Acta Med. Okayama, 2010
Vol. 64, No. 5, pp. 293–297

Acta Medica Okayama
http://escholarship.lib.okayama-u.ac.jp/amo/

Original Article

Upper Lumbar Pedicle Screw Insertion Using Three-Dimensional Fluoroscopy Navigation: Assessment of Clinical Accuracy

Yoshihisa Sugimoto[a]*, Yasuo Ito[a], Masao Tomioka[b], Tetsuya Shimokawa[a], Yasuyuki Shiozaki[a], Tetsuro Mazaki[a], and Masato Tanaka[c]

[a]*Department of Orthopaedic Surgery, Kobe Red Cross Hospital, Kobe 651–0073, Japan,*
[b]*Department of Orthopaedic Surgery, Hyogo Emergency Medical Center, Kobe 651–0073, Japan,*
and [c]*Department of Orthopaedic Surgery, Okayama University Hospital, Okayama 700–8558, Japan*

We used a navigation system to insert 128 pedicle screws into 69 vertebrae (L1 to L3) of 49 consecutive patients. We assessed the pedicle isthmic width and the permission angle for pedicle screw insertion. The permission angle is the angle defined by the greatest medial and lateral trajectories allowable when placing the screw through the center of the pedicle. The rate of narrow-width pedicles (isthmic width less than 5 mm) was 5 of 60 pedicles (8%) at L1, 4 of 60 pedicles (7%) at L2, and none (0%) at L3, L4 and L5. The rate of narrow-angle pedicles (a permission angle less than 15 degrees) was 21 of 60 pedicles (35%) at L1, 7 of 60 (12%) at L2, 3 of 60 (5%) at L3, and none (0%) at L4 and L5. Of 128 pedicle screws inserted into 69 vertebrae from L1 to L3, 125 (97.7%) were classified as Grade 1 (no pedicle perforation). In general, the upper lumbar vertebrae have more narrow-width and -angle pedicles. However, we could reduce the rate of pedicle screw misplacement in upper lumbar vertebra using a three-dimensional fluoroscopy and navigation system.

Key words: upper lumbar, navigation, pedicle screw, anatomy, misplacement

Although pedicle screw fixation is essential to the reconstruction of spinal disorders, misplacement of these screws can cause neurologic and vascular injury. It is especially difficult to achieve correct screw placement in the upper lumbar vertebrae, due, in part, to the narrowness of the upper lumbar pedicles [1, 2]. Rampersaud *et al.* reported that the pedicle screw misplacement rate was higher in the upper than in the lower lumbar vertebrae [3]. Ofiram *et al.* showed that the upper lumbar spine had narrower pedicles than the lower thoracic spine, making pedicle screw insertion in the upper lumbar vertebrae more difficult [4].

Recently, several authors have reported on the usefulness of spinal navigation systems [5–8]. Navigation systems improve the accuracy of pedicle screw insertion [5–7], and they have made it possible for intraoperative three-dimensional assessment (axial, sagittal, and coronal) of pedicle screw trajectory. Three-dimensional fluoroscopy is the newest navigation system, and is superior to conventional CT-based imaging because anatomic registration is not required [6, 9, 10]. Furthermore, the intraoperative real-time position of the spine can be updated with this system.

We hypothesized that upper lumbar pedicle screws were easy to misplace due to the narrowness of pedicle, and that this navigation system would help us to insert upper lumbar pedicle screws correctly. This study had 2 objectives. First, we took anatomical

Received January 29, 2010; accepted June 8, 2010.
*Corresponding author. Phone: +81–86–223–9727; Fax: +81–86–235–7273
E-mail: yoshihisa64@hotmail.com (Y. Sugimoto)

measurements of the L1 to L5 pedicles and studied the characteristics of the upper lumbar spine. Second, we assessed the accuracy of upper lumbar (L1-3) pedicle screws that were placed using the three-dimensional fluoroscopy and navigation system.

Patients and Methods

We prospectively inserted 128 pedicle screws into 69 vertebrae (L1 to L3) of 49 consecutive patients using a 3D fluoroscopy navigation system. Screws were placed into 32 pedicles at L1, 46 pedicles at L2, and 50 pedicles at L3. There were 31 men and 18 women with an average age at examination of 54 years (range 16 to 86 years). In this series, 28 patients had spinal trauma, 19 had degenerative disorders, and 2 had metastatic bone tumors. Screws inserted into vertebrae with burst fractures, pedicle fractures, and tumor invasion were excluded. No patients in this study had idiopathic scoliosis with vertebral rotation.

Anatomical measurement of L1 to L5 pedicles. For anatomical evaluation, we chose 30 vertebrae each from L1 to L5 (total 150 vertebrae) in good condition examined by fine cut (1.25 mm) CT. All CT scans were made prior to pedicle screw insertion. Patients less than 18 years old, those who had degenerative scoliosis or compression fracture secondary to osteoporosis, and those in whom the pedicle view was oblique were excluded. We measured the distance of the short axis of the pedicle using coronal reconstructed CT. As Robertson *et al.* point out in their report, conventional axial CT is not suitable for evaluating pedicle diameter because the pedicle is tilted, especially at L4 and L5 (Fig. 1) [11]. We did not measure the pedicle transverse width, but, rather, the isthmic width (Fig. 1) using coronal reconstructed CT. We also assessed the permission angle for pedicle screw insertion (Fig. 2). This is the angle defined by the most medial insertion line or trajectory allowable when placing the screw through the center of the pedicle and the most lateral insertion line or direction allowable. The pedicle screw trajectory was chosen so as not to perforate the pedicle and the lateral wall of the vertebra. The most medial trajectory was chosen

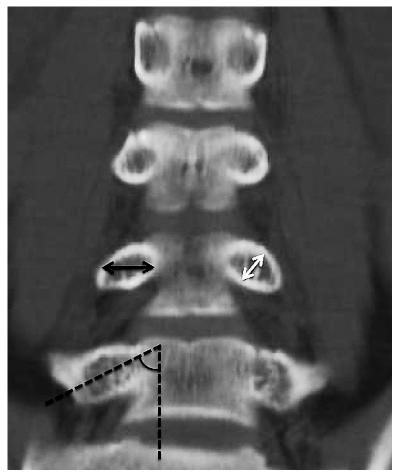
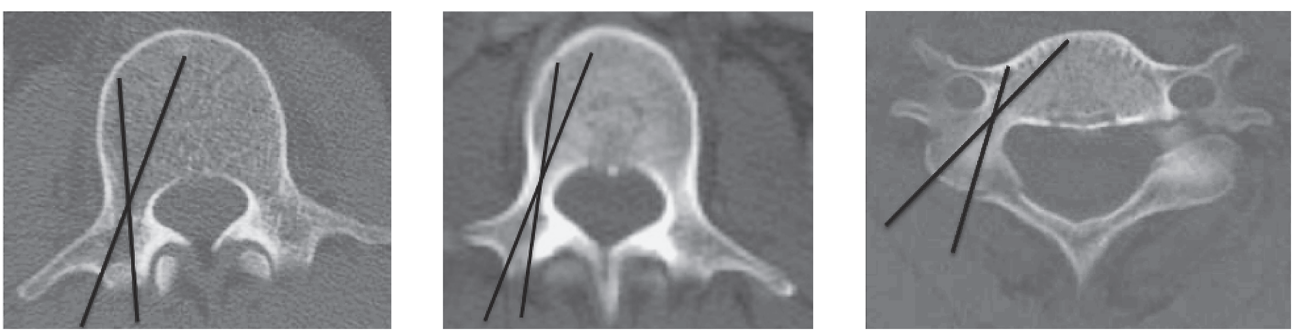


Fig. 1 Anatomical measurement using coronal CT.
Black arrow, pedicle transverse width; White arrow, pedicle isthmic width; Black dotted line, pedicle tilt angle.



A B C

Fig. 2 Pedicle screw permission angle.
The permission angle is the angle defined by the most medial insertion line or trajectory allowable when placing the screw through the center of the pedicle and the most lateral insertion line or direction allowable.
A, normal L1 vertebra; **B**, an L1 vertebra having a narrow pedicle and narrow permission angle; **C**, a C6 vertebra having a narrow pedicle but relatively wide permission angle.

Table 1 Anatomical measurement of L1 to L5 pedicle

	isthmic width (mm)	tilt angle (degree)	permission angle (degree)	narrow width (%)	narrow angle (%)
L1	7 (3 to 11)	2 (−6 to 10)	16 (8 to 22)	8	35
L2	8 (4 to 14)	5 (−6 to 24)	18 (11 to 28)	7	12
L3	9 (6 to 14)	20 (−2 to 47)	19 (13 to 23)	0	5
L4	10 (8 to 14)	46 (13 to 67)	23 (18 to 28)	0	0
L5	10 (7 to 15)	58 (44 to 83)	25 (19 to 23)	0	0

Data of isthmic width, tilt angle and permission angle was showed by average.
( ) indicates range.
Narrow width: mean pedicle isthmic diameter is less than 5 mm.
Narrow angle: mean pedicle permission angle is less than 15 degrees.

so as not to pass through the midline of the vertebral body.

A narrow pedicle could make it very difficult to place a screw correctly without a navigation system. In this study of L1 to L5 vertebrae, we defined a narrow pedicle as a) pedicle isthmic width less than 5 mm, and/or b) a permission angle less than 15 degrees.

Assessment for pedicle screw insertion. A dynamic reference arc was attached to the spinous process of interest. Three-dimensional fluoroscopy (Siremobile Iso-C3D, Siemens Medical, Erlangen, Germany) then acquired multiple successive images as it performed an automated 190° rotation around the patient in 120 sec. During this period, the surgeon can step away from the operating field to reduce radiation exposure. These images can be obtained using a high-resolution technique (100 images in a 2-min cycle). After image acquisition, the Stealth Station (Medtronic Surgical Navigation Technologies, Louisville, CO, USA) generated axial, sagittal, and coronal reconstructions of the imaged anatomy, and screw trajectory planning proceeded in a manner similar to that used for standard CT-based image guidance.

We obtained a postoperative fine-cut (1.25-mm) CT scan in all patients. After acquiring an axial image, including the whole length of each screw, the medial and lateral deviation of the screw was classified into 3 grades: Grade 1, screw threads just barely cut into the cortex; Grade 2, screw perforation of the cortex by up to 2 mm; and Grade 3, screw perforation of the cortex by > 2 mm.

Results

Anatomical measurement of L1 to L5 pedicle. Average pedicle isthmic width (Fig. 1) as measured using coronal CT was 7 mm (range 3 to 11) at L1, 8 mm (range 4 to 14) at L2, 9 mm (range 6 to 14) at L3, 10 mm (range 8 to 14 mm) at L4, and 10 mm (range 7 to 15) at L5 (Table 1). Average pedicle tilt angle as measured on the coronal CT (Fig. 1) was 2 degrees (range −6 to 10 degrees) at L1, 5 degrees (range −6 to 24 degrees) at L2, 20 degrees (range −2 to 47 degrees) at L3, 46 degrees (range 13 to 67 degrees) at L4, and 58 degrees (range 44 to 83 degrees) at L5. The average permission angle (Fig. 2) was 16 degrees (range 8 to 22) at L1, 18 degrees (range 11 to 28) at L2, 19 degrees (range 13 to 23) at L3, 23 degrees (range 18 to 28) at L4, and 25 degrees (range 19 to 23) at L5.

The number of narrow-width pedicles (isthmic width less than 5 mm) was 5 of 60 pedicles (8%) at L1, 4 of 60 pedicles (7%) at L2, and none (0%) at L3, L4 and L5. The number of narrow-angle pedicles (permission angle less than 15 degrees) was 21 of 60 pedicles (35%) at L1, 7 of 60 (12%) at L2, 3 of 60 (5%) at L3, and none (0%) at L4 and L5. Eight of the 9 narrow-width pedicles were also classified as narrow-angle pedicles.

Assessment for pedicle screw insertion. Of 128 pedicle screws inserted into 69 vertebrae from L1 to L3, 125 (97.7%) were classified as Grade 1 (no pedicle perforation), and 3 of 128 screws (2.3%) were classified as Grade 2 (Table 2). Complications such as neurological injury and vascular injury were not observed in any patients.

Table 2 Accuracy of pedicle screw insertion

	L1	L2	L3
grade 1	31	45	49
grade 2	1	1	1
grade 3	0	0	0
total	32	46	50

Grade 1: screw threads just cut into the cortex
Grade 2: screw perforation of the cortex by up to 2mm
Grade 3: screw perforation of the cortex by > 2mm

Discussion

The width of the upper lumbar pedicles is narrower than those of the lower thoracic and lower lumbar pedicles [1, 4, 11]. In this study, the average pedicle isthmic width measured on coronal CT was 7mm at L1, 8mm at L2, 9mm at L3, 10mm at L4, and 10mm at L5. Furthermore, the number of narrow pedicles (isthmic width less than 5mm) was 5 of 60 (8%) at L1, 4 of 60 (7%) at L2, and none (0%) at L3, L4 and L5. Because of the narrow width, the pedicle screw misplacement rate is generally higher in the upper lumbar than in the lower thoracic or lower lumbar vertebrae [3, 4]. Rampersaud *et al.* reported that their pedicle screw misplacement rates when using fluoroscopic navigation were 29% at L1, 19% at L2, 13% at L3, 12% at L4 and 4% at L5 [3].

Our study demonstrated a small permission angle for pedicle screw insertion in the upper lumbar pedicles. The average permission angle was 16 degrees at L1, 18 degrees at L2, 19 degrees at L3, 23 degrees at L4, and 25 degrees at L5 (Table 1). The number of narrow pedicles (permission angle less than 15 degrees) was especially high in these upper lumbar vertebrae: 21 of 60 pedicles (35%) at L1, 7 of 60 (12%) at L2, 3 of 60 (5%) at L3, and none (0%) at L4 and L5. In the cervical spine, pedicles are narrow, but the permission angles are relatively large (Fig. 2). However, small isthmic widths in the upper lumbar pedicles corresponded to small permission angles in this study, so we sometimes encountered screw insertion difficulty in the upper lumbar pedicles even when using the navigation system.

In this study, 128 pedicle screws were inserted into 69 vertebrae from L1 to L3, of which 125 (97.7 %) were classified as Grade 1 (no pedicle perforation). We considered clinically significant screw deviation in this study to be Grade 3, and since none of our screws were misplaced to this degree, our series had a misplacement rate of 0%. Several authors have reported that navigation systems reduce pedicle screw perforation compared with the freehand technique [5-7]. We had a misplacement rate of 2.8 % in cervical pedicle screw insertion using the Iso-C3D navigation system using same criteria [8]. Kotani *et al.* reported that the perforation rate of pedicle screws placed in scoliosis patients was 11% in the freehand technique group and 1.8% in the CT-based navigation system group (in that study, exposure of one-fourth of the screw thread was defined as screw perforation) [11]. Rajasekaran *et al.* assessed 478 thoracic pedicle screws inserted in patients with spinal deformity and showed that there were 54 (23%) pedicle breaches in the non-navigation group compared to only 5 (2%) in the navigation group (Iso-C3D) [6].

Lumbar pedicle widths have generally been measured using axial CT [1, 3, 4]; however, there are 2 problems with this method. First, the transverse width measured by axial CT is not always an accurate pedicle isthmic width [11, 12]; L4 and L5 pedicles, especially, have a large tilt in the coronal plane [11]. This study also showed that the average pedicle tilt angle as measured in the coronal CT was 2 degrees at L1, 5 degrees at L2, 20 degrees at L3, 46 degrees at L4, and 58 degrees at L5. Therefore, the pedicle isthmic width should not be measured by axial CT but by coronal reconstructed CT [12]. Second, when we measured pedicle width using conventional axial CT during preoperative planning, we sometimes underestimated the pedicle width because an axial CT slice can shift above or below the actual center of the pedicle. One of the advantages of navigation-based surgery is that we can choose an accurate pedicle screw diameter and trajectory by voluntary slice using 3D data.

References

1. Mitra SR, Datir SP and Jadhav SO: Morphometric study of the lumbar pedicle in the Indian population as related to pedicular screw fixation. Spine (2002) 27: 453-459.
2. Kim NH, Lee HM, Chung IH, Kim HJ and Kim SJ: Morphometric study of the pedicles of thoracic and lumbar vertebrae in Koreans. Spine (1994) 19: 1390-1394.
3. Rampersaud YR, Pik JH, Salonen D and Farooq S: Clinical accu-

racy of fluoroscopic computer-assisted pedicle screw fixation: a CT analysis. Spine (2005) 30: E183–190.

4. Ofiram E, Polly DW, Gilbert TJ Jr and Choma TJ: Is it safer to place pedicle screws in the lower thoracic spine than in the upper lumbar spine? Spine (2007) 32: 49–54.
5. Laine T, Lund T, Ylikoski M, Lohikoski J and Schlenzka D: Accuracy of pedicle screw insertion with and without computer assistance: a randomised controlled clinical study in 100 consecutive patients. Eur Spine J (2000) 9: 235–240.
6. Rajasekaran S, Vidyadhara S, Ramesh P and Shetty AP: Randomized clinical study to compare the accuracy of navigated and non-navigated thoracic pedicle screws in deformity correction surgeries. Spine (2007) 32: E56–64.
7. Kotani Y, Abumi K, Ito M, Takahata M, Sudo H, Ohshima S and Minami A: Accuracy analysis of pedicle screw placement in posterior scoliosis surgery: comparison between conventional fluoroscopic and computer-assisted technique. Spine (2007) 32: 1543–1550.
8. Ito Y, Sugimoto Y, Tomioka M, Hasegawa Y, Nakago K and Yagata Y: Clinical accuracy of 3D fluoroscopy-assisted cervical pedicle screw insertion. J Neurosurg Spine (2008) 9: 450–453.
9. Holly LT and Foley KT: Percutaneous placement of posterior cervical screws using three-dimensional fluoroscopy. Spine (2006) 31: 536–540.
10. Euler E, Heining S, Riquarts C and Mutschler W: C-arm-based three-dimensional navigation: a preliminary feasibility study. Comput Aided Surg (2003) 8: 35–41.
11. Robertson PA and Stewart NR: The radiologic anatomy of the lumbar and lumbosacral pedicles. Spine (2000) 25: 709–715.
12. Li B, Jiang B, Fu Z, Zhang D and Wang T: Accurate determination of isthmus of lumbar pedicle: a morphometric study using reformatted computed tomographic images. Spine (2004) 29: 2438–2444.