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Morphometric characteristics of the inner and outer diameter of lumbar pedicles on computed tomography

Charakterystyka morfometryczna średnicy wewnętrznej i zewnętrznej nasad łuków kręgów lędźwiowych w tomografii komputerowej

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Abstract

Background and purpose: The inner pedicle diameter is very important in pedicle screw placement in order to achieve safe and strong posterior stabilization. The optimal pull-out strength can be achieved by a screw which fits into the pedicle medulla. The aim of the present study was to compare the inner and outer pedicle diameters of lumbar pedicles, to determine the inner/outer pedicle diameter ratios, and to develop a simple measure for estimating optimal pedicular screw size.
Material and methods: 178 lumbar pedicles of 20 patients were evaluated. Inner and outer pedicle diameters of lumbar vertebrae were measured in computed tomography (CT). A simple linear regression analysis was performed to assess the relationship between the inner and outer pedicle diameters.
Results: The widest pedicle outer diameter was seen at L5, with a mean of 16.538 ± 1.899 mm. The narrowest pedicle outer diameter was seen at L1, with a mean of 8.310 ± 1.870 mm. The maximum inner pedicle diameter was at the L5 level, with a mean of 11.416 ± 2.664 mm, whereas the minimum was at the L1 level, with a mean of 5.510 ± 1.887 mm. The regression coefficient between the inner and outer pedicle diameter was 0.68 for all pedicles combined.
Conclusions: We have demonstrated the relation of the inner and outer pedicle diameter of lumbar pedicles and described

Streszczenie

Wstęp i cel pracy: Wewnętrzna średnica nasady łuku kręgu ma istotne znaczenie w skręcaniu nasad śrubami w celu uzyskania bezpiecznej i mocnej stabilizacji tylnej. Optymalną wytrzymałość na rozciąganie można osiągnąć przez dobór śrub pasujących do rdzenia nasady. Celem niniejszego badania było porównanie wewnętrznych i zewnętrznych średnic nasad łuków kręgów lędźwiowych i określenie współczynników średnic wewnętrznej i zewnętrznej, a także opracowanie prostej metody pomiaru służącego do oceny optymalnego rozmiaru śruby stosowanej do zespoleń nasad.
Materiał i metody: Oceniono 178 nasad łuków kręgów lędźwiowych u 20 pacjentów. Wewnętrzne i zewnętrzne średnice nasad łuków kręgów lędźwiowych mierzono za pomocą tomografii komputerowej (TK). Związek między średnicą wewnętrzną i zewnętrzną nasady łuku oceniono za pomocą analizy regresji liniowej.
Wyniki: Największą średnicę zewnętrzną miał kręg L5 (średnia: 16,538 ±1,899 mm), a najmniejszą kręg L1 (średnia: 8,310 ±1,870 mm). Największą średnicę wewnętrzną stwierdzano w przypadku kręgu L5 (średnia: 11,416 ±2,664 mm), a najmniejszą – w przypadku kręgu L1 (średnia: 5,510 ±1,887 mm). Współczynnik regresji między średnicą wewnętrzną i zewnętrzną nasady dla wszystkich nasad łącznie wyniósł 0,68.

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an easy and reliable method to estimate the inner pedicle diameter from the outer diameter on CT.

Key words: computed tomography, lumbar pedicle, cortex, medulla, transpedicular fixation.

Wnioski: Przedstawiono zależność średnicy zewnętrznej i wewnętrznej nasad kręgów lędźwiowych. Opisano również łatwą i wiarygodną metodę oszacowania wewnętrznej średnicy nasady na podstawie zewnętrznej średnicy nasady zmierzonej w TK.

Słowa kluczowe: tomografia komputerowa, nasada łuku kręgu lędźwiowego, kora, rdzeń, stabilizacja przeznasadowa.

Introduction

The use of transpedicular screws as a fixation device for posterior spinal surgery has become increasingly popular worldwide. The transpedicular screw fixation system provides the best stability in an unstable spine [1]. It is the only spinal fixation system that transfixes all three spinal columns and resists motion in all planes. Therefore, it allows incorporation of fewer normal motion segments to achieve an unusual degree of stabilization [2,3].

A pedicle screw's holding strength in the vertebral bone depends on many factors. Age-related bone loss diminishing the integrity of the vertebral trabecular bone leads to failure of screw fixation or diminished healing response of the osteoporotic bone [4,5]. Other factors that influence the bony purchase and subsequent fixation strength of a pedicle screw include the depth of penetration, the diameter and other design characteristics of the screw [6-8]. The optimal pedicular screw dimensions must fit into the pedicular medulla [9-11].

A knowledge of the pedicle morphometry has utmost importance to ensure safe and strong pedicle screw placement. Particularly, the inner diameter of the pedicle is the primary constraint for screw insertion. Surgeons typically wish to place the largest diameter screw possible for a given level to have the greatest fixation strength [12-14].

The purpose of our study was to compare the inner and outer pedicle diameter from L1 to L5, and to determine the inner/outer pedicle diameter ratios for each lumbar pedicle.

Material and methods

We selected 89 vertebrae from 20 patients who required lumbar computed tomography (CT) and were evaluated in our hospital. The patients included in this study were randomly chosen from the patient's registry. Patients' age ranged from 16 to 70 years (mean 47 years). Ten patients (50%) were men with an average age of 42.7 years and 10 (50%) were women with an average age of 46.1 years; no significant difference in the mean age of male and female patients was observed. Height ranged between 152 and 186 cm (mean 163.9 cm). Body weight was 52 to 91 kg (mean 69.7 kg). Patients had no evidence of spinal deformities, tumours, fractures, infections, congenital anomalies, or instrumentation. All patients were scanned using the Somatom Emotion 16 multislice CT system (Siemens, Berlin, Germany). CT studies were performed with 0.5-mm-slice thickness. Parameters on CTs were measured using the computerized image analysis software "BABSOFT BS200Pro imaging system".

The criteria for recording measurements were similar to those described by Krag *et al.* in 1988 [15]. Using the bone window, the transverse section on which the left and right pedicle appeared largest was selected for printing on a radiograph at 80% magnification. This image was referred to as the mid-pedicle cut. The pedicle longitudinal axis was drawn through the middle of the pedicle by visual best fit. At the narrowest width of the pedicle, a line was drawn perpendicular to the longitudinal axis in order to measure the following dimensions: (1) the outer pedicle diameter and (2) the inner pedicle diameter (Fig. 1). Linear measurements were taken from the CT images using dividers and a 0.5-mm ruled scale.

Statistical analysis

Statistical analysis was performed using SPSS 11.0 software. Mann-Whitney U-test was used for comparisons between genders. Student's t-test was used for comparisons between left and right pedicles. $P < 0.05$ was considered statistically significant. A simple linear regression analysis was also conducted to estimate the slope coefficients that describe the linear relationship between the inner pedicle diameter and outer pedicle diameter.

Results

The widest pedicle outer diameter was seen at L5, with a mean of 16.538 mm (range 12.479-19.503 mm). The narrowest pedicle outer diameter was seen at L1,

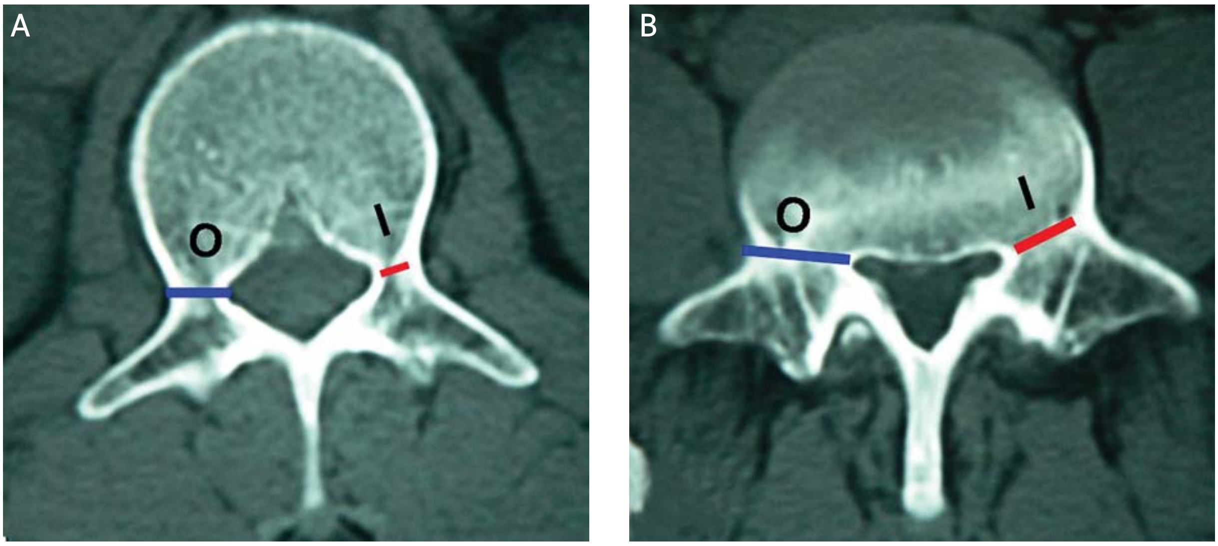

Fig. 1. (A) Transverse sectioned CT of L1 vertebra demonstrates: I – the inner diameter of the left pedicle, O – the outer diameter of the right pedicle; (B) transverse sectioned CT of L5 vertebra demonstrates: I – the inner diameter of the left pedicle, O – the outer diameter of the right pedicle

with a mean of 8.310 mm (range 4.851-12.494 mm) (Table 1). The maximum inner pedicle diameter was at the L5 level, with a mean of 11.416 mm (range 6.911-17.002 mm), whereas the minimum was at the L1 level, with a mean of 5.510 mm (range 2.737-9.846 mm).

Inner and outer pedicle diameters differed significantly between males and females ($p < 0.05$) (Figs. 2-3). Men had greater outer diameters in L1, L2, and L3 vertebrae and greater inner diameters in L1, L2, and L4 levels. Although differences in pedicle dimensions were found between right and left pedicles (including the outer pedicle diameter and the inner pedicle diameter), they were not statistically significant, i.e. not consistently larger to either the left or right.

The simple linear regression coefficients among the lumbar pedicles' inner diameters are given in Table 2. The purpose of the simple linear regression analysis was to estimate the inner pedicle diameters of lumbar vertebrae by using the outer pedicle diameters. The simple linear regression coefficients for L1 to L5 pedicles were similar. Therefore, all pedicles were combined and a simple linear regression model was constructed. The simple linear regression coefficient was 0.68 for all pedicles.

Table 1. Inner and outer diameters of the pedicles measured in the present study

Vertebral level	Pedicle inner diameter (± SD) (mm)	Pedicle outer diameter (± SD) (mm)
L1	5.510 ± 1.887	8.310 ± 1.870
L2	5.823 ± 1.958	8.833 ± 1.602
L3	7.002 ± 1.718	10.558 ± 2.039
L4	8.698 ± 1.886	12.537 ± 2.569
L5	11.416 ± 2.664	16.538 ± 1.899

SD – standard deviation

Discussion

Transpedicular fixation of the thoracic and lumbar spine is the standard procedure for spinal stabilization following deformity correction, spinal decompression, and spinal instability. The advantages of pedicular screw fixation over other methods are its superior pull-out strength, rigidity, and relative safety. Pedicular screw fixation of the cervical, thoracic, thoracolumbar, and lumbar spine can be performed safely by trained surgeons using the freehand technique [16,17]. Although the significance of the cancellous part of the pedicle has been indicated in correct pedicle screw placement, there is very limited information on the details of the inner pedicle diameter in the literature. The inner pedicle diameter of lumbar pedicles ranged from 5.5 mm to 8.1 mm in the study by Islam *et al*. [18]. The inner pedicle diameter measured in our study ranged from 5.510 mm to 11.416 mm. The inner pedicle diameter measured in this study is consistent with the study by Islam *et al*.

There are many advantages of using CT to investigate pedicle morphology. CT measurements of the outer cortical diameter correlated well with actual

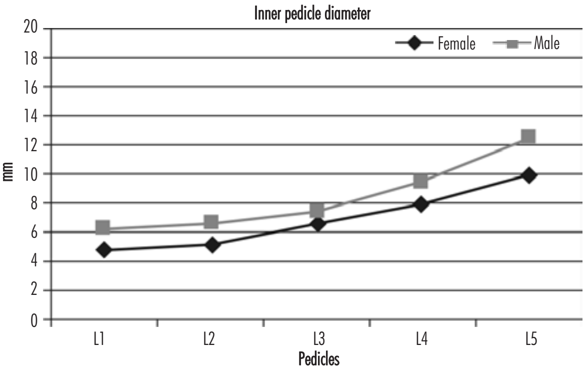

Fig. 2. Comparison of mean range of the inner pedicle diameter between genders

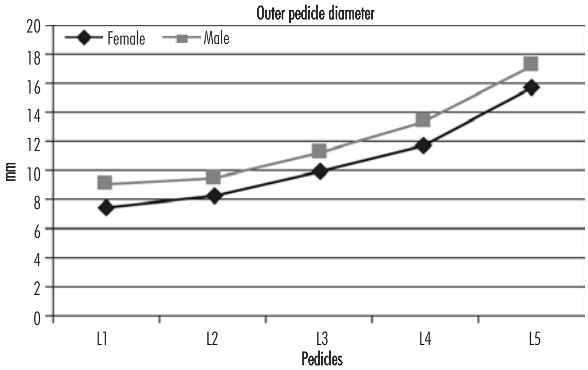

Fig. 3. Comparison of mean range of the outer pedicle diameter between genders

cortical measurements using calipers. The average difference noted was 0.33 mm, with a range of 0.03 to 1.18 mm [19]. In the present study, the CT evaluation method described by Krag *et al*. [15] was preferred.

The narrowest point of the inner pedicle diameter and medial and lateral wall thickness of the pedicles affect the safety of transpedicular screw fixation. The key to a successful transpedicular screw placement is that the smallest part of the pedicle, especially the deep isthmus section, should be safely penetrated. Otherwise, severe complications, such as pedicle breakage as well as vascular and visceral injuries, may occur. Such fixation is not recommended when the outer diameter of the pedicle is < 4.5 mm, as a critical breach was observed in 12 to 18% of cadavers studied [20]. Use of a larger screw will lead to violation of the medial or lateral cortex of the pedicle and may lead to neurological deficit. However, in the event that the pedicle wall was perforated, nerve compression seldom occurred. This may be because of the 2 + 2 mm interval space, i.e., 2 mm of epidural space between the pedicle medial wall and the dura mater and 2 mm of subarachnoid space. It is safe to insert a pedicle screw below L3 with a diameter greater than 6 mm [2,21].

Table 2. Simple linear regression coefficients between inner and outer pedicle diameters at specific lumbar levels

	Simple linear regression coefficients
L1	0.676
L2	0.674
L3	0.662
L4	0.691
L5	0.695

There have been numerous studies focused on pedicle morphology previously [22-27]. In the literature, the average outer pedicle diameter was reported to range from 18 mm in the L5 vertebra to 7 mm in the L1 vertebra. Outer pedicle diameter in L1 and L5 was found to be 7.0 mm and 10.9 mm, respectively, by Berry *et al*. [28], 6.8 mm and 18.4 mm by Kim *et al.* [24], 10.3 mm and 21.6 mm by Robertson and Stewart [25], 7.4 mm and 9.9 mm by Scoles *et al.* [26], and 8.7 mm and 18.0 mm by Zindrick *et al.* [27]. We measured the average outer pedicle diameter to range from 8.310 mm to 16.538 mm. The dimension of outer pedicle diameter increased caudally. Pedicle dimensions in this study were consistent with those of previous studies [18,22,24-31].

The inner pedicle diameter can be measured from vertebra CT. It might be difficult to measure the inner pedicle diameter in small printed CT images and in low resolution CTs. Additionally, the radiologist may not be familiar with reading and measuring the inner pedicle diameter. If the inner diameter cannot be obtained from regular lumbar CT, the outer diameter can be used to estimate the inner lumbar diameter. The formula is "inner diameter = simple linear regression coefficient × outer pedicle diameter". In the present study, simple linear regression coefficients for L1 to L5 were similar. Therefore, all pedicles were combined and a simple linear regression model was constructed. Finally, the simple linear regression coefficient was 0.68 for L1 to L5 pedicles. Thus, the corrected formula is "inner diameter = 0.68 × outer pedicle diameter".

Conclusions

1. Screw diameter should fit into the medulla with its widest diameter for proper screw placement.

2. We have demonstrated the relation of the inner and outer pedicle diameter of lumbar pedicles and described an easy and reliable method to estimate the inner pedicle diameter from the outer diameter on CT with the formula mentioned above.

Disclosure

Authors report no conflict of interest.

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