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Clinical Article

Pedicle Morphometry for Thoracic Screw Fixation in Ethnic Koreans : Radiological Assessment Using Computed Tomographic Myelography

Yong Soo Choi, M.D.,[1] Young Jin Kim, M.D., Ph.D.,[1] Hyeong-Joong Yi, M.D., Ph.D.,[2] Young-Joon Kim, M.D., Ph.D.[1]
Department of Neurosurgery,[1] Dankook University College of Medicine, Cheonan, Korea
Department of Neurosurgery,[2] Hanyang University Medical Center, Seoul, Korea

Objective : In the thoracic spine, insertion of a pedicle screw is annoying due to small pedicle size and wide morphological variation between different levels of the spine and between individuals. The aim of our study was to analyze radiologic parameters of the pedicle morphometry from T1 to T8 using computed tomographic myelography (CTM) in Korean population.
Methods : For evaluation of the thoracic pedicle morphometry, the authors prospectively analyzed a consecutive series of 26 patients with stable thoracic spines. With the consent of patients, thoracic CTM were performed, from T1 to T8. We calculated the transverse outer diameters and the transverse angles of the pedicle, distance from the cord to the inner cortical wall of the pedicle, and distance from the cord to the dura.
Results : Transverse outer pedicle diameter was widest at T1 (7.66 ± 2.14 mm) and narrowest at T4 (4.38 ± 1.55 mm). Transverse pedicle angle was widest at T1 (30.2 ± 12.0°) and it became less than 9.0° below T6 level. Theoretical safety zone of the medial perforation of the pedicle screw, namely, distance from the cord to inner cortical wall of the pedicle was more than 4.5 mm.
Conclusion : Based on this study, we suggest that the current pedicle screw system is not always suitable for Korean patients. Computed tomography is required before performing a transpedicular screw fixation at the thoracic levels.

KEY WORDS : Korean · Thoracic vertebrae · Pedicle screw · Safety zone.

INTRODUCTION

Transpedicular screw fixation is a commonly used surgical procedure correcting spinal instability caused by fracture, tumor, deformity, or degenerative disease[17,20]. Although pedicle screw instrumentation has been popular for use in the lumbar spine for decades, its use in the thoracic spine remains restricted because of technical and anatomical pitfalls specific to the upper thoracic spine. The use of pedicle screw in the thoracic spine can sometimes cause an unacceptable screw position, because diameter of the thoracic pedicle is too small and variable compared to the standard lumbar pedicle[3,4,10,22].

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• Address for reprints : Young Jin Kim, M.D., Ph.D.
Department of Neurosurgery, Dankook University College of Medicine,
San 29 Anseo-dong, Cheonan 330-714, Korea
Tel : +82-41-550-3979, Fax : +82-41-552-6870
E-mail : spine1225@yahoo.co.kr

In a study performed by Fisher et al.[4], the authors reported that 68 pedicle screws (33.8%) violated the pedicle wall among of the 201 pedicle screws inserted into the thoracic spine and of these perforations, 36 (52.9%) were lateral, 27 (39.7%) were medial, and 5 (7.4%) were anterior perforations. The breach rate still reaches 7.5%, despite the emergence of navigation techniques to avoid misplacement[16]. In spite of these anatomical constraints in the thoracic spine, however, there have been few analyses on the thoracic pedicle morphometry.

The aim of our study was to establish radiologic parameters of the pedicle morphometry from T1 to T8 using computed tomographic myelography (CTM) in Korean population. Also, we suggest the "theoretical safety zone" of the medial perforation upon thoracic pedicle screw fixation on the basis of the present analysis. To our knowledge, it is the first report that the morphological characteristics of pedicles at the thoracic level have been study using thoracic CTM on a prospective basis.

MATERIALS AND METHODS

This study was a prospective evaluation of patients with stable thoracic spines. Twenty-six patients who were evaluated with CTM for diagnosis and surgical planning in the degenerative lumbar lesions were included and allowed into the study. All patients with unstable thoracic spine and previous thoracic lesion were excluded from this study. All 26 patients with lumbar lesions underwent myelography to evaluate the extent of their nerve root compression, or narrowing of spinal canal, in the upright position. The authors examined thoracic and lumbar CT scans using spiral CT (GE, VCT, Milwaukee, WI, USA) after obtaining myelography, with the consent of patients without additional charge. Thin-slice thoracic CT scans were conducted as 3 mm sections.

Transverse outer pedicle diameter (TOPD) is the smallest diameter of the pedicle on axial CT image which showed exact middle pedicle transversely. Transverse pedicle angle (TPA) is the TPA measured from the midline to the mid-axis of the pedicle. Epidural space (EDS) is the shortest distance from the dura to the transverse inner pedicle wall. Subdural space (SDS) is distance from the dura to spinal cord which was measured transversely at axial CT image (Fig. 1). Independent two physicians repeatedly measured the parameters. We calculated the mean value after adding right to left values which was measured three times.

Digital calipers of the PACS program (MultiVox.NET, TechHeim, Seoul, Korea), calibrated to an accuracy of 0.01 mm, were used for measurement of each parameter. Statistical analyses were performed using SPSS, version 9.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Patient demographics

Twenty-six patients were enrolled into the study; 8 were female and 18 were male. The mean age of participants was 38.3 years (range 18-51). There were 19 cases of herniated lumbar disc (HLD) and 7 cases of lumbar stenosis, including 5 cases of recurrence. Four patients were from the final analysis due to diagnoses of ankylosing spondylitis; incidental primary osseous tumor and poor CT scan images such as blurring and tilting were found.

Transverse outer pedicle diameter and transverse angle of the pedicle

The largest mean TOPD from T1 to T8 was 7.66 ± 2.14 mm at T1 level. The smallest mean pedicle diameter was 4.38 ± 1.55 mm at T4 level. The diameters become smaller from T1 to T4 level and gradually increase below T5 level. The largest mean transverse angle of the pedicle was 30.2 ± 12.0° at T1 level. Mean TPAs become smaller at lower levels of the thoracic spine (Table 1).

EDS, SDS and theoretical safety zone

The distance from the dura to the transverse inner pedicle wall is the EDS.

Based on our study, the mean distance from the pedicle inner cortical wall to the dura ranged from 1.40 mm to 1.94 mm. Distance from the dura to spinal cord is SDS. The mean distances from the dura to spinal cord range

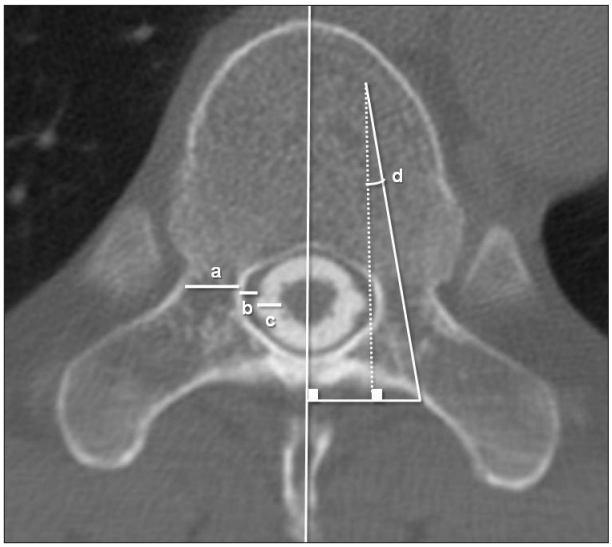

Fig. 1. An axial section of the computed tomographic myelogram scan shows the method of measuring radiological parameters for the pedicle morphometry. a : transverse outer pedicle diameter (TOPD), b : epidural space (EDS), c : subdural space (SDS), d : transverse pedicle angle (TPA).

Table 1. Results of measuring radiological parameters of the current study (mean ± 2SD)

Level	TOPD (mm)	TPA (°)	EDS (mm)	SDS (mm)	EDS + SDS (mm)
T1	7.66 ± 2.14	30.2 ± 12.0	1.94 ± 0.31	4.41 ± 1.72	6.35 ± 1.96
T2	6.36 ± 1.81	18.4 ± 10.0	1.72 ± 0.44	3.27 ± 1.51	4.99 ± 1.82
T3	4.71 ± 1.49	12.5 ± 6.5	1.47 ± 0.51	3.06 ± 1.38	4.53 ± 1.65
T4	4.38 ± 1.55	11.0 ± 5.9	1.41 ± 0.37	3.11 ± 1.12	4.52 ± 1.47
T5	4.49 ± 1.46	9.4 ± 4.7	1.40 ± 0.61	3.31 ± 1.68	4.71 ± 2.09
T6	4.67 ± 1.92	8.8 ± 4.2	1.46 ± 0.32	3.16 ± 1.25	4.62 ± 1.38
T7	4.89 ± 2.19	8.7 ± 5.4	1.50 ± 0.52	3.30 ± 1.42	4.80 ± 1.87
T8	5.23 ± 2.25	8.5 ± 3.9	1.46 ± 0.65	3.19 ± 1.32	4.65 ± 1.93

EDS : epidural space (distance from the dura to the transverse outer pedicle wall), EDS+SDS : theoretical safety zone (distance from the cord to transverse outer pedicle wall), SD : standard deviation, SDS : subdural space (distance from the dura to the cord), TOPD : transverse outer pedicle diameter, TPA : transverse pedicle angle

between 3.06 mm and 4.41 mm. Theoretical safety zone of the medial perforation is EDS added to SDS. The largest mean distance was 6.35 ± 1.96 mm at T1 level and the smallest mean distance was 4.52 ± 1.47 mm at T4 level (Table 1).

DISCUSSION

Pedicle screw fixation of the thoracic spine has become a popular method for surgical treatment in traumatic instability, tumor, deformity, and degenerative disease. Biomechanically, it is better than hooks and rod systems, and it allows application of meaningful correct forces. However, misplacement of the thoracic pedicle screw occurs sometimes[3,4,8,10,13,20,21,22]. The risk from the pedicle violation of the screw is higher because the thoracic pedicles are smaller and variable compared with lumbar pedicles. It is hardly surprising that the rate of reported pedicle wall perforation in the thoracic spine ranges from 15.9 to 54.7%[1,8,13,21]. Despite the difficulty in precise instrumentation, there are few reports on analysis of the thoracic pedicle morphometry. Moreover, most studies were focused on cadavers or on dry human bones[2,12,14,15,19].

After analyzing pedicle width, pedicle height, and coaxial depth from the lamina to anterior vertebral cortex of individual T1-T6 vertebrae obtained from 18 human cadavers, McLain et al.[14] suggested that mean pedicle diameter in thoracic levels (T1-T6) exceeded 5 mm and that these diameters uniformly decreased as specimens were taken caudally from T2 level. However, there were some limitations in their study. They analyzed human cadavers, ages 62 from 82 years at the time of death. According to the previous report, age has been considered an important variable in describing the pedicular morphometry[9,23]. Moreover, the cadavers which were older-aged at death, may be osteoporotic or osteopenic. Vertebrae of the cadavers soaked in formalin for a long time may be friable and brittle. The demineralized vertebrae that can be easily broken, may exert a negative effect on measuring for the thoracic pedicle morphometry. However, in our study, young adults without thoracic lesion were selected. Additionally, accurate digital calipers were used for measurement of the radiologic parameters.

There are several techniques to prevent a pedicle from being perforated by the screw[5-8]. Kim et al.[8] evaluated the accuracy of image-guided thoracic pedicle screw placement *in vitro* and *in vivo*. Although the accuracy of thoracic pedicle screw placement is improved with the use an image-guidance system, pedicle violations still happened in 6.7% *in vivo* and in 19.2% *in vitro*. Husted et al.[7] introduced an alternative method of extrapedicular screw insertion within the pedicle rib unit. Although this method have marked difference in size of the pedicle rib unit as compared with both transverse width of the pedicle and chord length, there is a potential risk such as penetration of surrounding structures, such as great vessels.

It is known that pedicular morphometric characteristics vary in different population groups[1,2,9,11]. Kim et al.[9] reported that a statistical difference exists between the transverse diameter of the pedicles of Caucasians and Koreans. In response, they concluded that the use of the pedicle screws in Asians is questionable. Datir and colleagues[2] reported that there is a difference between population of Indian ethnicity and other Caucasian populations in pedicle size, and that variations in different population groups should be considered when considering the use of thoracic pedicle screw fixation. However, Liau and colleagues[9] suggested that the differences in pedicle size compared to Caucasians could be attributed to the overall shorter body stature of Asians. They insisted that it is the height, rather than the ethnicity of the patient, that is responsible for the variation in the pedicle size among different ethnic groups.

It is controversial as to whether there is a difference in the transverse diameter of the pedicle between males and females, however there was no difference in the transverse diameter of the pedicle between right and left sides[9,12,15,18].

In this study, similar to other studies, TOPD was shown a decreasing dimension from T1-T4 followed by an increasing dimension from T5-T8[1,9,12,14,15,18]. Fig. 2. illustrates the percentage of TOPD in T1-T8, less than 4.0 mm compared with other studies. Surprisingly, 36% of T4 and 34% of T5 were less than 4.0 mm, and this means that it is not always feasible in conduct a current standard pedicle screw system except T1, T2, and lower thoracic level. Table 2

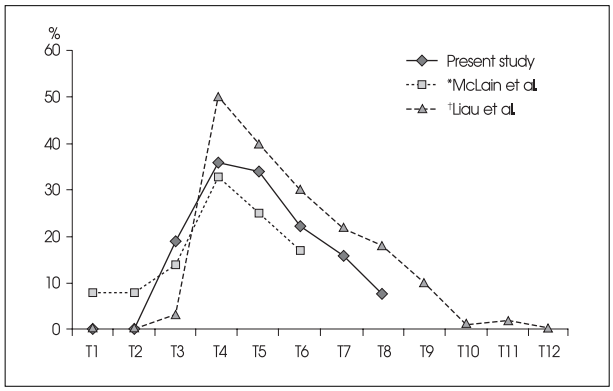

Fig. 2. Percentage of TOPD, which was less than 4.0 mm compared with other studies. *McLain et al.[14] : percentage of transverse outer pedicle diameter less than 4.5 mm in T1-T6. †Liau et al.[11] : percentage of transverse outer pedicle diameter less than 4.5 mm in T1-T12 in male.

Table 2. Minimum diameters of the standard screws routinely used

Screws	Min. Ø of screw (mm)
CD Horizon® Legacy™ spinal system, Medtronic	4.0
Xia® screw system, Stryker	4.5
Universal spine system, Synthesis GMBH	5.0
Gold pedicle screw system, GS Medical	4.5
Global spine screw set, U&I	4.0
4CIS pedicle screw system, Solco biomedical	4.5

Min. : minimum, Ø : diameter

demonstrates the size of the standard pedicle screw generally used for the thoracic lesion. The majority was measured above 4 mm in size. The authors suggest that 3.0 mm or 3.5 mm screw, which considered biomechanical study for strength force and load sharing, is designed for thoracic pedicle screw fixation.

Another outstanding feature regards the measurement of epidural space EDS (distance from the dura to transverse inner pedicle wall) and SDS (distance from the dura to spinal cord) using CTM. The theoretical safety zone of the medial perforation is equal EDS added to SDS. The largest mean distance is 6.35 ± 1.96 mm at the T1 level and the smallest mean distance is 4.52 ± 1.47 mm at T4 the level (Table 1). We suggest that 4.5 mm is a theoretical "safety zone" before neurological problems arise. To our knowledge, this is first prospective study performed to evaluate the safety zone of the medial perforation in the thoracic pedicle screw fixation, using CTM.

There are several limitations to this study. We did not account for the fact that cerebrospinal fluid (CSF) flows in the dural sac. The spinal cord is constantly bathed in the movement of CSF. Two dimension sections of CTM for measuring the parameters are just real time image at examination. Therefore, this "safety zone" is confined to the imaginary, not practical context. In addition, there is a potential for underestimating transverse diameter values by CT scans. It is thought to result from the average volume measured by analyzing the transverse image of a convex pedicle. Third, there might be inter-observer error.

Transpedicular screw placement is not always possible in thoracic vertebrae. Therefore, preoperative CT evaluation is recommended for prospective candidates of thoracic pedicle screw fixation.

CONCLUSION

This study was a prospective evaluation of patients with lumbar lesions, but with stable thoracic spines. It might be not always suitable to utilize the current standard pedicle screw system. We suggest that 4.5 mm (EDS + SDS) is a theoretical "safety zone" in the medial perforation in thoracic pedicle screw fixation before neurological problems occur. Information of relevant diameters, distance from cord to pedicle inner wall and angle of each pedicle will be of great help to the spine surgeon.

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