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Original Article

Comparison of the accuracies of transpedicular screw insertion during computed tomography-free, -based, and intraoperative computed tomography spinal surgeries

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ABSTRACT

Purpose: This study aims to compare the accuracies of transpedicular screw (TPS) insertion using with computed tomography (CT)-free, CT-based, and intraoperative CT (iCT) with integrated navigation during lumbar spinal surgery.
Materials and Methods: This study is a retrospective cohort study comparing perioperative data from three patient groups—CT-free navigation (CTF) group, CT-based navigation (CTB) group, andiCT group—who were treated at the Orthopedic Department of Chang Gung Memorial Hospital, Chiayi, Taiwan. Patients who received posterior lumbar TPS insertion with the assistance of computer navigation from January 2002 to June 2011 were included in the study. All demographic and perioperative data were collected from reviews of the medical charts. Postoperative CT images were reviewed to determine screw position.
Results: This study enrolled 56 patients: 22 patients were enrolled in the CTF group (106 screws), 15 patients in the CTB group (70 screws), and 19 patients in the iCT group (114 screws). The rate of screw insertion without pedicle wall penetration was 89.62% in the CTF group, 98% in the CTB group, and 98% in the iCT group. ($p = 0.01$) The rate of pedicle wall penetration >2 mm was 5.66%, 0%, and 0% in the CTF, CTB, and iCT groups, respectively. One patient in the CTF group developed a residual neurologic deficit. There were noscrew-related complications in the CTB or iCT groups.
Conclusion: The use of CT navigation (CT-based and iCT navigations) results in a significantly higher accuracy of screw insertion compared with two-dimensional fluoroscopic navigation for TPS insertion ($p = 0.01$). Intraoperative CT-integrated navigation provides additional advantages, including simpler registration and the ability to double-check positioning during the operation, andtends to produce less blood loss.

1. Introduction

The misplacement of transpedicular screws (TPS) often creates unwanted complications.[1] Several methods had been used to enhance the accuracy of pedicle screw insertion, including the bone landmark method, open laminar method, fluoroscopic navigation, CT-based navigation, and intraoperative CT (iCT) navigation.[2–5] Pedicle screw accuracy during spinal surgery has been reported to be between 79–100%.[6,7] Theoretically, by using a navigation system the incidence of TPS misplacement should decrease.[8] However, the accuracies of different navigation systems are rarely reported in the literature. This aim of this study is to compare the accuracy of TPS insertion usingCT-free (CTF), CT-based (CTB), and iCT with integrated navigation (BrainLab AG, Feldkirchen, Germany; Siemens, Munich, Germany) during lumbar spinal surgery.

2. Materials and methods

2.1. Subjects

This is a retrospective cohort study comparing perioperative datafrom three patient groups—CTF group,CTB group, the iCT group—who were treated at the Orthopedic Department of Chang

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Gung Memorial Hospital, Chiayi, Taiwan. Patients who received posterior lumbar TPS insertion with the assistance of computer navigation from January 2002 to June 2011 were included in the study. Patients were grouped into the three groups according to the navigation method used. The CTF navigation system was used from 2002–2004, the CTB navigation system was used from 2007–2009, and the iCT navigation system was used from 2010–2011. Screws that were placed in the thoracic region were excluded from analysis. All demographic and perioperative data were collected by reviewing the medical charts. This study was approved by the institutional review board (IRB No. 100-0901B) of our hospital.

2.2. TPS-insertion methods

2.2.1. CTF navigation

TPS insertion was assisted with the use of a two-dimensional (2D) fluoroscopic navigation station (VectorVision[2] fluoro; Brainlab AG, Feldkirchen, Germany). The reference frame was attached to the spinous process of the vertebra, and the optical sensor camera was also properly positioned. The surgical tools, including the pedicle awl, probe, and screwdriver, were tracked. A calibration image was obtained using an image intensifier (Siremobil 2000, Siemens, Munich, Germany). Anteroposterior and lateral fluoroscopic images of the two vertebrae adjacent to the reference arm were obtained. After the data were captured and transferred to the workstation, a computer-simulated image of the patient's anatomy and the registered tools were displayed in each view. We located the entry point and trajectory of each TPS using the registered pointer and guidance from the navigation system. The pilot hole was prepared using a registered pedicle probe. A TPS of sufficient length and diameter was inserted according to the specifications of the navigation system. The pilot hole was not entirely checked by the ball-tipped probe.

2.2.2. CTB navigation

For this method, TPS insertion was assisted by the use of a three-dimensional (3D) CT navigation station (VectorVision spine; Brainlab AG, Feldkirchen, Germany). Image data from the initial preoperative CT scans were obtained and transferred from the CT scanner to the navigation workstation to produce a 3D image of the targeted spinal segment. With the patient in a prone position, a reference clamp was securely attached to the spinous process of the vertebra. After pair-point matching using at least four local bone landmarks on the targeted vertebra, the CT image was used to guide TPS insertion. The surgical instruments, includingthe pedicle awl, probe, and screwdriver, were tracked. The surgeon located the entry point for the TPS using the registered pointer. After the entry point was located, the navigation system displayed the screw trajectory through sagittal and axial views. The pilot hole was then prepared, and the screw was placed using guidance from the navigation system. The pilot hole was not entirely checked by the ball-tipped probe. A TPS of sufficient length and diameter was also selected according to specifications of the navigation system.

2.2.3. iCT navigation

For this method, TPS insertion was assisted with the use of an iCT navigation system (Spine & Trauma iCT; Brainlab AG, Feldkirchen, Germany; Figs. 1, 2). The navigation system was composed of a sliding gantry 40-slice CT scanner (SOMATOM Sensation open, Siemens, Munich, Germany) with the following specifications: 241.2 mm at 120 kVp, 200 mAs, rotation time of 1 second, multiplanar reconstructions with slice thickness/increment of 3 mm, and a frameless infrared-based navigation station (BrainLab, VectorVision sky; BrainLab AG, Feldkirchen, Germany). With the patient in a prone position, a reference clamp was securely attached to the spinous process of the vertebra. A control CT scan was performed for registration. Images from the initial control CT scans were obtained and transferred from the CT scanner to the navigation workstation to produce a 3D image of the relevant spinal segment and to provide automatic registration. After verifying the registration of the target vertebrae, the CT image was used to guide TPS insertion. The surgical instruments, including the drill guide and probe, were tracked. The surgeon located the entry point of the TPS using the registered pointer. After the entry point was located, the navigation system displayed the trajectory through sagittal and axial views. The pilot hole was prepared with the drill guide, and the screw was entirely placed with guidance from the navigation system. The pilot hole was not entirely checked by the ball-tipped probe. A TPS of sufficient length and diameter was also selected according to the specifications of the navigation system. After TPS insertion, a confirmation CT scan was immediately performed.

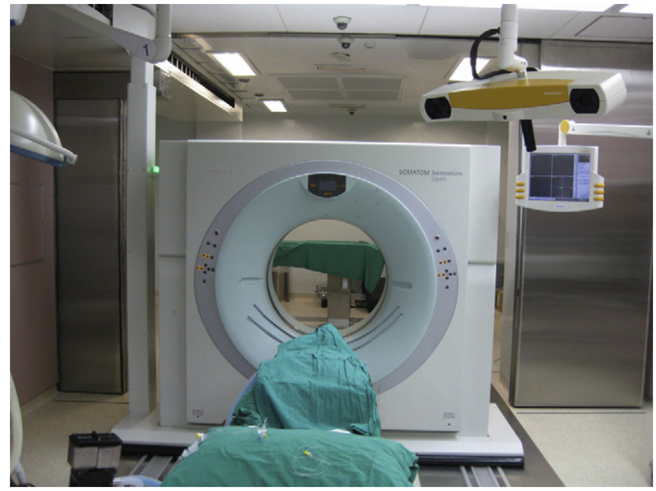

Fig. 1. Intraoperative CT scan obtained using an integrated computer navigation system in the operating suite.

2.3. Assessment of screw position

Screw position was assessed in the CTF and CTB groups using CT scans 1–4 days after surgery. The postoperative CT images were reviewed for screw position by measuring the digitalized images (PACS, Centricity Enterprise Web, version 3.0; GE Medical systems, Fairfield, Connecticut, United States). The axial reconstructions were analyzed by an investigator blind to the method of insertion. The assessment utilized a measurement scale in the digital image system. The distance breeched by the screw was graded as follows, as previously described by Belmont et al[9]: screw entirely in the bone, <2 mm from the bone, 2–4 mm from the bone, and >4 mm from the bone.

2.4. Statistical analysis

All demographic and perioperative data were assessed using the Chi-square test or Mann-Whitney rank sum test using SPSS software (version 12.0; SPSS Inc. Chicago, Illinois, United States). Results were considered statistically significant if the p value was <0.05.

3. Results

Fifty-six patients were included in this study, and they were divided into three groups according to the method of TPS insertion.

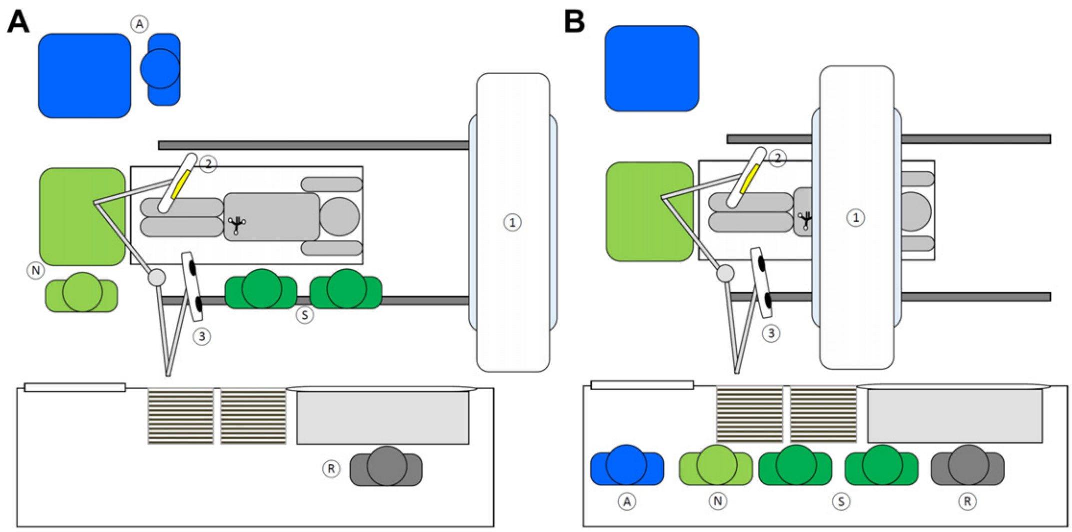

Fig. 2. (A) Before intraoperative CT (iCT) scan; (B) during iCT scan. Symbols: ① : iCT; ② : touchscreen; ③ : camera; Ⓐ : anesthesia team; Ⓝ : scrub nurse; Ⓢ : surgeons; Ⓡ : radiologist.

There were 22 patients in the CTF group (106 screws), 15 patients in the CTB group (70 screws), and 19 patients in the iCT group (156 screws; 114 screws in the lumbar region were included and 42 screws in the thoracic region were excluded). The demographic data (Table 1), including patient number, age, and American Society of Anesthesiologists (ASA) physical status class I–III, were not significantly differentbetween the three groups. Blood loss in the iCT group tended to be lower, but it was not shown to bestatisticallysignificant. Moreover, on average the iCT group had more screws inserted per patient ($p = 0.009$).

The rate of screw insertion without pedicle wall penetration was 89.62% (95 of 106 screws) in the CTF group, 98% (69 of 70 screws) in the CTB group, and 98% (112 of 114 screws) in the iCT group ($p = 0.01$; post hoc CTF < CTB = iCT). Pedicle breach distances >2 mm were observed in 5.66% (6 of 106 screws), 0%, and 0% of insertions in the CTF, CTB, and iCT groups, respectively. In the CTF group, five screws demonstrated breach <2 mm (2 medial and 3 lateral), five screws demonstrated breach 2–4 mm (2 medial and 3 lateral), and one screw demonstrated 6-mm lateral breech. One patient in this group developed some residual neurologic deficits due to the 6-mm laterally breeched screw. In the CTB group, one screw demonstrated 1.2-mm medial breach. In the iCT group, one screw had 0.3-mm lateral breach and 1.8-mm medial breach. There were no other screw-related complications in the CTB or iCT groups.

4. Discussion

TPS insertion accuracywas highest in the CTB (98%) and iCT groups (98%). Using CTB or iCT navigation, spinal surgery and screw insertion into the lumbar spine can be executed with a high degree of accuracy. In a cadaveric study comparing four methods of pedicle screw insertion, the breech rate of using anatomical landmarks, fluoroscopic navigation, and fluoroscopic-CT navigation were 29.4%, 32.4%, and 20.6%, respectively.[2] In our data, the breach rate for fluoroscopic navigation was 10.38% and 2% for CT-based navigation. In another retrospective comparative study by Costa et al, the accuracy of TPS insertion (504 screws in 100 patients) was 91.8% in the CTB group and 95.2% in the iCT group (O-arm).[10] No statistically significant differences were found between these two groups. In our results, the CTB group and iCT groups both exhibited high TPS accuracy, up to 98%, which is comparable to the results

Table 1
Demographic data of the 56 patients included in this study.

	CTF	CTB	iCT	p
No.patients	22	15	19	0.730
Age (y)	62.10 ± 12.38	62.59 ± 11.11	56.79 ± 22.14	0.081
ASA	I 5	I 4	I 4	0.100
	II 12	II 8	II 10	
	III 5	III 3	III 4	
Diagnosis				
Degenerative	17	12	12	
Scoliosis	10	8	6	
Spondylolisthesis	5	2	2	
Failed back surgery	2	2	3	
Traumatic	5	3	2	
Adolescent idiopathic scoliosis	0	0	5	
Screw/patient	5.10 ± 1.65	5.13 ± 1.45	8.21 ± 3.42	0.009* (iCT > CTF = CTB)
Blood loss (mL)	1302.94 ± 717.74	1275 ± 630.26	850 ± 410.28	0.085
Preoperative Hb (g/dL)	12.93 ± 1.28	13.41 ± 1.25	13.77 ± 2.16	0.622
Preoperative Hct (%)	38.41 ± 2.82	39.75 ± 6.61	40.81 ± 5.89	0.580

CTF: CT-free navigation; CTB: CT-based navigation; iCT: intraoperative CT integrated navigation; ASA: American Society of Anesthesiologists physical status (class I–III). Values are the mean ± standard deviation. * $p < 0.05$.

reported by Costa et al. The improvement in the accuracy of screw insertion using CTB and iCT navigation was the result of the better trajectories that could be obtained using 3D-CT image guidance. With better screw accuracy, the CTB and iCT navigation methods can be used to treat severely deformed spinal conditions and trauma and can be used during revision surgery.[11] In a cadaveric study by Chan et al, the researchers concluded that pedicle width <4.0 mm is associated with a higher risk of pedicle perforation.[12] Under verified registration, the CT image can accurately depict bone morphology including pedicles, vertebral bodies, previous spinal implants, bone grafts, tumors, adjacent visceral and vascular structures, and even neural elements. Therefore, the correct choice of trajectory and screw size can be made using guidance from CT images using either CTB or iCT navigation during the treatment of severe deformities.[13] However, iCT navigation has some advantages over CTB navigation as it demonstrates reduced surgical time, less blood loss, a more accurate CT image, requires less time for registration, and it gives the surgeon the ability to double-check the screw during the operation. In the comparative study by Costa et al, the researchers found that the surgical time was significantly reduced when using intraoperative CT (O-arm) navigation with an automatic registration system to avoid pair-point matching registration.[10] During CTB navigation, pair-point match registration is mandatory due tochanges in the patient's position after anesthesia; however,this can be eliminated by using an intraoperative CT scan without changing the patient's position. In addition, more accurate spine adjacent association in iCT navigation can also be expected, which prevents multiple verifications during multiple-level surgeries. In this study, patients in the iCT group had significantly more screws inserted, but the patients tended to have less blood loss. We believe that this was due to the reduction in the surgical time necessary for registration compared with the multiple manual registrations required in the CTF and CTB groups. In addition, multiple-level screw insertion in the iCT group was easier due to the scanned level, which can include whole spinal segments and reduce the need for the multiple scans required for CTF navigation[14] and portable CT navigation (such as O-arm),[15] which avoids additional radiation exposure during surgery. The confirmation CT scan in the iCT group also provided immediate data on screw positioning after insertion, allowing for prompt correction when necessary.[11] CTB navigation can only be confirmed by 2D fluoroscopy.

The limitations of this study include the lack of records regarding the radiation dose, time required to complete registration, and time required to finish screw insertion due to the retrospective nature of the study.

5. Conclusions

CT navigations (CTB and iCT navigation) result in significantly higher screw insertion accuracies as compared with 2D fluoroscopic navigation for TPS insertion ($p = 0.01$). Intraoperative CT-integrated navigation provides additional advantages, including simpler registration and the ability to double-check positing during the operation, and it also tends to result in less blood loss.

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