SURGICAL TECHNIQUE

Analysis of accuracy of computer-assisted navigation in cervical pedicle screw installation

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Objective: To observe the accuracy of computer-assisted navigation (CAN) in cervical pedicle screw installation and to analyze the reasons for screw malposition.

Methods: From October 2004 to December 2009, 144 cervical pedicle screws were installed in 25 patients with cervical spinal diseases using CAN. Screw position and direction were measured on sagittal and transection images from intraoperative navigation and postoperative CTs.

Results: Among 144 screws inserted from C3 to C7, two perforated the upper pedicle wall and three deviated from the lateral pedicle wall. The rate of accurate cervical pedicle screw placement with CAN was 96.5% (139/144) in our group. There was no statistical difference in the position and direction of the pedicle screws according to navigation images and CT scans.

Conclusion: CAN can result in high accuracy of cervical pedicle installation. The excursion phenomenon is responsible for malposition of pedicle screws. Only by understanding the navigational principles of CAN and the characteristics of cervical spinal surgery, together with personal experience, can good use be made of CAN.

Key words: Cervical vertebrae; Computer-assisted; Excursion phenomenon; Pedicle screw; Surgery

Introduction

Because of the superiority of three column fixation, cervical pedicle screw fixation should produce good results¹. However, cervical pedicles have variable anatomic structure and the adjacent tissues are complex. The potential risk of injury to adjacent neural and vascular tissue is great. Therefore increasing the accuracy of screw insertion and decreasing the incidence of malposition of pedicle screws is a key issue. Computer-assisted navigation (CAN) has been used in lumbar pedicle screw installation for some years, and has been shown to remarkably increase the accuracy of lumbar pedicle screw insertion². How accurate is cervical pedicle screw installation with CAN? Since October 2004, cervical pedicle screw fixation under CAN has been implemented in the Department of Orthopaedics of the Provincial Hospital Affiliated to Shandong University in China. We have analyzed the intraoperative

and postoperative positions of the pedicle screws and discuss in this article the reasons for malpositioning of pedicle screws under CAN.

Materials and methods

Case data

There were 25 patients in this group, including 16 men and 9 women. The average age was 42.4 years (range, 23–68 years). The disorders included cervical spine injury in 12 patients, cervical myelopathy due to kyphosis or instability in 11 patients, cervical spondylotic radiculopathy in 1 patient, and ossification of the posterior longitudinal ligament in 1 patient.

Surgical technique

Under general anesthesia, the patient was placed in a prone position, and the neck fixed with Gardner-Wells skull traction or a Mayfield three-pin skull frame. The cervical spine was maintained in a neutral position, and the shoulders pulled caudad with a heavy bandage to allow clear intraoperative lateral radiographic images of the lower cervical spine. A midline incision was made and the cervical laminae were exposed to the edges of both lateral masses. While maintaining proper cervical

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Figure 1 Measurement of intraoperative navigational image. (A) Transverse image: screw's relative position in pedicle = c/d ; direction = angle between a and b. (B) Sagittal image: screw's relative position in pedicle = c/d ; direction = angle between a and b.

alignment, a reference frame was fixed onto the spinous processes, and the lower cervical spine scanned at 1-mm interval using CT-SIREMOBIL Iso-C 3D (Siemens, Medical Solutions, Erlangen, Germany). The data were then transferred to the computer workstation of an image-guiding system (infrared-inducing navigation system, Stryker, Chengdu, China) to reconstruct a three-dimensional image on a monitor screen. The entrance point and direction were confirmed on the basis of the sagittal and trans-sectional pedicle images. A 2-mm diameter awl was driven down the pedicle into the vertebral body in the position planned on the basis of the CT image. After the awl's position was confirmed by C-arm, the screw was inserted.

Test of screws' positions

The positions of the cervical pedicle screws were assessed on sagittal and trans-sectional images of postoperative transpedicular CT scans. Data concerning the positions of the cervical pedicles was collected from images of intraoperative navigation (Fig. 1) and postoperative CT scans (Fig. 2). Each screw's position was defined by its relative position in the cervical pedicle, and each screw's direction was defined by the angle between the midline of the screw and the upper border or midline

of the relevant cervical body. On the trans-sectional images, each screw's relative position was defined by the ratio of the distance (from the midline of the screw to the inner pedicle edge) compared with the pedicle width, and the screw's direction was defined by the angle between the midline of the screw and the cervical body. On the sagittal images, each screw's relative position was defined by the ratio of the distance (from the midline of the screw to the upper pedicle edge) compared with the pedicle width, and the screw's direction was defined by the angle between the screw's midline and the cervical body's upper line.

Statistical analysis

The positions of the screws on navigational images and postoperative CT images were compared by using Student's *t*-test for group comparison (SPSS 11.5), the significance level was $\alpha = 0.05$.

Results

A total of 144 screws were inserted from C3 to C7, five of which perforated the pedicle wall, therefore the rate of accurate cervical pedicle screw placement with CAN was 96.5% (139/144). After comparative analysis, no statistical

Figure 2 Measurement of postoperative CT image. (A) Transverse image: screw's relative position in pedicle = c/d ; direction = angle between a and b; (B) Sagittal image: screw's relative position in pedicle = c/d ; direction = angle between a and b.

Table 1 The result of comparative analysis of the screws' positions on navigational images and postoperative CT images ($\bar{x} \pm s$)

Item	Screw number	Navigation	CT	<i>t</i>	<i>P</i> Value
Trans-sectional angle (°)	121	45.87 $\pm$ 3.78	44.97 $\pm$ 3.25	0.37	0.61
Trans-sectional position	121	0.49 $\pm$ 0.02	0.49 $\pm$ 0.03	0.85	0.45
Sagittal angle (°)	99	3.87 $\pm$ 0.07	3.82 $\pm$ 0.05	1.02	0.39
Sagittal position	99	0.49 $\pm$ 0.03	0.48 $\pm$ 0.06	1.26	0.21

differences were found in the positions of the pedicle screws on navigational and postoperative CT images (Table 1).

Among the five screws which perforated the pedicle walls, two were discovered to have perforated the upper pedicle wall by C-arm intraoperatively, including one left screw in one patient's C3 and one right screw in another patient's C3; these were then surgically adjusted. One of the two patients had symptoms of nerve root irritation postoperatively, this disappeared after administration of neurotrophic drugs for 2 weeks, and there were no subsequent sequelae. The other patient had no neural symptoms postoperatively.

Postoperative CT scans revealed that three screws had deviated from the lateral pedicle wall towards the vertebral artery. The three screws include two right screws in C3 and one left screw in C4. No bleeding or ischemic symptoms occurred during or after surgery.

Discussion

Because of the high perforation rates during insertion of cervical pedicle screws³, and the potential risk of injury to the vertebral artery or neural structures by displaced pedicle screws, the key to improving the results of this surgical procedure is to improve the accuracy of cervical pedicle screw placement. To this end, many methods have been proposed, such as the funnel technique³, Abumi method⁴, and installation under CAN system. Of these, installation of screws under the CAN system is the most effective. The CAN system allows simultaneous visualization of anatomical structures and surgical instruments intraoperatively by providing a dummy three-dimensional display on a screen which can directly guide manipulation and increase accuracy of screw placement. Richter *et al.* reported a 100% rate for accurate cervical pedicle insertion with CAN⁵. In this study, the accurate rate of cervical pedicle screw placement with CAN was 96.5% (139/144), which confirms that the CAN system can improve the rate of accurate cervical pedicle screw placement.

Although the CAN system is a useful tool for spinal surgery⁶⁻⁸, any spinal surgeon using such a system should

be aware of its possible errors. Furthermore, the spinal surgeon should never rely on the virtual information he or she receives from the CAN system without verifying it themselves. The spinal surgeon must ensure that the correct vertebrae are assessed via image intensifier control or other techniques.

Two types of error can be implicated in the perforation of either the upper or lateral pedicle wall by five screws in this study. In our opinion, errors are caused by a combination of the navigational principles involved and the characteristics of the cervical surgery. It is not random, some consistent factors can be identified. In computer-assisted surgery the patient's image information can be acquired by digital scanning technology and transformed into dummy three-dimensional graphics. Manipulation can then be guided by three-dimensional orientation technology. Intraoperative navigation imaging relies on the principle that the involved tissues are rigid. Once a navigation image has been produced, the anatomic position of the operative objects in three-dimensional space must not move at all. However, the characteristics of cervical surgery are such that this principle does not entirely hold true. The relative shift of the object's anatomic position in three-dimensional space has been called "the excursion phenomenon"⁹. If the deviated distance is 1 mm, the error caused by the navigation image will also be 1 mm (Fig. 3). If the deviated distance is too great, the screw directed by navigation image will perforate the cervical pedicle.

In this study, two screws were shown by C-arm to have perforated the upper pedicle wall by >2 mm, and these were revised during the operation. In our opinion, a shortened distance caused by excursion of cervical bodies was the reason. The mobility of the cervical spine is significantly increased in the presence of cervical fracture; general anesthesia and muscle relaxation also contribute to its instability. When an awl is inserted into the cervical pedicle, this puts pressure on the cervical spine from behind and pulls the paravertebral muscle laterally, significantly increasing the angle of cervical lordosis. At the same time, the distance between the corresponding vertebral bodies' rear structures shortens. That is, the actual distance from the reference frame to the targeted pedicle is

Figure 3 (A) L represents the distance from the targeted pedicle to the reference frame in the preoperative navigation image. (B) Deepened cervical lordosis causes L to shorten during surgery. As a result, the targeted pedicle undergoes excursion. While the navigation image still shows the distance is L, in actuality, if this is used as the sole guide, the screw will be inserted headward and perforate the pedicle.

shortened. Accordingly, the targeted pedicle showed in the navigation image is located beyond the actual targeted pedicle. Therefore, a screw placed in the pedicle according to the navigation image may actually perforate the upper pedicle wall.

Three screws perforated the lateral pedicle wall in this study, these were not revised because the extent of pedicle perforation shown by intraoperative silent navigation imaging was ≤ 2 mm. It is considered that when an awl is inserted into the cervical pedicle, the cervical spine deviates up and down, relative excursion between the vertebral bodies occurs, and the position of the reference frame shifts. Therefore, excursion of the three-dimensional space corresponding to the reference frame occurs. Thus the relative position of the awl and pedicle is not fixed: the awl may be within the pedicle in one image, while it is out of the pedicle in another image. When an inexperienced operator accepts an image showing that the awl is within the pedicle, error may occur. On the other hand, when the surgeon adjusts an awl in a cervical pedicle, the awl continues to be fixed within the pedicle, and the vertebral body will shift according to the direction of the awl. Although the awl's direction has changed according to the navigation image, the awl fixed together with the pedicle will have been inserted along the original direction. At this point, if we remove our hands, the awl's true direction will be displayed on navigation image.

Although registration (matching) of the instrumented vertebrae is possible in all cases, it can be difficult, especially in C3 and C4, as these vertebrae have very small spinous processes and in many patients the posterior surface of the vertebrae, which is used for surface matching, is quite similar. Therefore, it is possible to achieve an acceptable registration on C3 with the surface data of C4

or vice versa. This problem underlines the mandatory need for the surgeon to verify that he or she instruments the correct vertebra. Another error may result from the reference clamp which is attached to the spinous processes. In the middle of the cervical spine the smallness of the spinous processes make it difficult to achieve stable fixation of the reference clamp, especially as most reference clamps were initially designed for the lumbar and thoracic spine. Adapted reference clamps or other fixation techniques should be developed to suit cervical spine anatomy. In addition, a 2-mm diameter awl will bend when it is inserted into the cervical pedicle. All of these will cause the excursion phenomenon, which leads to navigational error.

If we wish to increase the accuracy of computer-assisted cervical pedicle screw installation, the excursion phenomenon must be decreased. We believe that the Mayfield three-pin skull frame is superior to Gardner-Wells skull traction in the prone position, because its fixation and traction is more effective. Firm fixation and avoidance of touch are necessary to stabilize the reference frame during surgery. In order to avoid relative excursion of the vertebral bodies, reamer and percutaneous adjacent incisions are preferred. Judgment must be made according to invariable navigation images. The position of the awl in the pedicle must be ensured according to both sagittal and trans-sectional images simultaneously, and its position located at the pedicle midline as far as possible. In order to minimize shift of the cervical spine, the awl must be inserted slowly along the pedicle wall.

Because computer-assisted cervical pedicle screw fixation is superior biomechanically and has an increased accuracy rate, it has good prospects for clinical application. Mastering CAN technology involves a period of

learning curve¹⁰. The use of CAN for cervical pedicle screw insertion will make a good spinal surgeon even better, but it can never make a bad spinal surgeon a good one. "A fool with a tool is still a fool" is therefore a good motto to adopt for the use of CAN systems in the cervical spine. Only by understanding the navigational principles and the characteristics of cervical spinal surgery will the reason for malposition be completely understood. Together with personal experience, the superiority of CAN will be given full play.

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