Cervical pedicle screw insertion using a computed tomography cutout technique

Technical note

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Object. The pedicle screw has been reported to provide the strongest fixation for the cervical spine, but there is a possibility of malpositioning the screws, which may cause fatal complications such as vertebral artery and neural injuries. Using the conventional freehand technique, between 6.7 and 29% of the screws have been found to be malpositioned. If an accurate entry point and insertion trajectory through the isthmus of the pedicle can be maintained during surgery, safer insertion of the pedicle screw should be achieved. The authors have developed a new pedicle screw insertion method, called the “CT cutout” technique, and report on the technical and clinical aspects of this new technique in terms of accuracy.

Methods. A total of 130 pedicle screws were inserted from C-2 to T-1 in 29 consecutive patients using the new technique. In the CT cutout technique, a CT slice of every vertebra in which the authors intended to insert pedicle screws was captured from 3D CT images of the cervical spine with the gantry parallel to the pedicle. A life-sized CT image was developed for each level, and the desired insertion line, passing through the middle of the isthmus, was drawn on the image. The images were then cut along the insertion line and the posterior margin of the lamina, and sterilized. During surgery, the proper cephalocaudal entry point was determined using a lateral fluoroscopic image, the CT cutout was placed on the posterior surface of the lamina, and the appropriate entry point and trajectory of pedicle screw insertion were chosen with reference to the CT cutout. The percentage of malpositioned pedicle screws and the deviation between the intended entry point and angle of the pedicle screw, and those that were achieved in practice, was investigated using postoperative CT images.

Results. Three perforations (2.3%) in which more than half a screw diameter was exposed outside the pedicle, and 2 penetrations (1.5%) in which a screw diameter was completely exposed, were identified on the postoperative CT images. All breaches were directed laterally. No neural or vascular injuries were observed. The deviation between the intended entry point and angle of the pedicle screw and the actual values was 0.20 ± 0.75 mm and 1.46 ± 4.21°, respectively.

Conclusions. Several techniques for pedicle screw insertion such as computer-assisted navigation, CT-based navigation, and acquisition of fluoroscopic intraoperative pedicle axis views have been used for improving accuracy. However, there remains a possibility of misplacement, and these costly procedures often require delivery of a high x-ray dose to both patients and surgeons, and/or time-consuming configuration of reference points during surgery. The CT cutout technique is an easy, low-cost procedure that can be performed with the aid of single-plane fluoroscopy and without the need of configuration. This new technique shows great promise for safe pedicle screw insertion for the cervical spine. (DOI: 10.3171/2009.6.SPINE09352)

Key Words • surgical technique • cervical spine • pedicle screw fixation • computed tomography cutout • accuracy

Use of the pedicle screw for the cervical spine has been reported to provide stronger fixation than alternative methods, such as use of the lateral mass screw and transarticular screw for the middle/lower cervical spine.2,3,8 However, proper insertion of the pedicle screw appears to be technically difficult, and several arguments against the use of pedicle screws have been proposed: 1) it is difficult to identify the proper insertion point and trajectory of the screws because the posterior aspect of the lamina has few anatomical landmarks; 2) the pedicle is a tiny structure in the middle/lower cervical spine; and 3) misplacement of the screw may cause catastrophic complications such as vertebral artery and spinal cord/nerve root injuries because such organs are adjacent to the pedicle. A screw perforation incidence rate of 6.7–29% has been reported using the manual (freehand) screw insertion technique,1,2,6,12 and such malpositioning is reported to likely occur from C-3 to C-6, where the pedicle diameter is relatively small.5,6 Nevertheless, in the pedicle screw insertion technique, the proper cephalocaudal point is relatively easily determined by intraoperative lateral fluoroscopic imag-
Therefore, if the proper insertion point (where the line passing the center of the isthmus of the pedicle and the posterior margin of the lamina cross) and the proper insertion trajectory of this line can be determined on the axial plane (Fig. 1) during surgery, insertion of the pedicle screw should become easier and safer. Based on this principle, the authors introduce a new pedicle screw insertion technique using life-sized CT images, on which the proper insertion point and angle are indicated, as an intraoperative reference tool. In this technique, the CT image is cut as if performing a traditional Japanese paper cutout, so we have named this technique the “CT cutout” technique. In this paper, the technique is described, and the accuracy of pedicle screw insertion in our clinical series is demonstrated.

**Methods**

**Surgical Technique**

In this new technique, a 3D CT scan of the cervical spine of the patient is obtained, using a 1-mm slice thickness (Aquilion 16, Toshiba Medical Systems Corp.). On the monitor, a single best axial image is chosen for each vertebral level, on which the pedicle, lamina, and transverse foramen are all included (Fig. 1). The CT image is developed at life size, and bilateral lines that pass through the centers of the isthmus of the pedicles are drawn directly on the CT image (Fig. 1). The CT image is cut like a “cutout” along the lines passing through the middle of the pedicles and the posterior margin of the lamina (Fig. 1). The vertebral level and right/left are indicated on each CT cutout. These CT cutouts are sterilized using ethylene oxide and used as references for screw insertion during surgery. The calibration of the CT scans should be checked before surgery to ascertain whether they are truly life-sized, the calibration scale should be sterilized together with the CT scan cutouts, and the size remeasured to confirm that the scale was not shrunk by the sterilization process in the first couple of cases. We did consider tracing the boundary on some other, harder materials, but we abandoned this idea and continued using the present procedure because the likelihood of error is increased if the number of processes is increased.

The paravertebral muscles are retracted to the lateral margins of the lateral masses. When inserting a pedicle screw in the C-2 pedicle, the dorsal aspect of the pedicle at C-2 should be exposed, and the margin of the spinal canal confirmed using the spatula. Where the pedicle screw is to be inserted, the Gelpi retractor is useful in retracting the paravertebral muscles of each level as widely as possible.

The CT cutout is held with a custom-made jig to prevent the CT cutouts from bending. Excess parts can be trimmed. The CT cutout with the jig is fitted along the posterior surface of the lamina and the spinous process.

![CT cutout technique](image)

**Fig. 1.** Computed tomography images showing the proper insertion point and insertion trajectory of pedicle screws, and examples of the outline of the CT cutout. © = right side.
Cervical pedicle screw insertion using the CT cutout technique

The “true lateral pictures,” in which the lines of the cephalad and caudal endplates of the vertebra and bilateral outlines of the facet joints are properly overlapped in the intensifier image, should be obtained at each level where insertion of pedicle screws is intended. An adequate cephalocaudal insertion point on the sagittal plane is determined in the lateral fluoroscopic image, and adequate bilateral insertion points on the axial plane are then determined by reference to the CT cutout. Small holes are drilled bilaterally using a Surgairtome (Conmed Linvatec) with a tiny bur (Fig. 2). The reason that bilateral holes are drilled at this point is that the screw head may disturb the fitting of the CT cutout after we finish inserting 1 side of the pedicle screw. Probing, tapping, and screw insertion are then performed in reference to both the angle of the CT cutout and the lateral fluoroscopic image (Fig. 2).

The rod is connected between screws, and occasionally decompression and posterior bone grafting are performed. The surgical processes are also indicated in Fig. 3 in a demonstration using saw bone.
Study Population

Twenty-nine consecutive patients who underwent posterior cervical reconstruction surgery since 2006 were involved in the present study, including 6 patients with cervical myelopathy due to rheumatoid arthritis, 4 patients with cervical myelopathy due to athetoid cerebral palsy, 5 with metastatic cervical tumor, 7 with cervical kyphosis, 5 with traumatic fracture dislocation, and 2 with pyogenic spondylitis. There were 19 men and 10 women in the study, with a mean age of 61.2 ± 17.4 years.

One hundred and thirty pedicle screws were inserted in these patients, at levels from C-2 to T-1. We attempted to insert pedicle screws in any cases in which the external diameter of the pedicle on the axial image of CT was 3.5 mm or more, and we performed the procedure with the sole aid of intraoperative lateral fluoroscopy. We did not experience any withdrawal of the pedicle screw insertion due to insertion failure in the present case series.

Consequently, 32 pedicle screws were inserted at C-2, 10 at C-3, 20 at C-4, 14 at C-5, 17 at C-6, 10 at C-7, and 27 at T-1. The mean width of the external diameter of the pedicle measured on the axial image of the preoperative CT was 5.7 ± 1.8 mm at C-2, 4.5 ± 0.9 mm at C-3, 4.7 ± 0.7 mm at C-4, 4.8 ± 0.9 mm at C-5, 4.2 ± 0.5 mm at C-6, 5.5 ± 0.9 mm at C-7, and 6.9 ± 1.0 mm at T-1. Cervical posterior fixation systems used included the Vertex MAX (Medtronic, Inc.) for 20 patients, Oasys (Stryker) for 2, Summit (Depuy Spine, Inc.) for 1, and the Olerud cervical system (Anatomica, Inc.) for 6. The diameters of the screws used in this series were 3.5 mm in most cases; 4.5-mm screws were occasionally used at T-1.

Follow-Up Evaluation

Postoperative 3D CT images were obtained at the levels at which pedicle screws were inserted, and any malpositioning of the pedicle screws in the sagittal and axial planes was evaluated. Exposure of the screw outside the pedicle by more than half the screw diameter was termed “perforation,” and complete exposure of the screw from the pedicle was termed “penetration.” These 2 classifications were considered to be possible critical breaches in the present study. Additionally, the deviation...
of the actual entry point and angle of the pedicle screw from what was intended was evaluated, and the accuracy of pedicle screw insertion using this technique relative to preoperative intention was determined. If the actual insertion point was closer to the transverse foramen than intended, this was defined as “+,” and if the actual insertion trajectory was more toward the transverse foramen, this was also defined as “+” (Fig. 4).

Statistical Analysis

The Student t-test was used for comparing the diameter of the pedicle between those with and without critical breach. A probability value of < 0.05 was considered statistically significant.

Results

Three perforations (2.3%) and 2 penetrations (1.5%) were identified on the postoperative 3D CT images. All breaches were directed laterally, and no cephalocaudal misplacement was observed. Therefore, the possible critical breach rate was 3.8% in this patient series. The 3 cases of perforation occurred at C-3, C-4, and C-6, and both cases of penetration occurred at C-6 and C-7. One case of penetration involved an 83-year-old man who suffered traumatic fracture dislocation at C6–7, in which the fractured lamina was floating. There was no indication of a learning curve for this technique; no neural or vascular injuries were observed during surgery, and no postoperative clinical symptoms relating to such injuries were experienced.

The deviation between the actual entry point and the angle of the pedicle screw with those intended was 0.20 ± 0.75 mm and 1.46 ± 4.21°, respectively. The mean outer diameter of the pedicle in the 5 cases with possible critical breach was 4.6 ± 1.0 mm compared with 5.4 ± 1.4 mm from others without critical breach, a difference that was not statistically significant (p = 0.12).

Illustrative Cases

Case 1

Posterior pedicle screw fixation at C4–5 was performed using this new technique for fracture-dislocation at this level in a 74-year-old man (Fig. 5). Postoperative CT images demonstrated proper insertion of the pedicle screws.

Case 2

Posterior pedicle screw fixation at C4–6 was performed using this technique for cervical myelopathy accompanying kyphosis in a 36-year-old man (Fig. 6). Postoperative CT images demonstrated proper insertion of the pedicle screws except for 1 inserted at the left side of C-4, which was classified as perforation of less than half of a screw diameter.

Case 3

Posterior extensive reconstruction surgery including pedicle screw fixation at C2–4 was performed using this technique for a metastatic spinal tumor that extended from C-5 to T-3 in a 38-year-old woman (Fig. 7). Postoperative CT images demonstrated proper insertion of the pedicle screws.

Discussion

To date, there have been several clinical reports describing the accuracy of pedicle screw insertion in the cervical spine. In their series of patients with nontraumatic degenerative vertebrae, Neo et al. reported ex-
periencing screw breaches in 29% using the freehand technique, ranging from < 2 mm screw exposure to complete penetration, and half (15% of the total) were possible critical breaches. Abumi et al. also reported that they experienced a 6.7% screw breach rate in their series of trauma patients, again using the freehand technique, although they provided no details regarding the degree of perforation.

In the attempt to improve the accuracy of pedicle screw insertion, several authors have introduced additional aids, including: 1) the usage of navigation systems, reporting the ability to gain more accurate pedicle screw insertion from 1.2 to 11% of misplacement of the pedicle screws; and 2) the acquisition of intraoperative pedicle axis views using fluoroscopy, in which Yukawa et al. reported that they gained better accuracy of pedicle screw insertion (4.0% possible critical breach) in their trauma series than with using the freehand technique without any navigation systems. However, misplacement cannot be completely avoided even after introducing such aids. Ludwig et al. reported that the rate of screw breach did not exhibit any statistically significant difference between a computer-assisted navigation group and a free-hand group in their cadaver study. Also, time-consuming configuration of reference points during surgery must be performed with a computer-assisted navigation system. In addition, CT-based navigation and intraoperative pedicle axis view techniques deliver a high x-ray dose to both patients and/or surgeons during surgery, which should be avoided if at all possible.

In the present study, the CT cutout technique has been demonstrated to provide better accuracy of pedicle screw insertion in the cervical spine than the freehand technique. However, we cannot simply compare previous data with ours because patient selection was different with respect to disease type, age, and sex, and the system for evaluation of accuracy also varied.

The CT cutout technique is an easy, low-cost procedure that can be performed with the aid of single-plane fluoroscopy, giving lower exposure to x-rays. It does not require the configuration of reference points, which leads to shorter operation time. Moreover, rotational error for pedicle screw insertion, which occurs especially during probing, can be avoided in the CT cutout technique because the surgeon can check the trajectory angle at any time during the procedure. In the usual procedure of pedicle screw insertion in the cervical spine, there is a risk that probing, tapping, and screw insertion can easily be misdirected laterally because the paraspinal muscles intervene. It is also reported that, anatomically, the lateral cortex of the pedicle is thinner than the medial cortex, which is the reason that the majority of pedicle screw perforations have been reported as likely to occur at the lateral aspect adjacent to the vertebral artery. Therefore, we have to take this tendency into account even when applying the CT cutout technique. On the other hand, a breach outside the pedicle in the cephalocaudal direction is reported to be rare, as in the results of the present study, because the shape of the pedicle from C-3 to C-6 is reported to be oblong with a cephalocaudal length greater than the mediolateral length.

The CT cutout technique is contraindicated for those whose pedicle diameter is less than the diameter of the screw, and those whose lamina has been removed or is severely fractured or unstable. We do not think this technique is contraindicated in those whose bone inside the pedicle appears sclerotic. In such cases, we can make the path for the pedicle screw using a Surgairtome with a tiny diamond bur with reference to the CT cutout, rather than being forced to make the path using probing.

This new CT cutout technique shows great promise for safer pedicle screw insertion in the cervical spine than the freehand technique. However, we should bear in mind that aids such as this CT cutout technique and several
navigation systems are only supportive of the manual insertion technique. Karaikovic et al.\textsuperscript{5} described the morphological features of the pedicles in the cervical spine, and they demonstrated that the pedicle at each level has its own features; that is, the direction of the pedicle at C-2 and C-3 on the sagittal plane is from posterocaudal to anterocephalad, although the direction at and below C-4 is almost parallel to the endplate of the vertebra. Moreover, the direction of the pedicle on the axial plane is the closest to the horizontal at C-5 (mean 46.33° in men, 46.87° in women).\textsuperscript{5} We should be aware of these anatomical features even when we apply such aids, and any pedicle screw insertion should be performed under the guidance of experienced spinal surgeons.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References


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