Pedicle screw placement in the thoracic spine: a randomized comparison study of computer-assisted navigation and conventional techniques

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【Abstract】Objective: To evaluate the accuracy of computer-assisted pedicle screw installation and its clinical benefit as compared with conventional pedicle screw installation techniques.

Methods: Total 176 thoracic pedicle screws placed in 42 thoracic fracture patients were involved in the study randomly, 20 patients under conventional fluoroscopic control (84 screws) and 22 patients had screw insertion under three dimensional (3D) computer-assisted navigation (92 screws). The 2 groups were compared for accuracy of screw placement, time for screw insertion by postoperative thin-cut CT scans and statistical analysis by $\chi^2$ test. The cortical perforations were then graded by 2-mm increments: Grade I (good, no cortical perforation), Grade II (screw outside the pedicle <2 mm), Grade III (screw outside the pedicle >2 mm).

Results: In computer assisted group, 88 (95.65%) were Grade I (good), 4 (4.35%) were Grade II (<2 mm), no Grade III (>2 mm) violations. In conventional group, there were 14 cortical violations (16.67%), 70 (83.33%) were Grade I (good), 11 (13.1%) were Grade II (<2 mm), and 3 (3.57%) were Grade III (>2 mm) violations ($P<0.001$). The number (19.57%) of upper thoracic pedicle screws (T1-T4) inserted under 3D computer-assisted navigation was significantly higher than that (3.57%) by conventional fluoroscopic control ($P<0.001$). Average screw insertion time in conventional group was (4.56 ±1.03) min and (2.54 ±0.63) min in computer assisted group ($P<0.001$). In the conventional group, one patient had pleura injury and one had a minor dura violation.

Conclusions: This study provides further evidence that 3D computer-assisted navigation placement of pedicle screws can increase accuracy, reduce surgical time, and be performed safely and effectively at all levels of the thoracic spine, particularly upper thoracic spine.

Key words: Surgery, computer-assisted; Bone screws; Spinal fractures

Application of transpedicular screws for posterior fixation in the treatment of spinal instability has made continuous evolution and refinement in technique. Pedicle screws in the lumbar spine are considered to be the best and most rigid form of posterior spinal fixation. Because of the small size and complex three-dimensional (3D) morphology of the thoracic pedicle, thoracic pedicle screws are less than perfectly placed and may associate with serious morbidity.

Transpedicular screw placement in the thoracic spine can be an extremely challenging procedure and has not been widely advocated.1 Pedicle screw fixation has numerous advantages over other methods of spinal fixation but is risky for serious complications.2,3 In practice, the surgeons frequently aim to improve the accuracy of thoracic pedicle screws.4,5 Clinical and cadaveric studies have shown that 15% to 50% of thoracic screws violate the pedicular cortex when placed by anatomic landmarks, fluoroscopic techniques, or both.6,8 The need for improved accuracy and consistency in the placement of thoracic pedicle screws has led to investigations on the applications of computer navigated spine surgery, which provides the possibility to acquire data and transfer automatically to the computer navigation system by an interface.
METHODS

Patients

Forty-two Chinese patients with trauma, spinal stenosis, segmental instability, metastasis or spondylolisthesis who underwent surgeries using posterior pedicle screw instrumentation of the thoracic spine in 2006 were randomly allocated to 2 study groups: 22 patients in computer-assisted group and 20 patients in conventional group. In the computer-assisted group, the pedicle screw insertion was done using intraoperative 3D computer navigation by Vector Vision (Brain LAB, Germany). In the conventional group, the pedicle screw insertion was performed under the conventional C-arm fluoroscopy (no computer navigation was available). All surgeries were performed by the same surgical team experienced in spine surgeries in the same hospital. The titanium implants were used routinely in all patients.

Conventional surgery

After a standard posterior approach on the appropriate vertebral levels was achieved, the C-arm was appropriately rotated and tilted in the necessary direction to obtain an end-on view of the pedicle. A sharp pedicle curette was used to drill a pilot hole in selected pedicles under biplanar fluoroscopic control (posteroanterior and lateral views). The blunt pedicle starter was then used along the path of least resistance to cross the pedicle into the vertebral body. Holes then were probed with a pedicle probe to feel for the pedicle walls so as to detect any breach. Holes were redirected when required. Next, pedicle screws were inserted using anteroposterior and lateral fluoroscopic guidance. If needed, some patients underwent reoperations to redirect misplaced pedicle screws. The time taken for insertion of each screw was measured.

Computer-assisted surgery

All patients undergoing computer-assisted pedicle screw installation required a preoperative spiral-mode CT scans (Siemens, Forchheim, Germany) of the spinal segments. These image data were transferred to the surgical assistance system for further processing to produce a 3D model of the selected vertebrae. Data acquisition was done using Vector Vision. After registration and match, a pointer tool was used to identify the entry site that was prepared by a burr. The tool was then used to develop a trajectory of appropriate direction using the virtual coronal, sagittal, and axial plane images available (Figure 1). The direction and depth of pedicle finder were guided and confirmed frequently using the tool navigator. The length and diameter of screws were measured from the markings on the trajectory or the setup of “planning a screw”. The chosen screws were calibrated and registered with the navigator before insertion so that the screw insertion was accurately performed using the autopilot images. This average setup time per screw was added to the time taken for actual screw insertion time.

Grade of screw placement

Postoperative CT scans were performed using 2 mm cuts with 1-mm overlap to assess the accuracy of screw placement in all patients. The radiographs and CT scans were analyzed with respect to the breach of the pedicle wall by screws either medially, laterally, inferiorly or superiorly. The distance of the tip of screws from the lateral cortex of the vertebra was also measured in axial CT sections. Screw placement was graded on CT as follows: Grade I, no pedicle perforation (good); Grade II, only the threads outside the pedicle (<2 mm); Grade III, core screw diameter outside the pedicle (≥2 mm, Figure 2). Grade II and Grade III screws were considered as true cortical violation. The T1-T3 levels were grouped as upper thoracic vertebrae, T4-T7, levels as middle, and T8-T12 levels as lower. The number of screws in each group was recorded respectively. The data were analyzed by $\chi^2$ test, using statistical software package SPSS13.0.

RESULTS

Pedicle screws were placed in all levels of thoracic spine (T1-T12). In computer-assisted group, there were 92 pedicle screws, including 18 (19.57%) in the upper thoracic spine, 36 (39.13%) in the middle, and 40 (43.48%) in the lower. In the conventional group, there were 84 pedicle screws, including 3 (3.57%) in the upper thoracic spine, 23 (27.38%) in the middle, 58 (69.05%) in the lower (Figure 3, $P<0.001$ in the upper thoracic spine between 2 groups). Of the 92 screws evaluated in computer-assisted group, there were 88 screws with Grade I cortical violation, 4 (4.35%) screws with Grade II. Of the 84 screws in the conventional group, there were 11 (13.10%) with Grade II and 3 (3.57%) with Grade III. $\chi^2$ analysis revealed higher rate of cortical perforation in the conventional group (16.67%) as compared with that in the computer-assisted group (4.35%, $P<0.001$, Table1). Average screw insertion time was (4.56±1.03) min (range: 3.53-
5.59 min) in the conventional group and (2.54±0.63) min (range: 1.91-3.17 min) in the computer-assisted group (Table 1, P<0.001). In the conventional group, one pa-
tient had pleura injury and one had a minor dura violation, but no patients retreated. The pleura was treated by drain-
ing and the dura was repaired by suture. One of the grade III cases had nerve root injury and underwent revision. No cases had permanent complication.

**DISCUSSION**

Pedicles are the strongest part of the vertebra, and pedicle screw fixation affords multidimensional control, giving greater rigidity with high fusion rate. These advantages have led to widespread adoption of pedicle screw fixation in the lumbar spine for multiple clinical applications, including deformity, tumor, infection, fracture and degenerative conditions. The anatomy of tho-
racic spine differs in several aspects from the lumbar spine. In addition, there are regional variations within the thoracic pedicles in the dimension and orientation. There are more risks of neural damage due to decreased canal cord ratio in this region. The dura is often stretched over the pedicles and even minor violations can damage the cord. That is also the main reason why we had less pedicle screws fixation surgeries on upper thoracic spine before the computer navigation was used in our study (Figure 3). Scoles et al measured the morphology of adult spines and determined that the minimum pedicle diameter was 3.0-3.5 mm at T6, 6.4-7.3 mm at T1 and 7.2-7.4 mm at T12. Vaccaro et al showed pedicular size to be widely variable, ranging from
a smallest mean transverse diameter of 4.5 mm at T₄, to a largest mean transverse diameter of 7.8 mm at T₁₂. Other authors have confirmed these similar values.⁶,¹¹,¹⁴

The technique of pedicle screw insertion depends to a large extent on the anatomic landmarks and experience of surgeons. Although many surgeons have described the free-hand technique, single lateral view radiographs, or single anteroposterior and lateral view radiographs in insertion of the thoracic pedicle screws, the results are not easily reproducible.⁷,¹⁵ Hence the pedicle breach rate may be dangerously high when the anatomy is altered. Clinical and cadaveric studies have shown that 15% to 50% of thoracic screws violate the pedicular cortex when placed based on anatomic landmarks, fluoroscopic techniques, or both.⁶,⁷,¹⁴ The technique of insertion is usually “blind” since the pedicle is not directly visible. Therefore, it is not surprising that high penetration rates have been reported in several prior studies. Castro et al⁸ reported a malposition rate of 25% in cadaver studies and 40% in patients assessed using postoperative CT scans. Carbone et al⁶ reported 12.7% penetrated the pedicle cortex in the thoracic spine. Merloz et al¹⁷ reported a 13% penetration rate (18 of 138) in the noncomputer-assisted group in the lower thoracic and lumbar spine. In our study, 16.67% of screws penetrated pedicle cortex in conventional group and one patient had pleura injury and another had a minor dura violation, but no patients retreated. Thus, there is an overall high rate of screw malposition. Some surgeons opt for intraoperative fluoroscopic guidance, it may even be impossible in some upper thoracic spine. The accuracy using fluoroscopic technique is questionable. It is desirable to increase the accuracy in pedicle screw fixation of thoracic spine. The C-arm was frequently brought into the surgical field, which increased radiation exposure to the surgeon, increased surgical time, thus increased the infection rate.¹⁸,¹⁹

In recent years, computer-assisted navigation has been on the rise in an attempt to obviate the chance of pedicle screw malposition in difficult thoracic surgeries.¹⁷,²⁰,²¹ In our study, before using computer navigation, we performed the upper thoracic pedicle screw fixation in only 3.57% of the patients (3 of 84, Figure 3) and the cortex penetration rate was 16.67% (full thoracic spine), but we inserted 19.57% of (18 of 92) thoracic pedicle screws and the penetration rate was only 4.35% under 3D computer navigation (Table 1). The average time required to insert the pedicle screws was (2.54±0.63) minutes in the computer-assisted group, significantly shorter than (4.56±1.03) minutes in conventional group (P<0.001, Table 1). The intraoperative CT-based navigation system is more accurate and quick. There have been increasing reports on the navigated spine surgery. Amiot and Poulin²² analyzed their results of CT-based navigation-guided thoracic, lumbar and sacral pedicle screws with the historical control group of patients treated surgically with conventional techniques. The historical controls had no pedicle screws placed in upper thoracic spine. They found that the computer navigation could significantly reduce the incidence of incorrectly positioned pedicle screws. Merloz et al¹⁷ reported a 5% cortex penetration rate (7 of 140) in the computer-assisted group and a 13% penetration rate (18 of 138) in the noncomputer-assisted group in the lower thoracic and lumbar spine. In navigation, the surgeon can keep certain distance from the operating field while screening the spine. This considerably reduces the amount of radiation exposure to the surgeon and thereby decreases the risk of infection.²³ The comfort of the surgeon is also enhanced as the screws could be inserted without checking of the C-arm.

The increased setup time and registration-related errors are a drawback to CT-based navigation systems, which rely on acquired data before surgery.²¹,²⁴ If the patient has a little bit motion during the operation, the inaccuracy rate will be raised. The time required for registration procedure on 1-level instrumentation was 5-20 minutes which will increase the whole surgery time and make it more complex.²¹ However, the increased accuracy of pedicle screw insertion arguably outweighs the disadvantage of required additional surgical time. Surgeons can be more confident because the real-time image-interactive navigation function allows the selection of the optional trajectory and point of entry for pedicle screw insertion.²¹ It is reported that the new Iso-C3D C-arm based computer navigation came into use. Iso-C3D on-table data are transferred directly to a computer navigation system, and the entire process of registration is avoided. Hence, this real-time images reduce the time taken, the fiddle factor, and inaccuracies of registration.²⁵ There is still a space for improvement in the technology to address the inherent pitfalls with navigation systems.²⁵ The price of the machine is still high, not good for comprehensive use.
The ideal technique for spinal-level localization would have the following characteristics: easy availability in the operating theater, accurate, lowest radiation exposure to the professional team and the patient, simple technique which is easily reproducible at any time during surgery, usable with all forms of spine surgery, permanently recordable. Anyway, computer-assisted 3D navigation surgery is superior to fluoroscopic technique alone in thoracic surgeries using pedicle screw instrumentation, particularly in upper thoracic surgeries, as it reduces pedicle perforations, surgical time, and radiation exposure, increases accuracy and also surgeon confidence to a large extent.

REFERENCES


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