Analysis of lumbar pedicle morphology in degenerative spines using multiplanar reconstruction computed tomography: what can be the reliable index for optimal pedicle screw diameter?

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Abstract

Purpose The measurement of transverse pedicle width is still recommended for selecting a screw diameter despite being weakly correlated with the minimum pedicle diameter, except in the upper lumbar spine. The purpose of this study was to reveal the difference between the minimum pedicle diameter and conventional transverse or sagittal pedicle width in degenerative lumbar spines.

Methods A total of 50 patients with degenerative lumbar disorders without spondylolysis or lumbar scoliosis of $>10^\circ$ who preoperatively underwent helical CT scans were included. The DICOM data of the scans were reconstructed by imaging software, and the transverse pedicle width (TPW), sagittal pedicle width (SPW), minimum pedicle diameter (MPD), and the cephalocaudal inclination of the pedicles were measured.

Results The mean TPW/SPW/MPD values were 5.46/11.89/5.09 mm at L1, 5.76/10.44/5.39 mm at L2, 7.25/10.23/6.52 mm at L3, 9.01/9.36/6.83 mm at L4, and 12.86/8.95/7.36 mm at L5. There were significant differences between the TPW and MPD at L3, L4, and L5 ($p < 0.01$) and between the SPW and MPD at all levels ($p < 0.01$).

Conclusions The MPD was significantly smaller than the TPW and SPW at L3, L4, and L5. The actual measurements of the TPW were not appropriate for use as a direct index for the optimal pedicle screw diameter at these levels. Surgeons should be careful in determining pedicle screw diameter based on plain CT scans especially in the lower lumbar spine.

Keywords Pedicle screw · Diameter · Multiplanar reconstruction computed tomography · Degenerative lumbar disease

Introduction

Lumbar instrumentation surgery using pedicle screws has become the standard technique to fuse or correct deformities in various lumbar degenerative disorders such as spondylolisthesis and scoliosis. Preoperative evaluation of the pedicle morphology and appropriate screw size selection based on computed tomography (CT) images are essential for the accurate insertion of pedicle screws. The actual measurement values of the transverse pedicle width (TPW) on the axial plane of the CT image are recommended as an index to determine the appropriate pedicle screw diameter [1–4]. However, the shape of the coronal section of lumbar pedicles is not round, but oval, especially at the lower lumbar spine. Furthermore, the major axis of the oval is horizontally inclined. These facts suggest that the TPW is not always the same as the minimum pedicle diameter (MPD). In addition, in cases where the MPD is much smaller than the TPW, the pedicle screw can perforate the wall of the pedicle and injure the nerve root.

From the perspective of pedicle morphology, the narrowest section of the lumbar pedicle exists on the plane

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vertical to the pedicle axis [5]. Therefore, it is essential to measure the MPD on this plane for determining the optimal pedicle screw diameter. However, little is known about the relationship between the MPD and the conventional transverse or sagittal pedicle width (SPW) in patients with degenerative lumbar disorders. Recently, multiplanar reconstruction (MPR)-CT has enabled us to reconstruct the data in planes voluntarily.

The purpose of this study is to reveal the difference between the MPD and conventional TPW or SPW and to create an index of optimal pedicle screw diameter based on the conventional TPW and/or SPW.

Materials and methods

The subjects were 50 consecutive patients (23 men and 27 women) who underwent preoperative MPR-CT for lumbar surgery at our hospital between August 2008 and July 2010. Patients with spondylolysis or lumbar scoliosis $>10^\circ$ were excluded. The subjects were aged between 52 and 85 years, with the mean age of 70.1 years at the time of CT scanning. Regarding the patients' degenerative lumbar disorder, 16 (9 men and 7 women) had lumbar spinal canal stenosis, and 34 (14 men and 20 women) had lumbar degenerative spondylolisthesis. Light Speed Plus (GE Healthcare, Chalfont St. Giles, UK) was used for CT scans. The settings used for the CT scans were as follows: helical mode; slice thickness, 1.25 mm; tube voltage, 120 kVp; tube current, 300 mA; window center, 300; and window width, 2,000.

The DICOM data of the CT scans were imported into a three-dimensional imaging reconstruction software package (Exa Vision LITE; Ziosoft Inc., Tokyo, Japan). The 4 morphometric parameters from L1 to L5 (100 pedicles per level for a total of 500 pedicles) were measured on the 3 different planes. The linear and angular precisions of the measurements using the software are 0.01 mm and 0.01° , respectively. We defined the pedicle axis as the line bisecting the pedicle isthmus on the axial and sagittal planes. The following morphometric parameters were measured:

Transverse pedicle width

The minimum endosteal distance perpendicular to the pedicle axis on the axial plane parallel to the upper vertebral endplate (Fig. 1a).

Sagittal pedicle width

The minimum endosteal distance perpendicular to the pedicle axis on the sagittal plane parallel to the anteroposterior midline of a vertebral body (Fig. 1b).

Minimum pedicle diameter

The maximum diameter of the circle whose center is on the pedicle axis and not beyond the inner cortex of the pedicle through the oblique coronal planes that are perpendicular to the pedicle axes of both the axial and sagittal planes (Fig. 1c, the plane C in Fig. 2).

Cephalocaudal inclination (CI)

The angle made by the major axis of the pedicle section on the plane perpendicular to the pedicle axis of both the axial and sagittal planes and the line perpendicular to the upper vertebral endplate (Fig. 1c).

Statistical analysis was performed using StatView Version 5.0 (SAS Institute Inc., Cary, NC, USA). The Mann–Whitney *U* test was used to compare parameters. Results were considered statistically significant at $p < 0.05$.

Results

All measured data are shown in Table 1.

At L1 and L2, MPD was not different from TPW, but significantly smaller than SPW (MPD vs. SPW; $p < 0.0001$) (Fig. 3). At L3, L4 and L5, MPD was significantly smaller than TPW and SPW (MPD vs. TPW at L3; $p = 0.0015$, MPD vs. TPW at L4 and L5; $p < 0.0001$, MPD vs. SPW at L3, L4 and L5; $p < 0.0001$) (Fig. 3).

The CIs increased significantly towards the lower levels of the lumbar spine below L3 ($p < 0.0001$) (Fig. 4).

Simple linear regression analysis gave the following equations (y : MPD, x_t : TPW): $y = 0.911x_t + 0.108$ at L1 ($R^2 = 0.932$, $p < 0.0001$), $y = 0.913x_t + 0.134$ at L2 ($R^2 = 0.925$, $p < 0.0001$), $y = 0.813x_t + 0.631$ at L3 ($R^2 = 0.891$, $p < 0.0001$) (Fig. 5a), $y = 0.611x_t + 1.322$ at L4 ($R^2 = 0.653$, $p < 0.0001$) (Fig. 5b), and $y = 0.395x_t + 2.281$ at L5 ($R^2 = 0.447$, $p < 0.0001$) (Fig. 5c).

Simple linear regression analysis also gave the following equations (y : MPD, x_s : SPW): $y = 0.617x_s - 2.254$ at L1 ($R^2 = 0.368$, $p < 0.0001$), $y = 0.621x_s - 1.092$ at L2 ($R^2 = 0.440$, $p < 0.0001$), $y = 0.642x_s - 0.041$ at L3 ($R^2 = 0.444$, $p < 0.0001$), $y = 0.750x_s - 0.193$ at L4 ($R^2 = 0.496$, $p < 0.0001$), and $y = 0.776x_s + 0.416$ at L5 ($R^2 = 0.670$, $p < 0.0001$) (Fig. 5d).

Discussion

The findings of this study reveal that the conventionally used measurements of the TPW and SPW do not reflect the exact MPD, except in the case of the TPW at L1 and L2. This difference is due to the shape of the pedicle sections

Fig. 1 Measurement methods of morphometric parameters on the planes reconstructed by MPR-CT. **a** Transverse pedicle width on the axial plane (*double-headed arrow*). **b** Sagittal pedicle width on the sagittal plane (*double-headed arrow*). **c** This reconstructed oblique

coronal plane is perpendicular to the pedicle axis of both the axial and sagittal planes. Minimum pedicle diameter (*double-headed arrow*) and cephalocaudal inclination (angle α)

Fig. 2 The three-dimensional schema of the oblique coronal plane (C) used for the measurement of the minimum pedicle diameter. This oblique coronal plane is perpendicular both to the axial plane including the pedicle axis of the sagittal plane (A) and to the sagittal plane including the axial plane (B)

Table 1 Measurements of morphometric parameters of the lumbar pedicles

Parameter	L1	L2	L3	L4	L5
TPW (mm)					
Mean	5.46	5.76	7.25	9.01	12.86
SD	1.69	1.73	1.82	1.91	2.47
SPW (mm)					
Mean	11.89	10.44	10.23	9.36	8.95
SD	1.57	1.75	1.63	1.36	1.54
MPD (mm)					
Mean	5.09	5.39	6.52	6.83	7.36
SD	1.60	1.64	1.57	1.45	1.46
CI (°)					
Mean	3.47	5.01	18.04	39.06	51.81
SD	4.75	7.60	9.39	8.36	5.18

SD standard deviation, TPW transverse pedicle width, SPW sagittal pedicle width, MPD minimum pedicle diameter, CI cephalocaudal inclination

on the plane perpendicular to the pedicle axis, which is oval and has its major axis inclined horizontally at the lower lumbar spine, thus resulting in a large CI. On the other hand, the MPD and TPW at the upper levels were

Fig. 3 Comparison between the transverse pedicle width (TPW), sagittal pedicle width (SPW), and minimum pedicle diameter (MPD) at each level. Error bars show standard deviations. ** $p < 0.0001$, * $p = 0.0015$

Fig. 4 Cephalocaudal inclination (CI) at each level. Error bars show standard deviations. Asterisks indicate that the measurement was significantly different from that of the adjacent upper level ($p < 0.0001$)

almost the same because the major axis of the pedicle sections on that plane was almost identical to the sagittal axis, thus resulting in a small CI.

Many morphological studies of lumbar pedicles have been performed by direct measurements on cadavers [3, 6–9] or indirect measurements on plain radiographs [8, 10] and computed tomography scans [1–4, 8, 10–12]. Since CT scanning can measure inner cortical parameters, which are reported to be well correlated with those of direct cadaveric measurements [3, 4], the preoperative evaluation of lumbar pedicles using CT is currently recommended for selecting the length and diameter of the pedicle screw. Regarding the selection of the pedicle screw diameter, the measurements of the TPW on the axial plane of CT scans are recommended [1–4].

Since CT scanning techniques have already been developed, we can obtain voluntary sections using MPR.

Measurements of lumbar pedicle morphology using MPR-CT are reported to be both useful and accurate [5, 13]. Furthermore, recent research indicates that significant differences exist between the TPW and the MPD [14]. Li et al. [5] evaluated the section of the pedicle isthmus that is entirely vertical to the pedicle axis using MPR-CT; they propose that this plane is more appropriate for measuring the narrowest diameter of the lumbar pedicle than the axial plane.

In the present study, the mean MPDs were about 2.2 and 5.5 mm smaller than the mean TPWs at L4 and L5, respectively. Out of 67 pedicles with a TPW of 8 mm or larger at L4, 7 (10.4%) had a minimum pedicle width of <6 mm. In addition, at L5, out of 96 pedicles with a TPW of 8 mm or larger, 16 (16.7%) had a minimum pedicle width of <6 mm. These findings suggest that the use of pedicle screws with large diameters based on the TPW can cause perforations in the lumbar pedicles in the lower lumbar spine. The perforations of lumbar pedicles often occur in the inferior–medial or superior–lateral pedicle walls because of the inclination of the major axis of the pedicle, especially at lower levels. The former can result in injuries to the nerve roots running along the inferior–medial pedicle wall; the latter can lead to weak pullout strength and load sharing [15]. Therefore, we strongly suggest that surgeons should not select the maximum pedicle screw diameter simply on the basis of the TPW in the lower lumbar spine.

It is desirable to select a pedicle screw with an optimal diameter by evaluating the MPD for a given pedicle, whereas we are compelled to pay substantial amount of effort for the CT reconstruction and the measurement. However, there is no concise index for optimal pedicle screw diameter calculation based on a correlational analysis between the MPD and conventionally measured pedicle parameters.

To the best of our knowledge, this is the first report to propose an index for the selection of an optimal pedicle screw diameter based on linear regression analysis. The indices for selecting an optimal pedicle screw diameter based on measurements of the conventional TPW are as follows (y : optimal screw diameter, x_t : TPW): $y = 0.9x_t + 0.1$ at L1 and L2, $y = 0.8x_t + 0.6$ at L3, $y = 0.6x_t + 1.3$ at L4, and $y = 0.4x_t + 2.3$ at L5. At L5, the determination coefficient from the simple linear regression analysis between the TPW and MPD was weaker than those at the other levels. Therefore, the index for the screw diameter based on the SPW may be more appropriate for calculating the optimal pedicle screw size at L5 using the following equation (y : optimal screw diameter, x_s : SPW): $y = 0.8x_s + 0.4$.

The limitations of our study are as follows. We assumed that the pedicle screws were inserted along the pedicle axis

Fig. 5 Correlations between the minimum pedicle diameter (MPD) and transverse pedicle width (TPW) at L3 (a), L4 (b), and L5 (c) and between the MPD and sagittal pedicle width (SPW) at L5 (d)

in this study. When the practical entry point or direction differs from those of the pedicle axis, the practical MPD along the pathway of the pedicle screws may be smaller than the MPD. In such cases, we should use smaller pedicle screws.

Conclusions

We measured the MPD of lumbar pedicles using MPR-CT and analyzed its correlation with the TPW and SPW. The MPD was approximately equal to the TPW at L1 and L2, whereas it was significantly smaller at L3, L4, and L5. The MPD was significantly smaller than the SPW at all levels. This is the first report demonstrating a relationship between the TPW and MPD measured on a plane reconstructed using MPR-CT in the lumbar spine. Surgeons should consider these differences when selecting lumbar pedicle screw diameters especially at the lower levels.

Conflict of interest None.

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