Deciphering the Morphometric Nuances of Lumbar Pedicles in a Jordanian Population: The Diversity

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ABSTRACT

Introduction: Transpedicular fixation in lumbar spine surgery using pedicle screws has become the standard technique for stabilization of the unstable spine. However, some complications arise with the introduction of pedicle screws. Accurate knowledge of pedicle morphometrics and dimension measurements are vital. To the best of our knowledge, there has been no *in-vivo* analysis and measurements performed on Jordanian people to evaluate lumbar pedicle morphometrics (width and height) based on CT scans.

Objectives: This study was steered to obtain 2-dimensions measurements of the lumbar pedicle using 2D transverse CT images. In addition, to examine whether gender might affect these measurements.

Materials and Methods:A retrospective analysis of acquired data conducted by reviewing patients managed at King Hussein Medical Center (KHMC) and their radiology images records. Patient images retrieved from the electronic hospital database for a 2-year period (2018 - 2020).

Results: This analysis included 50-femalesand 71-males. The mean age of 42.38±17.40 years for the whole population. The statistical difference between lumbar pedicle mean horizontal dimension among males and females was significant from L1 to L5 vertebral bodies, showing that horizontal dimension in male group is wider (P< 0.05). The Same trend was observed between mean lumbar pedicle vertical dimension, showing higher vertical dimensions in male group (P< 0.05).

Conclusion: This novel national study presented comprehensive knowledge for pedicle morphometry and orientation. It has elucidated gender variations between Jordanian and other populations.

Keywords: Pedicle dimensions; morphometric; transpedicular screw fixation.

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INTRODUCTION

Transpedicular fixation in lumbar spine surgery using pedicle screws has become the standard technique for stabilization to achieve safe, short segment rigid fixation, and immobilization of the unstable spine. This technique succeeds in these goals for a variety of spinal disorders such as fractures, spondylolisthesis, and deformities [1-3]. However, some complications arise with the introduction of pedicle screws such as misplacement of the screws, pedicle wall violation, loss of fixation hardware, screw loosening, and neurovascular injury [4-7]. The rate of complications related to pedicle screw fixation procedures is 2.4% [8]. Hence, accurate knowledge of pedicle morphometrics and dimension measurements are vital for patients undergoing pedicle screw instrumentation.

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The lumbar pedicles morphometrics has been addressed in several previous reports worldwide. Some studies performed direct measurements of the pedicleon cadaveric spines using calipers and goniometers

[9-15], while some studies were based on CT images measurements [16-22]. A recent analysis collected by direct measurements using CT images measurements combined with data obtained from planar radiographic images[23-28]. To the best of our knowledge, however, there has been no *in-vivo* analysis and measurements performed on Jordanian people to evaluate lumbar pedicle morphometrics (width and height) based on CT scans. Thus, this study was steered to obtain two-dimensions measurements of the lumbar pedicle using 2D transverse CT images and to compare the results with data reported worldwide.In addition, we examined whether gender might affect these measurements.

MATERIALS AND METHODS

Ethics

A retrospective analysis was performed using patient CT scans from the database of the radiological department at King Hussein Medical Center (KHMC) for the period of January 2018 to January 2020. This study was approved by the Institutional ethics committee of the Royal Medical Services (36/5 /2021). As this study was a retrospective analysis, the requirement for patient consent was waived.

Patients

Data were collected initially from 142 consecutive patientswho had thoracolumbar thin slices CT scan. Ten patients presented with congenital or acquired anomalies; spondylolisthesis (viz: malformation of vertebrae, sacralization, lumbarization and spondylolysis, five patients had oncology pathologies, two patients were under 18 years old, and four patients showed postoperative changes, all have been excluded.

Inclusion/ exclusion criteria

Inclusion criteria:

1) A lack of a past spinal surgery.
2) A lack of active spinal pathology.
3) Symmetric pedicle morphometrics on axial and sagittal cuts measured.

Exclusion criteria were:

1) Patients diagnosed to have Oncology cases, spondylolisthesis, arachnoiditis.
2) Patients developed postoperative infection.
3) The presence of spinal congenital anomalies.
4) Age <18.

Study Design

This study steered in a retrospective manner, by appraising the radiological images of all patients screened at radiological department -King Hussein Medical Center (KHMC). Patient medical reports were obtained from the electronic hospital database.

Radiologic evaluation assessment

Morphometric pedicle analysis was carried out for all lumbar levels from L1 to L5. All patients recruited in our study underwent a two-dimensional CT scan evaluation, which was performed on a Philips Brilliance 64 –Slice MDCT scanner V.2.6, (Philips Healthcare, Netherlands). We calculated the following radiological parameters:

Pedicle width: The narrowest pedicle distance measured in the transverse section (Fig. 1).

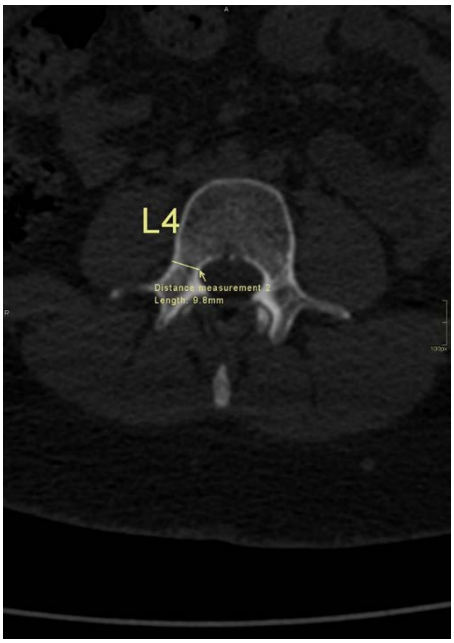

Figure. 1: Axial image of a lumbar vertebra demonstrating the measurement of L4 pedicle width.

Pedicle height: The smallest pedicle distance measured in the sagittal section along the pedicle axis (Fig. 2). For these parameters, the distribution characteristics were calculated independently. Two radiologists (Q. M and M.R) conducted the same measurements on all patients.

Figure. 2: Oblique sagittal image of a lumbar vertebra demonstrating the measurement of L4 pedicle height.

Statistical analysis

The allocation of the characteristics was calculated for each of the parameters for all lumbar levels. For statistical analysis, patients' data were registered and kept in Microsoft Excel 2010 Spreadsheets. We extracted the relevant information and analyzed it using SPSS version 23.0. Data are reported as the medians (and ranges) or the mean values +/- standard deviation. The intraclass correlation coefficient was used to determine the interobserver agreements for both neuroradiologists in regard to CT observations. We conducted an unpaired sample t-test on each of the parameters and compared males to females. Statistically significant values were documented at $p<0.05$.

RESULTS

The final sample of the analysis included 50- femalesand 71- males who met the inclusion/exclusion criteria, and the male-to-female ratio was 1.42:1. The ages of patients were between 18 and 88 years with a mean of 42.38±17.40 years for the whole population. Among males, the mean age was 41.42±17.01 years (range : 19- 88 years), while females' age ranges were 18-80 years and with a mean of 43.74±18.02 years.Statistically, there was no significant difference amongst the two groups enrolled for the assessment in terms of: mean age (Table I).

Table I shows the morphological elements of lumbar vertebral pedicles studied in our analysis. The mean widths of lumbar pedicles in the male group from L1vertebrae to L5 vertebrae were: 8.21± 2.24 mm (5.0- 16.3 mm), 8.45 ± 2.22 mm (1.0-16.1 mm), 10.41 ± 2.10 mm (5.5-14.9 mm), 12.13 ± 1.84 mm (8.6-18.3 mm), and 15.18 ± 2.61 mm (9.4-21.6 mm), respectively (Table II). Those of females were: 6.65 ± 1.42 mm (3.6-9.6 mm), 7.26± 1.39 mm (4.4 - 10.3 mm), 8.86± 1.69 mm (4.5-12.5 mm), 10.56± 1.87 mm (6.4-14.2 mm) and 14.15 ± 2.38 mm (9-19 mm) respectively (Table III).

The mean heights of lumbar pedicles in males from vertebral bodies L1 to L5 were 15.23 ±2.03 mm (7.1-18.5 mm), 14.41 ± 2.74 mm (3.1- 18.0 mm), 13.99 ± 1.75 mm (7.0-17.5 mm), 13.07±1.85 mm (9.4-17.5 mm) and 12.24 ± 1.74 mm (8.3-17.1 mm), respectively. Those of females were 13.58 ± 1.13 mm (10.9- 15.6mm), 13.22± 1.31 mm (10-15.8 mm), 12.81±1.42 mm (9.5-15.7 mm), 11.79 ± 1.45 mm (9.0-16.4 mm), and 10.76 ± 1.86 mm (5.5-15.0 mm), respectively. The differences between lumbar pedicle mean horizontal dimensions among males and females were statistically significant from L1 to L5 ($P< 0.05$). The Same trend was observed between mean lumbar pedicle vertical dimensions between males and females from L1 to L5 ($P< 0.05$). There was generally excellent interobserver reliability for CT parameter measurements by both radiologists (intraclass correlation coefficients ≥0.85).

Table 1: Patient demographical data and mean morphometrics characteristics comparison between two gender groups.

Parameter	Characteristics	Male group	Female group	't' value	p value
Age (years)		41.41	42.38	0.32	0.74
Pedicle Width (mm)	L1	8.213	6.646	3.88	0.0001
	L2	8.449	7.260	258	0.001
	L3	10.413	8.860	3.6	0.0006
	L4	12.125	10.556	3.48	0.0002
	L5	15.182	14.150	3.8	0.0004
Pedicle height (mm)	L1	15.227	13.580	7.47	0.00001
	L2	14.415	13.220	3.4	0.0001
	L3	13.996	12.808	3.7	0.0001
	L4	13.068	11.792	3.57	0.0006
	L5	12.237	10.764		

Table II: Detailed measured morphometrics characteristics in male group

	N	Minimum	Maximum	Mean	Std. Deviation
AGE	71	70	19	88	41.42
L1 height	71	7.1	18.5	15.227	2.0270
L2 height	71	3.1	18.0	14.415	2.7387
L3 height	71	7.0	17.5	13.996	1.7472
L4 height	71	9.4	17.5	13.068	1.8544
L5 height	71	8.3	17.1	12.237	1.7436
L1 width	71	5.0	16.3	8.213	2.2407
L2 width	71	1.0	16.1	8.449	2.2188
L3 width	71	5.5	14.9	10.413	2.0955
L4 width	71	8.6	18.3	12.125	1.8371
L5 width	71	9.4	21.6	15.182	2.6116

Table III: Detailed measured morphometrics characteristics in female group

	N	Minimum	Maximum	Mean	Std. Deviation
AGE	50	18	80	43.74	18.018
L1 Height	50	10.9	15.6	13.580	1.1288
L2 Height	50	10.0	15.8	13.220	1.3082
L3 Height	50	9.5	15.3	12.808	1.4227
L4 Height	50	9.0	16.4	11.792	1.4507
L5 Height	50	5.5	15.0	10.764	1.8606
L1 width	50	3.6	9.6	6.646	1.4180
L2 width	50	4.4	10.3	7.260	1.3896
L3 width	50	4.5	12.5	8.860	1.6984
L4 width	50	6.4	14.2	10.556	1.8716
L5 width	50	9.0	19.0	14.150	2.3843

DISCUSSION

Transpedicular screw fixation surgeries of the lumbar spine were pioneered by Roy-Camilleare becoming progressively more common. Furthermore, a wide spectrum of hardware and trajectory options is also available[1]. There are several factors that contribute to the biomechanical strength of pedicle screw constructs, such as screw length, diameter, thread design, and bone quality. To obtain rigid fixation, accurate measurement of the pedicle dimensions and selection of proper screws size are essential. An increase in pedicle screw diameter has been shown to be a major factor that increases pull-out strength [25]. Hence, the ideal pedicle screw diameter should be the largest possible.

In areas where inconsistency commonly occurs among patients and populations, physicians need to be aware of the variable lumbar pedicle morphology and orientation when planning pedicle screw insertion using a free-hand technique or with guidance by a navigation system. Meticulous pre-operative planning with CT scans is important to confirm the suitable diameter, length, and trajectory for pedicle screw placement.

Accurate pre-operative anatomical evaluation of the targeted lumbar pedicles is of paramount importance to determine the size of the screws and its direction of insertion to prevent complications or surgical failure. The most devastating reported complication associated with pedicle screw insertion is neurological injury secondary to mal-positioning of the screw. The limited literature shows that gender and racial differences occur in lumbar pedicle morphometry. This finding motivated us to assess the different nuances of lumbar pedicles morphometric parameters in Jordanian residents by means of CT evaluation. [29-32].

Our study revealed that the lumbar pedicle width gradually increases when descending from the L1 pedicle level to the L5 vertebral level in both males and females. The average measured widths of lumbar pedicles in males at levels corresponding to L1 and L5 pedicles were 8.21± 2.24mm and 15.18± 2.61mm, whereas measured values for the females at same levels were 6.646± 1.42 mm and 14.15±

2.38 mm respectively. The statistical difference between mean widths of the lumbar pedicle between gender groups was significant from the L1 to L5 vertebral bodies (P< 0.05). Singel et al. carried out a review on an Indian population in regard to the lumbar pedicles morphometrics. They showed that the measured pedicle width was enlarged from descending from L1 to L5 in both gender groups. The average for males was 8.5 ± 2 mm (range: 6-11 mm), and that of females was 19.25 ± 3.25mm (range: 16-21mm) [29]. According to their results, no statistically significant difference was observed between the two gender groups in terms of pedicle widths. Another limited study conducted on eastern Anatolian population, showed similar results[28]. While in recent study carried on Turkish population, measuring L1 virtual width and height , results showed lower values in both genders [30].

In contrast our results showed a significant difference between pedicle widths between genders. Furthermore, the mean pedicle horizontal axis was less than that observed in this study.

Rajput et al. in a recent study conducted in Indian population, also observed that the crosswise pedicle diameter progressively enhanced from the L1 to L5 vertebral levels. The measured widths at L1was 7.24 ±2.22 mm (ranging from 5 -11mm) and that at L5 was 12.00 ±4.39 mm (ranging from 9 – 20 mm) respectively [31]. Our observations are in concordance with their study, although were larger. A larger study reviewed the lumbar pedicle morphometrics of 270-males and 270-females. They observed comparable trends to our study in regard to lumbar pedicle width [32].

According to our observations regarding the pedicle's height, we noticed that the maximum occurred at L1 in males and at L4 vertebral level in females. However, it declined from L1 to L5 vertebral level in both groups. The average measured heights of lumbar pedicles in males were 15.23±2.02 at L1 mm, and that at L5 was 12.24±1.74 mm respectively. While in females average at L1 was 13.58±1.13 mm and that at L5 was 10.76±1.86mm, respectively. The difference in the average lumbar pedicle heights between males and females was statistically significant from L1 and L5 (P< 0.05).

Likewise, Singel et al. noticed that pedicle height was the maximum at L2 in males and at L1 in females group, whereas it declined from L3 to L5 which is not in line with our study. Their measured values of the minimum and maximum pedicle vertical axis were 13.4 ±6 mm (11-17 mm) and 15±4.6 mm (13-17 mm) in males, while they were 13.25 ±2.5 mm (12-15 mm) and 15.5 ±2 mm (14-17 mm) in females, respectively[29]. Our observations showed statistically significant differences between the two gender groups.

Berry et al. found matching results to ours. They found an analogous tendency in terms of the pedicle vertical dimensions at all levels, similar to our observations[33].

On the other hand, in a review, Rajput et al. observed that the pedicle height declined slightly from L1 to L3 level but then increased at L4 and abruptly increased at L5[30]. To further understand which factors may affect the vertical and horizontal pedicular dimensions, Amonoo-Kuofi et al. conducted a review on these factors on Saudi Arabian population. They showed that there was an increase in the pedicles' vertical dimension from L1 to L5 level, and they noticed that the pedicle height in females was less than that in males [32].

All these results confirm that weight-bearing and biomechanical elements perform critical roles in the morphological variation of the pedicles [11-13]. Larger pedicle heights in the upper lumbar pedicles are hypothesized to be attributable to their location adjacent to the thoraco-lumbar transitional zone, which is an area with a complex zygapophyseal joint [34]. This facilitates the endurance of notable compressive forces transmitted from the relatively immobile dorsal spine to the highly mobile lumbar spine. Another hypothesis to explain the biomechanics of load transmission in the spine suggests that in the anteriorly concave dorsal spine, the load is conveyed from the posterior part to the anterior part of the vertebral column. In the posteriorly concave lumbar spine, the load is conveyed from the anterior part of the vertebral column to the neural arch. This transferring of forces is in harmony with the status of the gravity line. Thus, at the L5 vertebral level, forces through the pedicles have to pass in an antigravity direction [35]. Consequently, contemplating these factors, the pedicles of L5 vertebrae are considered to have the maximum width. Finally, variations in results according to several studies may

be attributed to national or racial variations or to specific typical body postures that depend on local customs and practices.

Nevertheless, this analysis has noticeable drawbacks. First of all, patients were not allocated based on their normal age distribution, so the results may not considerably reflect the actual anatomical distribution due to selection bias. Second, patients' demographic data in terms of height and body weight (BMI), may also play roles in anatomical variation but were not incorporated in the study. Third, the data from both pedicles in the same vertebrae were assumed to be independent, as we considered the average when we encountered wide differences on both sides. Given normal symmetry, this assumption may be incorrect, so the significance of the differences may be overestimated. Finally, the small sample of enrolled patients was insufficient to reach conclusions with adequate analysis power. Nevertheless, we still believe that this study could serve as a background for future studies to improve our understanding view of pedicle morphometry. The results obtained illustrated the variability of each lumbar pedicle's morphology and orientation, as well as observed differences based on gender and ethnicity parameters between populations. Such information may aid physicians in inserting lumbar pedicle screws more safely and accurately to avoid iatrogenic complications due to mal-positioning of pedicle screws, including nerve root injury, vascular injury, and internal organ injury. Moreover, meticulous pre-operative planning, multiple checkups using an intra-operative portable C-arm, and guidewire with pedicle finder systems could also help to alleviate iatrogenic complications, especially if an O-arm navigation system is not routinely used in clinics.

CONCLUSION

This novel national study has presented comprehensive knowledge for distinguishing pedicle morphometry and orientation for optimal pedicle screw introduction. Furthermore, it has elucidated gender variations in the morphometrics of lumbar pedicle orientation between Jordanian and other populations. Despite, some drawbacks of the analysis, detailed knowledge regarding the transverse and perpendicular dimensions of lumbar pedicles was also provided.

Future work: We need a study alleviating the drawbacks of the current study to provide solid evidence.

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Availability of data and materials: All data generated or analyzed during this study are included in thispublished article.

Authors' contributions

MQ: acquisition of data, writing manuscript, RM: acquisition of data, analysis and interpretation of data. LM: analysis and interpretation of data. SHT: analysis and interpretation of data, AA: analysis and interpretation of data, DR: analysis and interpretation of data, drafting manuscript AR: conception and design, analysis and interpretation of data, writing manuscript. All authors read and approved the final manuscript.

Consent for publication: Not applicable.

Conflicts of interest: The author certify that he has no affiliation with or any direct or indirect involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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