar and thoracolumbar areas was done. Linear and angular measurements of 336 vertebrae were collected for 25 males and 23 females. The results were compared between right and left and between both sexes. The L5 has the longest AVBH and the shortest PVBH in both sexes, it also, had the shortest and widest pedicle in both males and females. ratio of the AVBH to PVBH showed progressive increase in both sexes from T11 to L5. Similarly, the VBW increased progressively from the top to the bottom in both sexes, but it was significantly different between both sexes. The L1 was the most cranially oriented vertebrae in males while the L2 showed the most cranial orientation in females. Both sexes L5 was the most caudally oriented vertebrae. This study provides a database for vertebral morphometrics in the Jordanian population, there are slight differences between the right and left side in the upper studied vertebrae (T11-L2) and some measurement showed significant differences between males and females. These findings need to be taken into consideration when inserting pedicle screws.

KEY WORDS: Pedicle; Lumbar morphometry; Jordan; Lumbar vertebrae; Computed tomography-based study.

INTRODUCTION

Spinal fusion is one of several interventions used by spine surgeons to treat the widely diverse spinal pathologies, this includes degenerative disease of the spine, tumors, infection, spinal deformity, spinal injuries, and instability. Though there have been several additions to the posterior spinal fusion like anterior, lateral, and oblique interbody fusions over the last few decades (Reisener *et al*., 2020), the use of pedicle screws as primary fusion technique or to supplement other methods of fusions remains the gold standard particularly in the thoraco-lumbar spine.

The estimated number of elective lumbar fusion has increased by 63 % between 2004 and 2015 in the United States (Martin *et al*., 2019). With estimated incidence of pedicle screws misplacement of 15 % utilizing free hand technique (Hicks *et al*., 2010). In addition to risk of injury to nervous tissue and major vascular structures, with its catastrophic results, from mal-positioned pedicle screw, it may also compromise the biomechanical stability of the construct and the patient clinical outcome adversely (Jin *et al*., 2017).

Various intra-operative imaging techniques advances have improved the accuracy of pedicle screws insertion (Mason *et al*., 2014). However, the free hand technique and intra-operative fluoroscopy are the low-cost options available in many middle- and low-income countries (He *et al*., 2022). Accurate and safe screw placement are mandatory to improve the clinical outcomes, improve fusion rates and avoid complications, this is extensively reliant on a deep knowledge of the radiological and surgical anatomy of the thoracolumbar vertebrae.

This study aims at understanding the morphological features of thoraco-lumbar vertebrae from CT scan images in the Jordanian population, and to create a database for comparison with other races and populations.

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MATERIAL AND METHOD

This is a retrospective analysis of thoraco-lumbar CT scans from patients who underwent imaging for various indications. The study was approved by the institutional review board and all patient information was de-identified to protect patient privacy.

Adult patients (aged 18 years and older) who underwent Thoraco-lumbar CT scan and included vertebrae (T11 to L5) with good quality images, no abnormal findings and minimal artefact were included in this study. The following were excluded from analysis A) Patients with congenital spine anomalies. B) Patients with previous spinal surgery. C)Patients with spinal trauma.

A total of 336 vertebrae CT scan images were reviewed, the images were obtained by 16 row multidetector CT scanner (Philips brilliance), All images were obtained at 2 mm slice thickness, The following measurements were documented by a dedicated workstation using picture archiving and communication system (Fig. 1):

- Anterior Vertebral Body Height (AVBH) measured at the mid sagittal plan.
- Posterior Vertebral Body Height (PVBH) measured at the mid sagittal plan.
- Vertebral Body Width (VBW): The widest part of the vertebral body at the mid pedicle level.
- Angle of upper end plate of vertebral body with Horizontal line in the midsagittal plan, (Angel of Vertebral Body Orientation (AVBO))
- Inner cancellous pedicle height.
- Outer cortical pedicle height.
- Pedicle width.
- Angle formed by the longitudinal trajectory of the right and left-sided pedicles and the midline anteroposterior axis of the vertebra (Pedicle Axis Angle (PAA)).
- Postero-anterior Trajectory's Length of the Pedicle from the hypothetical entry point of the screw to the anterior cortex of the vertebra (PTLP) for the right- and left-sided pedicles.

All measurements were obtained by two independent observers, Intra- and inter-observer reliability was assessed

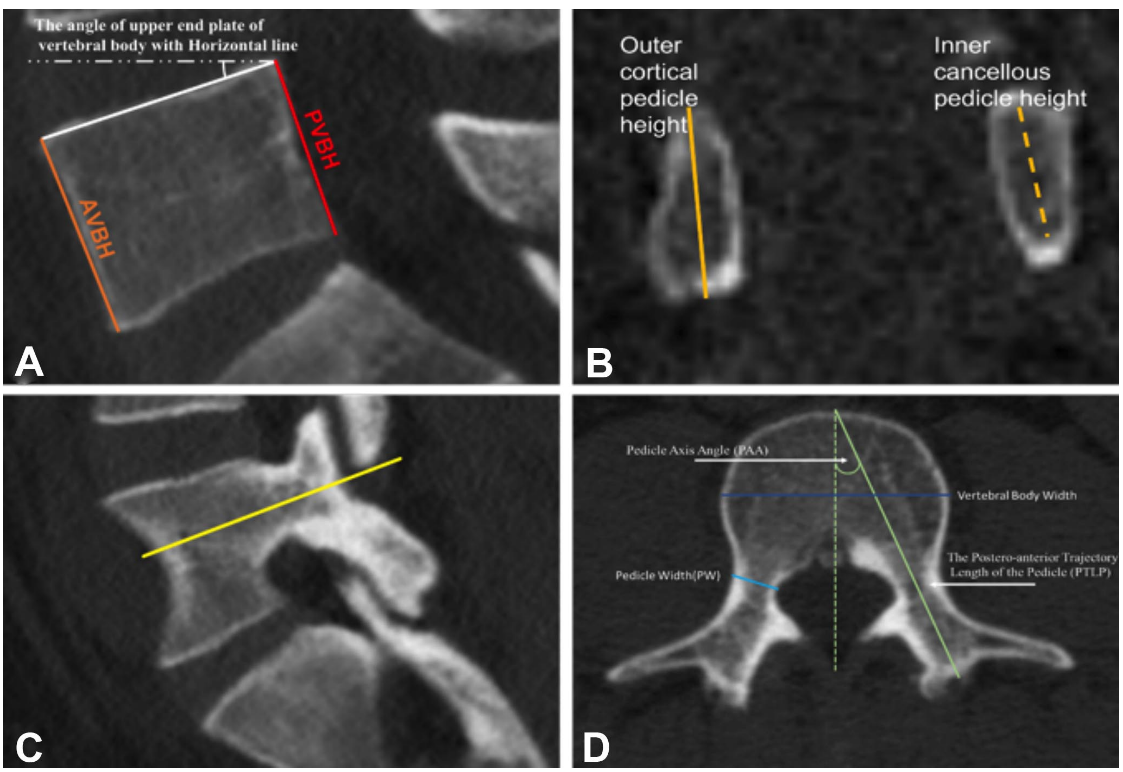

Fig. 1 Illustrates the different measurement calculated on lumbar CT scans. a) Midsagittal cut showing orange line AVBH, red line shows PVBH, and white line shows the angle formed by the superior endplate and a horizontal line b) coronal views at the mid pedicle level solid yellow line shows the outer cortical pedicle height, dashed yellow line shows the inner cancellous pedicle height. c) Sagittal view showing the mid pedicular level at which measurements are taken. d) axial views, light blue line shows the pedicle width, dark blue line shows (VBW), solid green line shows PTLP, PAA is shown by the angle formed by the dashed and solid green lines

using intra-class correlation coefficient (ICC), Any discrepancies between the two observers were resolved by consensus. The data was analyzed using SPSS version 25 (IBM Corp., Armonk, NY, USA), student's t-test was used to compare the morphometric parameters between the different levels of the lumbar spine, and between males and females. And a p-value <0.05 was considered statistically significant.

RESULTS

Vertebral body measurements: The AVBH was the longest at L5 level for both males (2.7 cm SD±0.23) and females (2.65 cm SD±0.26) which also, was found to have the shortest PVBH at (2.34 cm SD±0.24) for males and (2.23 cm SD±0.25) for females. While the T11 showed the shortest AVBH in both males and females (2.22 cm SD±0.18) and (2.1 cm (SD±0.2) respectively, the L2 level showed the maximum posterior height in males (2.87 cm SD±0.22) and (2.7 cm SD±0.19) in females. The ratio of AVBH/PVBH showed progressive increase from the level of T11 to L5, it ranged between (.88 to 1.16) in males and (.9 to 1.19) in females. The ratio was almost equal to one at the level of L4 in males and L3 in Females. A significant difference between both sexes in the PVBH was maintained from T11 to L3 and lost afterwards, while the AVBH was different between T11 and L1 only.

Though VBW increased gradually from T11 to L5 in both sexes ranging between (3.79 cm to 5.15 cm) for males and (3.17 cm to 4.75 cm) for females and the VBW was significantly larger in males (p value <.05), the overall increase in the VBW was 1.5 more times in females in comparison to 1.35 in males. The p-values were significant (<0.05) at each level when comparing male to female.

For males, the most cranially oriented vertebrae were the L1 with a mean angle of (9.47° SD±4.98), compared to the L2 in females which had and angle of (12.3° SD±5.1). Whilst both males and females had the L5 vertebrae as the most caudally oriented vertebrae with mean angles of (-14.2° SD±7.4) and (-15.63° SD±7.42) for males and females respectively. Statistical difference between males and female was seen between T11 and L2 with a p value <0.05, this statistical significance is lost between L3 and L5. The Vertebral body measurements are summarized in Table I.

Trajectory length and axial angle: The longest PTLP was found at the level of L2 for both males and females at a mean of (5.68 cm SD ±.43) and (5.39 cm SD±.42) respectively. While male shortest mean of PTLP was (5.18 cm SD±0.59) at the level of T11, female shortest PTLP was at T11 with a mean of (4.68 SD±0.51). While there was no statistical evidence of differences between the right and the left side in both sexes, there was significant differences (p<0.05) between males and females noted at all levels except for the T12 and L3.

Table I. Summarizes Vertebral body dimensions.

	T11		T12		L1		L2		L3		L4		L5
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
VBW	3.63	3.17	3.79	3.38	3.92	3.45	4.03	3.63	4.27	3.82	4.61	4.17	5.15
(cm)	(±0.33)	(±0.26)	(±0.35)	(±0.3)	(±0.32)	(±0.33)	(±0.35)	(±0.31)	(±0.32)	(±0.31)	(±0.36)	(±0.42)	(±0.44)
AVBH	2.22	2.1	2.37	2.25	2.53	2.42	2.69	2.6	2.66	2.6	2.61	2.62	2.7
(cm)	(±0.18)	(±0.2)	(±0.21)	(±0.17)	(±0.2)	(±0.15)	(±0.22)	(±0.17)	(±0.23)	(±0.22)	(±0.24)	(±0.27)	(±0.23)
PVBH	2.53	2.34	2.72	2.52	2.84	2.67	2.87	2.7	2.78	2.6	2.6	2.52	2.34
(cm)	(±0.15)	(±0.22)	(±0.2)	(±0.19)	(±0.26)	(±0.18)	(±0.22)	(±0.19)	(±0.25)	(±0.18)	(±0.27)	(±0.22)	(±0.24)
Ratio: AVBH / PVBH	0.88	0.9	0.88	0.9	0.9	0.91	0.94	0.97	0.96	1	1.01	1.04	1.16
AVBO	4.85	7.5	7.24	10.88	9.47	12.3	8.43	11.5	4.97	7.42	-3.04	-4.96	-14.2
(degrees)	(±3.96)	(±4.84)	(±4.15)	(±6.65)	(±4.98)	(±4.7)	(±4.44)	(±4.06)	(±3.76)	(±4.94)	(±6.04)	(±3.87)	(±7.4)

VBW: Vertebral Body Width in CM, AVBH: Anterior Vertebral Body Height in cm, PVBH: Posterior Vertebral Body Height in cm, AVBO: Angel of Vertebral Body Orientation in degrees.

The PAA showed a significant difference(p<.05) in the upper four levels (T11-L2) between the left and the right side, but these differences completely dissipated at the lower levels(L3-L5), however, there was no differences between males and females. The widest PAA was at the level of L5 in males (24.59° SD ±4.33) and females (25.45° SD ±5.34), in contrast the T11 had the narrowest angle among all vertebras and in both sexes with a mean of (11.92° SD±3.42) in males and (11.69 °SD ±4.2) in females, results are summarized in Table II.

Pedicle Morphometrics: In males the L4 and L5 equally had the shortest pedicles as measured by the outer cortical height on both sides right and left with average height of (1.38 cm SD± 0.21), the L5 was the shortest for females with an average height of (1.28 cm SD±.18). Again, the L5 showed the shortest inner cortical height for both males and females with an average of (.72 cm SD±.2) and (.68 cm SD±.15) respectively. Nonetheless, the L5 had the widest pedicle for all sexes and in both sides, it had an average width of (1.51 cm SD±.31) in males and (1.39 cm SD±.24) in females.

Table II. Summarizes trajectory length and axial angle, both PAA and PTLP for both sexes and sides.

	T11		T12		L1		L2		L3		L4		L5
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
PTLP	5.24	4.75	5.42	5.13	5.69	5.21	5.72	5.41	5.51	5.22	5.37	4.97	5.28
(Left, cm)	(±0.56)	(±0.48)	(±0.6)	(±0.57)	(±0.39)	(±0.43)	(±0.45)	(±0.41)	(±0.6)	(±0.5)	(±0.49)	(±0.45)	(±0.4)
PTLP	5.12	4.61	5.21	5.03	5.62	5.1	5.64	5.37	5.57	5.31	5.26	5.01	5.22
(Right, cm)	(±0.62)	(±0.54)	(±0.62)	(±0.56)	(±0.46)	(±0.52)	(±0.42)	(±0.44)	(±0.55)	(±0.55)	(±0.53)	(±0.48)	(±0.37)
PAA	13.53	13.78	13.22	13.94	13.76	13.75	13.82	14.42	16.03	15.62	18.91	19.13	25.39
(Left, Degrees)	(±3.42)	(±3.91)	(±2.43)	(±5.17)	(±2.75)	(±4.17)	(±2.91)	(±2.31)	(±3.05)	(±2.15)	(±3.49)	(±2.14)	(±4.72)
PAA	10.31	9.59	11.26	10.41	11.53	11.53	12.63	12.02	14.58	14.44	18.5	18.27	23.8
(Right,Degrees)	(±2.59)	(±3.41)	(±3.69)	(±4.29)	(±4.06)	(±3.38)	(±4.49)	(±3.7)	(±3.71)	(±3.06)	(±4)	(±2.36)	(±3.83)

The T11 had the highest pedicle in both measurements of inner and outer cortical heights for both males and females with an average outer cortical height of (1.7 cm SD±.17) for males and (1.55 cm SD±.19) for females, while it averaged on the measurement of the inner cortical height at (1.03 cm SD±.19) in males and at (.92 cm SD±.16) in females. While the narrowest pedicle in both males and females coincided at the L1 with a mean of (.75 cm SD±.19) for males and (.61 cm SD±.18) for females.

There was no statistical difference between right or left side regarding pedicle width neither to inner or outer pedicle height, while there was a significant difference between sexes in the outer pedicle height for T11 to L3, this difference was limited to T11 and T12 when measuring the inner cortical height. The left pedicle width showed a statistical difference between males and females ($p<.05$) at L1 to L4, on the right-side pedicles a similar significance was seen at T12, L1 and L4 (Table III).

Reliability studies: Intraclass correlation coefficient (ICC) ranged from .867 to .977, The angular measurements showed the lowest ICC intra rater reliability compared to length measurements which all showed results above.93.

Table III. Summarizes pedicle morphometrics, including the outer cortical pedicle height, inner cancellous pedicle height and pedicle width for both sides and sexes.

	T11		T12		L1		L2		L3		L4		L5
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
Left outer	1.7	1.56	1.69	1.55	1.62	1.5	1.59	1.41	1.51	1.39	1.38	1.32	1.38
cortical	(±0.17)	(±0.19)	(±0.16)	(±0.15)	(±0.17)	(±0.15)	(±0.22)	(±0.13)	(±0.2)	(±0.13)	(±0.21)	(±0.15)	(±0.21)
Right outer	1.7	1.54	1.67	1.55	1.61	1.5	1.57	1.4	1.5	1.38	1.37	1.31	1.37
cortical	(±0.17)	(±0.19)	(±0.15)	(±0.16)	(±0.18)	(±0.15)	(±0.22)	(±0.14)	(±0.2)	(±0.12)	(±0.22)	(±0.15)	(±0.21)
Left inner	1.03	0.93	1.05	0.93	0.95	0.9	0.85	0.75	0.86	0.78	0.81	0.73	0.73
cortical	(±0.19)	(±0.16)	(±0.21)	(±0.19)	(±0.22)	(±0.12)	(±0.21)	(±0.14)	(±0.23)	(±0.13)	(±0.21)	(±0.15)	(±0.19)
Right inner	1.03	0.92	1.02	0.91	0.93	0.88	0.83	0.75	0.84	0.77	0.78	0.75	0.72
cortical	(±0.2)	(±0.16)	(±0.23)	(±0.23)	(±0.23)	(±0.13)	(±0.22)	(±0.14)	(±0.23)	(±0.14)	(±0.22)	(±0.14)	(±0.2)
Left pedicle	0.84	0.71	0.85	0.72	0.76	0.63	0.8	0.68	0.95	0.81	1.2	1.01	1.56
width	(±0.25)	(±0.25)	(±0.26)	(±0.23)	(±0.17)	(±0.18)	(±0.22)	(±0.15)	(±0.24)	(±0.18)	(±0.27)	(±0.16)	(±0.31)
Right pedicle	0.78	0.69	0.82	0.68	0.74	0.6	0.74	0.65	0.92	0.8	1.14	0.99	1.46
width	(±0.24)	(±0.25)	(±0.21)	(±0.2)	(±0.2)	(±0.18)	(±0.22)	(±0.16)	(±0.24)	(±0.18)	(±0.24)	(±0.15)	(±0.33)

DISCUSSION

Excluding non-elective spinal fusions, the number of elective spinal fusion has increased by 63 % over the period of eleven years in the United States (Martin *et al*., 2019). This is likely to apply to the rest of the world and particularly in low to middle income countries. Pedicle screws for posterolateral fusion or to augment interbody fusion is becoming a standard of care in degenerative spine disease, especially in spondylolisthesis, recurrent disc herniation, deformity and unstable spinal fractures.

The lumbar spine is by far the most common site for degenerative disease of the spine. Patients do present with different symptoms including low back pain, radicular pain, lower limb weakness and neurogenic claudication. Accurately placed pedicle screws improve the biomechanical stability of the construct and patient clinical outcomes. Safeand accurate positioning of pedicle screws is crucial to prevent disastrous complications perioperatively like vascular or neural injury (Modi *et al*., 2008).

In 2012, Gelalis *et al*. (2012) confirmed in a systematic review, comparing studies using free-hand technique, Fluoroscopy aided, CT navigation and fluoroscopy-based navigation, the superiority of navigation-based techniques over free hand and fluoroscopy aided techniques. Though the cost of navigation, robotic or template assisted pedicle screws insertion maybe offset by reducing the rate of complications, hospital stay and re-operation rates, but the capital investment in such technologies remains out of reach of many centers in the world particularly in low to middle income countries. Nonetheless and despite Gelalis *et al*. (2012) findings free hand techniques and fluoroscopy assisted pedicle screws insertion remain the main techniques for implantation of pedicle screws world (Faldini *et al*., 2021).Vertebral morphometrics varies among different ethnic groups significantly and a thorough knowledge of the lumbar vertebrae morphometric in different populations is of essence to reduce complication rates and improve clinical outcomes(Christodoulou *et al*., 2005; Dzierzanowski *et al*., 2019).there is no previous studies which describe these measurement in the Jordanian population and this will be the first to report these results.

Previous report by Grivas *et al*. (2019) on the Greek population found the longest AVBH to be at the L5 level with a mean of (2.85 cm SD±.255) for males and (2.7 cm SD±0.23) for females, this is in comparison with (2.7 cm (SD±0.23)) for Jordanian males and (2.65 cm (SD±0.26)) for Jordanian females . When compared to our studied levels, the L5 will also have the shortest PVBH in both populations. The ratio of AVBH/PVBH progressive increase from top to bottom would reflect the contribution of each vertebral body morphology to the normal lumbar lordosis. The angle between the superior end plate and the horizon which contributes to the lumbar lordosis was widest in both the Jordanian and the Greek at the L5 and in both populations the angle was wider in females, this is likely to be explained by the fact that females has a greater sacral slope compared to males (Bailey *et al*., 2016).

The pedicle width is a major determinant to the diameter of the screw a pedicle can accommodate. The widest pedicle was found at L5, this is consistent with previous studies of the Greek, American and Turkish populations (Zindrick *et al*., 1987; Güleç *et al*., 2017; Grivas *et al*., 2019).The height of the pedicle, both the outer cortical and inner cortical, was inversely related to the level, with the T11 has the tallest pedicle of all vertebrae in males and females and on both sides right and left. This is again consistent with Grivas *et al*. (2019) findings of the Greek population when similar levels are compared.

The PAA is fundamental to the screw insertion trajectory, the finding did not differ from our clinical practice where we do 15,20- and 25-degrees medial angulation at L3, L4 and L5 respectively on screw implantation. However, between T11 and L2 we do symmetrical angulation on the right and left between 10 -15 degrees, to our surprise the PAA was significantly wider on the left compared to the right between T11 and L2 with a p-value <0.05, a finding that need to be taken in consideration when inserting pedicles screws. In our literature search, we were not able to find a similar reported finding, nor a clear explanation for this difference.

The longest PTLP was found at L2 in both males and females, it is similar to the findings in the Turkish male population, but different in females where the L3 showed the longest PTLP. For the Greek population the L4 was found to have the longest PTLP according to Grivas *et al*. (2019).

Despite its merits this paper is limited by the fact it was carried on non-pathological CT scans, which is not typical for patients who needs surgical intervention and thus we are not aware of the implication of pathologies particularly the degenerative disease of the spine, Also, due to the limitation on the sample size we were not able to clarify age related changes on the spine.

CONCLUSION

In conclusion, This study reports the radiological parametric characteristics of the thoraco-lumbar (T11-L5) spine of the Jordanian population based on non-pathological computed tomography, with no significant differences noted from published literature.

AL-MOUSA, A.; LUAY ABU ALIA1,2; IBRAHIM ELHAJ3 & YAZAN ALDARAWI. Morfometría de las vértebras T11-L5 en una población jordana: Estudio basado en tomografía computarizada. *Int. J. Morphol., 41(5)*:1330-1335, 2023.

RESUMEN: Este estudio proporciona información sobre la morfometría de las vértebras, la cual puede ser utilizada por los médicos oara determinar el tamaño adecuado de los tornillos transpediculares a utilizar en intervenciones de columna en la población jordana y para estudios comparativos con otras grupos. Se realizó un análisis retrospectivo de tomografías computarizadas normales de las áreas lumbar y toracolumbar. Se recogieron medidas lineales y angulares de 336 vértebras de 25 hombres y 23 mujeres. Los resultados se compararon entre vértebras derechas e izquierdas y entre ambos sexos. La L5 tiene el AVBH más largo y el PVBH más corto en ambos sexos, también tenía el pedículo más corto y más ancho tanto en hombres como en mujeres. La relación de AVBH a PVBH mostró un aumento progresivo en ambos sexos de T11 a L5. De manera similar, el VBW aumentó progresivamente de arriba hacia abajo en ambos sexos, pero fue significativamente diferente entre ambos sexos. La L1 fue la vértebra más orientada cranealmente en los hombres, mientras que la L2 mostró la orientación más craneal en las mujeres. En ambos sexos L5 fue la vértebra más orientada caudalmente. Este estudio proporciona una base de datos para la morfometría vertebral en la población jordana, donde existen ligeras diferencias entre el lado derecho e izquierdo en las vértebras superiores estudiadas (T11-L2). Algunas mediciones mostraron diferencias significativas entre hombres y mujeres. Estos hallazgos deben tenerse en cuenta al insertar tornillos pediculares.

PALABRAS CLAVE: Pedículo; Morfometría lumbar; Jordania; Vértebra lumbar; Estudio basado en tomografía computarizada.

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