

## Computed Tomography-Based Navigation-Assisted Pedicle Screw Insertion for Thoracic and Lumbar Spine Fractures

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**Background:** Incorrect placement of pedicle screws may lead to neurovascular injury, so the position is important for the reduction of spinal fractures. CT-based image-guided surgery has been promoted as a means to theoretically improve the accuracy of pedicle screw placement. Patients who underwent CT-based navigation-assisted pedicle screw fixation for thoracic or lumbar fractures were reviewed to evaluate the accuracy of pedicle screw placement for spinal fracture cases.

**Methods:** A computed tomographic (CT)-based image-guided system (BrainLAB) was used for pedicle screw insertion in 14 patients with thoracic or lumbar spine fractures. The accuracy of pedicle screw placement was analyzed by the preoperative and postoperative Cobb's angle and sagittal screw angle with a review of radiographic images, and the penetration of the pedicle cortex by postoperative CT scans.

**Results:** Under the guidance of CT-based navigation 102 screws were inserted. Cobb's angle was corrected to an average of 15 degrees in the 14 patients. The sagittal screw angle was less than 10 degrees for 92 (90.2%) screws, and the overall average was 5 degrees. The results of the postoperative CT review showed only 3 (2.9%) screws penetrated the pedicle cortex laterally and no screw penetrated medially. No iatrogenic neurological injury was found.

**Conclusion:** The accuracy of pedicle screw placement is crucial for thoracolumbar spine fracture fixation. The placement of pedicle screws can be done accurately with the aid of a CT-based image-guided system. Furthermore, this opens the possibility for surgeons to reduce radiation exposure by eliminating the need for intraoperative fluoroscopy.

(*Chang Gung Med J* 2012;35:332-8)

**Key words:** CT-based navigation, computer-assisted surgery, pedicle screw placement, thoracolumbar spine fractures

Pedicle screw fixation has been commonly used for spinal stabilization in spine surgery. The bio-

mechanical advantages of transpedicular screw fixation for spinal fractures include three-column control

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Received: Dec. 2, 2010; Accepted: Dec. 12, 2011

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of vertebral segments and fixation of a vertebral segment in the absence of intact posterior elements.<sup>(1)</sup> Biomechanically, it is better than the hook-rod system and allows more corrective force applications on the spinal column.<sup>(2-4)</sup> Incorrect placement of pedicle screws may adversely affect the reduction of spinal fractures, which in turn can lead to neurovascular injury, so the position of pedicle screws is critical in the fixation of thoracic and other spinal fractures. The advent of high speed computers and computed tomography (CT) has revolutionized medical imaging in preventing postoperative complications, and allows spine surgeons to perform CT-based image-guided surgery. The image-guided system has appeared to improve the surgical accuracy and safety of pedicle screw placement.<sup>(5)</sup> Radiographic images and postoperative computed tomography scans were reviewed to evaluate the accuracy of pedicle screw placement with CT-assisted navigation in thoracic or lumbar fractures.

## METHODS

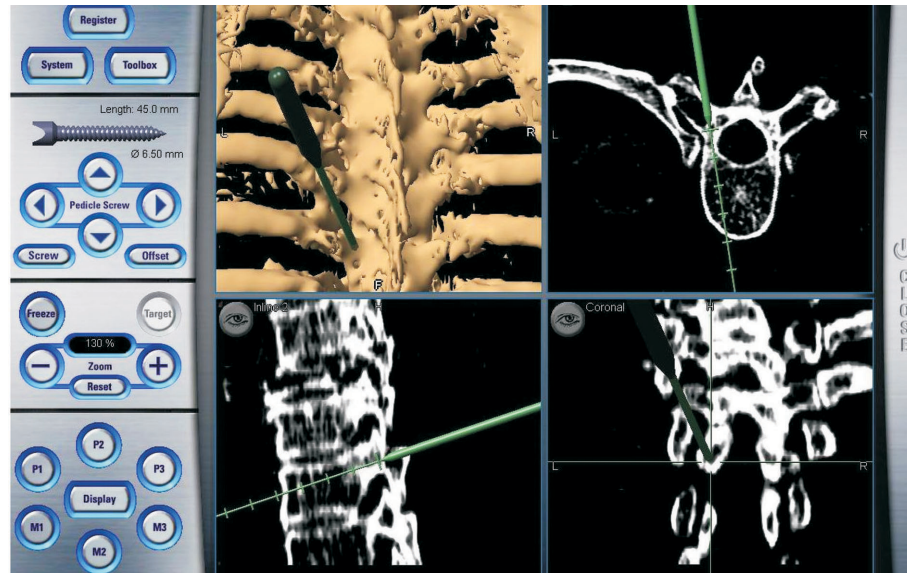
From August 2003 to January 2004, patients who received CT-based navigation-assisted pedicle screw insertion for thoracic or lumbar spine fractures were retrospectively reviewed. The inclusion criteria for the study were unstable vertebral body burst fractures, fracture dislocations or unstable pathologic fractures with neurological symptoms. Fourteen patients qualified for this study, and their causes of injury included falls from a height (4 cases), motor vehicle accidents (5 cases) and pathologic fractures (5 cases). The pathologic fractures included 2 cases of lung cancer metastasis, and 1 case each of osteoporotic fracture, spinal tuberculosis and ankylosing spondylitis. To treat these conditions, a CT-based image-guided surgery system (BrainLAB) was used to facilitate pedicle screw insertion. For all patients, thin-section CT scans (slice thickness, 2 mm) of the spinal segments to be instrumented were assessed preoperatively. The image data were transferred to the image processing software in the computer to reconstruct a three-dimensional bone structure model of the involved spinal segments. Then, a surface matching procedure was performed by selecting reference points on the dorsal bony surface of the posterior element, which was repeated for every motion segment. The registration procedure was completed

when the selected points in the surgical field were matched to their corresponding points in the image data set. With the visual assistance of the BrainLAB navigation system, the entry point for the pedicle screw was chosen at the junction of the lateral aspect of the lamina and transverse process, and the inclination and convergent directions of the pedicle screw were determined by a pedicle probe. Finally, the pedicle screw was inserted at the expected position, and direct visualization of screw implantation was shown on the computer display of the system (Fig. 1).

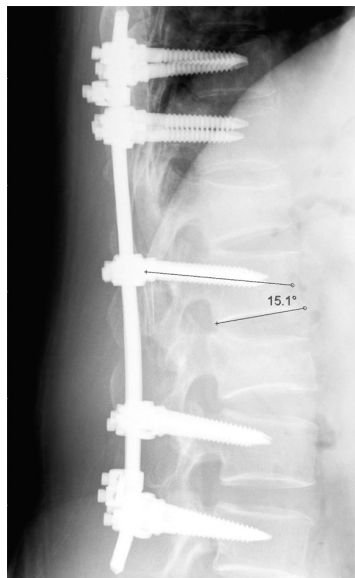
The accuracy of pedicle screw placement within the pedicle and the vertebral body was analyzed. Both preoperative and postoperative Cobb's angles were measured using sagittal radiographic images as the angle between two lines or lines drawn perpendicular to them, where a line is drawn parallel to the superior endplate of the superior end vertebra (above the highest fractured vertebra) and a line is drawn parallel to the inferior endplate of the inferior end vertebra (below the lowest fractured vertebra). The correction of kyphosis was determined by subtracting the postoperative Cobb's angle from the preoperative Cobb's angle. The sagittal screw angle was defined as the angle found between a line drawn parallel to the inferior endplate of the instrumented vertebra and a line drawn through the center of the screw (Fig. 2).<sup>(6)</sup> Thin-section (3 mm) postoperative computed tomography scans were assessed for all patients to determine the position of the pedicle screws and the penetration of the pedicle cortex (Fig. 3). The perforation of the pedicle cortex was classified as either medial or lateral, and categorized into the following four groups: 0–2.0 mm, 2.1–4.0 mm, 4.1–6.0 mm, or 6.1–8.0 mm.

## RESULTS

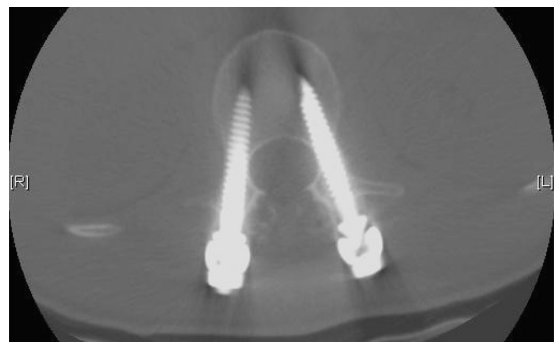
A total of 102 pedicle screws were inserted between T1 and L5 with the assistance of the CT-based navigation system. The average kyphosis correction between the preoperative and postoperative Cobb's angles in the 14 patients was 15 degrees (Table). The average sagittal screw angle of the 102 screws was 5 degrees and 92 (90.2%) screws had sagittal screw angles of less than 10 degrees. The postoperative CT scans revealed that only 4 (3.9%) screws had lateral penetration of the pedicle cortex.



**Fig. 1** The BrainLAB CT-based navigation system is used for pedicle screw insertion. With the visual assistance of the navigation system, the entry point is chosen at the junction of the lateral aspect of the lamina and transverse process. The pedicle screw is then inserted based on the guidance provided on the computer display of the system.



**Fig. 2** The sagittal screw angle is defined as the angle found between a line drawn parallel to the inferior endplate of the instrumented vertebra and a line drawn through the center of the screw.



**Fig. 3** The penetration of the anterior vertebral cortex, and medial and lateral pedicle cortex is determined using postoperative CT scans. There is no penetration of the pedicle cortex and anterior vertebral cortex in this case.

Among these 4 screws, pedicle perforation of 0-2.0 mm was found in 3 screws and 2.1-4.0 mm in 1 screw. No medial cortical penetration or anterior vertebral cortical penetration was observed. No cases of iatrogenic neurological injury were found, but there was one case of deep wound infection, which was resolved by debridement and intravenous antibiotic treatment.

## DISCUSSION

Transpedicular screw fixation offers three-column stabilization and has become an innovative treatment of thoracic and lumbar fractures. In 2002, Yue et al. conducted a retrospective observational study in which transpedicular screw fixation was performed in 32 patients with 79 individual vertebral injury levels,<sup>(1)</sup> and a total of 252 pedicle screws were placed between segments T2-L1. The study concluded that transpedicular screw fixation may offer supe-

**Table** Patient Data

	Age	Gender	Cause of fracture	Fracture site	Kyphosis correction	Fusion level		Screw number	Remarks
						From	To		
1	64	M	Traffic accident	T12	21	T10	L2	8	
2	39	M	Ankylosing Spondylitis	L1, L2	40	T10	L5	12	
3	19	M	Traffic accident	T12	14	T11	L1	4	
4	71	F	Metastasis	T3, T4	6	T1	T7	8	(1)
5	80	F	TB spine	T4, T5	8	T2	T8	8	
6	79	F	Osteoporotic Fx	T12	22	T10	L2	8	(2)
7	29	F	Fall	L1	19	T11	L3	8	(3)
8	63	M	Metastasis	T5, T8, T11	11	T2	L3	12	
9	43	M	Fall	T12, L2	8	T10	L4	10	
10	53	M	Traffic accident	T12	15	T8	T12	6	
11	23	F	Traffic accident	T12	10	T11	L1	4	(4)
12	41	M	Fall	L2	10	L1	L3	4	
13	45	F	Traffic accident	T12	15	T10	L1	6	
14	22	F	Fall	L1	11	T12	L2	4	

**Abbreviations:** TB: tuberculosis; FX: fracture; T: thoracic; L: lumbar. Remarks: (1) Right T1 screw with lateral wall penetration. (2) Right L1 screw with lateral wall penetration. (3) Left L3 screw with lateral wall penetration and deep wound infection, all three lateral pedicle perforations, 0-2.0 mm. (4) T11 screw with lateral wall penetration, 2.1-4.0 mm.

rior three-column control in the absence of posterior element integrity, and also provide rigid fixation for unstable upper, middle and lower thoracic spine injuries, and still yield early pain-free fusion results.

Pedicle screw insertion is a technically demanding procedure which still has limitations. The documented overall complication rate for the use of pedicle screws ranges between 21% and 27%.<sup>(7)</sup> In approximately 10% of cases, intraoperative complications developed into neurological impairment from causes such as nerve root injury, pedicle fracture, dural tear injury with cerebrospinal fluid leakage, vascular injury, visceral injury from screw overpenetration, and screw malposition. Pedicle violation often occurs in the thoracic spine because the pedicle screws emerge from the vertebral body into the sagittal and transverse plane at various insertion angles and the pedicle diameter and distance to the anterior vertebral cortex decrease at higher levels. In addition, thoracic screw placement is more difficult because the pedicles are smaller and vary in size, intraoperative fluoroscopic imaging is difficult to perform, and consistently reliable anatomic entry points and the trajectory for screw insertion are

unavailable. The potential risks of screw misplacement, including significant neurological damage to the spinal cord, aorta, vena cava, iliac vessels and azygos vein, are higher because of the smaller size of the pedicle and its proximity to the spinal cord and neurovascular structures of the spine.<sup>(8,9)</sup>

For the above reasons, the percentage of misplaced screws in the thoracic spine is quite significant. The reported rate of thoracic pedicle wall violation ranges from 15.9% to 54.7% in the literature.<sup>(2,10,11)</sup> Vaccaro et al. reported that 37 of 90 screws were found to have penetrated the pedicle cortex with a 41% pedicle perforation rate for free-hand thoracic pedicle screw placement performed by five experienced surgeons.<sup>(8)</sup> Liljenqvist et al. reported a 25% perforation rate of 120 thoracic pedicle screws in 32 patients with idiopathic scoliosis without any neurological complications.<sup>(2)</sup> Xu et al. reported a 54.7% thoracic pedicle perforation rate when using the anatomic Roy-Camille technique,<sup>(11)</sup> and the rate decreased to 15.9% when performing a partial laminectomy to locate the medial and superior walls of the pedicle using the open-lamina technique.

Image-guided techniques can enhance the accu-

racy of pedicle screw placement. Pedicle probes, serial radiography and C-arm fluoroscopy are used to assist pedicle screw insertion during surgery. In 2003, Carbone et al. published a retrospective review on the placement of 126 thoracic screws in 22 patients with thoracic and thoracolumbar injuries.<sup>(12)</sup> Postoperative computed tomography scans revealed that 16 screws (12.7%) penetrated the pedicle cortex, 4 (2.4%) medially and 13 (10.3%) laterally, and 7 screws (5.6%) penetrated the vertebral body. Although the pedicle screws could be inserted safely and effectively using multiplanar fluoroscopic imaging, the rate of screw misplacement was still as high as 12.7%.

A fluoroscopic-guided technique tends to be less expensive than a computer-assisted technique. However, it has several disadvantages, including radiation exposure, rib cage interference, bulky apparatus, and increased operating time.<sup>(12)</sup> Rampersaud et al. demonstrated that the radiation exposure level was significantly greater for surgeons and patients in fluoroscopically-assisted thoracolumbar pedicle screw placement.<sup>(13)</sup> The dose of radiation exposure was up to 10-12 times greater than for other fluoroscopically assisted non-spinal musculoskeletal procedures. The author suggested that spine surgeons who perform fluoroscopically- assisted thoracolumbar procedures monitor their annual radiation dose and reduce radiation exposure by avoiding body and hand positions at high radiation exposure levels, and minimizing fluoroscopy time. Also, fluoroscopy does not provide an axial plane view, which is important for spinal screw fixation because it provides critical trajectory information that neither the sagittal nor coronal plane view can provide. Fu et al.<sup>(14)</sup> have indicated the limitations of the fluoroscopic image-guided technique by showing five out of 74 screws exhibited pedicle wall violation on the axial plane with no violation on the sagittal plane, which is caused by lack of an axial plane view. Fluoroscopy can only provide real-time two-dimensional images of a complex three-dimensional spine structure.

There are several advantages of CT-based image-guided pedicle screw insertion in thoracic and lumbar spine fractures. The radiation exposure to surgeons, patients and operating room staff is reduced when intraoperative fluoroscopy is not used; additionally, the operating time and the risk of infection are also reduced. Adjusting fluoroscopy takes

longer than setting up a CT navigation system, so the operative time is shorter in CT-assisted navigation surgery than fluoroscopy-assisted surgery. Corbone et al. reported 3 cases of wound infection (7%) in 41 patients who underwent fluoroscopically-assisted thoracic screw placement, for which wound debridement and intravenous antibiotics were required.<sup>(12)</sup> The infection rate is associated with the operative time, so fluoroscopy-assisted pedicle screw placement seems to have a higher risk of wound infection.

In previous studies, some authors concluded that the accuracy of pedicle screw placement is improved and the risk of resulting complications from screw misplacement is reduced with intraoperative computer guidance. Laine et al. performed a randomized controlled clinical study to evaluate the accuracy of computer-assisted pedicle screw insertion versus conventional screw placement in 100 patients who received posterior thoracolumbar or lumbosacral pedicle screw instrumentation.<sup>(15)</sup> This study demonstrated that the pedicle perforation rate significantly decreased from 13.4% with the conventional technique to 4.6% with a computer-assisted surgical system and there were no clinical complications related to the use of computer assistance. Amiot et al. presented a comparative study between 100 patients surgically treated with conventional screw instrumentation using biplanar fluoroscopy and 50 patients with computer assistance for various spinal disorders such as degenerative segmental instability, traumatic fractures or spondylolisthesis.<sup>(16)</sup> The results proved that the computer-assisted surgical procedure was significantly superior to the conventional procedure, and the perforation rate decreased from 15% (83 of 544 screws) to 5% (16 of 294 screws). While 7 patients in the conventional group required reoperation because of neurological problems, no revisions were required for the computer-assisted group.

Pedicle screw insertion can be planned and the appropriate length and diameter of the screw can be determined if CT images are analyzed before surgery. The preoperative CT scans used in the navigation system are prepared within a matter of minutes. The software of the navigation system and the surgical tools are easy to use and the computer-generated three-dimensional CT image reconstruction provides critical anatomical information for pedicle screw placement. The CT-based computer-assisted pedicle screw placement could ideally eliminate



pedicle perforation, however, factors such as small pedicles, registration errors, hardware problems and lack of technical familiarity all may produce errors in screw placement which can limit the CT-based computer-assisted surgical procedure.<sup>(9)</sup> No learning curve effect was observed in a retrospective conventional technique cohort.<sup>(16)</sup> Overall, CT-based computer-assisted navigation surgery allows spine surgeons to more accurately insert pedicle screws for thoracic and spine deformities.<sup>(15,17-21)</sup>

### Conclusions

The accuracy of pedicle screw placement is critical for thoracic and lumbar spine fracture fixation and reduction. With the aid of CT-based navigation-assisted technology, the placement of pedicle screws can be done accurately by reducing the perforation rate and the risk of postoperative neurological complications. Furthermore, it is possible to minimize radiation exposure for surgeons and patients if intraoperative fluoroscopic image guidance is not used.

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## 電腦斷層導航系統於胸腰椎骨折之應用

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**背景：**椎弓螺釘對於脊椎骨折的復位固定相當重要，我們回顧我們以電腦斷層導航系統輔助之下施打的胸、腰椎椎弓螺釘，其術後之影像檢查及位置。

**方法：**共有 14 位病患因胸、腰椎骨折接受電腦斷層導航系統輔助之椎弓螺釘固定，我們以 X 光及電腦斷層檢視術後骨釘的角度及準確性。

**結果：**共 102 支椎弓螺釘在電腦斷層導航輔助之下施打，平均柯卜氏角度矯正為 15 度，平均矢狀切面之螺釘角度為 5 度，其中 92 之螺釘 (90.2%) 之矢狀切面角度小於 10 度。只有三支螺釘在術後的電腦斷層中發現有穿出外側骨皮質的情形，沒有內側骨皮質破損及醫源性神經受損情形發生。

**結論：**在電腦斷層導航系統輔助下施打椎弓螺釘可增加螺釘的準確度，不需術中的 X 光監測及調整，可減少手術中輻射暴露。

(長庚醫誌 2012;35:332-8)

**關鍵詞：**電腦斷層導航，電腦輔助手術，椎弓螺釘，胸腰椎骨折

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受文日期：民國99年12月2日；接受刊載：民國100年12月12日

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