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The accuracy of multi-slice three-dimensional computerized tomography on the verification of the pedicle screw trajectory

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Abstract

The purpose of our study was to determine the diagnostic power of three-dimensional reformatted multi-slice computerized tomography (CT) images on misplaced pedicle screws in spinal surgery. Eighty-four consecutive patients with 458 screws *in situ* were investigated prospectively using both axial CT slices and reformatted images after operation by two blinded investigators. All the screw misplacements were documented and the differences between the two imaging modalities were recorded. Axial CT slices were able to show only 23 of 60 misplaced pedicle screws; multi-slice CT was three times more powerful in the diagnosis of pedicle screw complications in spinal surgery ($p<0.05$). We concluded that multi-slice CT reconstruction should be the primary diagnostic tool after screw implantation in the human spine.

Introduction

The transpedicular screw placement during spinal surgery has increased in popularity. Over the last decades, the growing indications for surgery have been spondylolisthesis, segmental instability, vertebral fractures, spinal stenosis, degenerative disc disease, and scoliosis.[1] Both intra- and postoperative complication rates are significantly lowered by using the Funnel technique. This technique is commonly accepted by spinal surgeons and presents a slight modification of the Roy-Camille pedicle screw insertion method.[1-3] However, there are significant screw misplacements with pedicle perforation, endplate penetration, and vertebral body extrusion reported, with 40-67%, even in experienced hands.[4-6] These complications lead to complaints of significant radicular or mechanical pain, with or without neurological deficits, in the postoperative period. The reported rate of postoperative transient neurological involvement has been as high as 11%,[7] and of permanent root trauma between 1.5% and 3.2%.[8-10] These complications promoted surgeons to increase intraoperative safety; for example, with stereotactic guidance, electronic nerve stimulators, and neuromonitorization techniques (electroneuromyographs, evoked potentials, etc.), with scanning of pedicle screw trajectory by computerized tomography (CT), in the early postoperative period.[8,9,11-13]

Conventional radiography was the first utilized diagnostic tool to identify the accuracy of screw placement in the postoperative period but it has been found to be five times less efficient than axial CT slices.[4,14,15] However, there are some handicaps of axial CT scanning: first, the difficulty of following the oblique trajectory of screws in slices; second, the lack of three-dimensional (3D) formatted images; and third, the imprecise vision of implanted material because of metal artifacts.[6,8,14-17]

The purpose of our study was to investigate the pedicle screw accuracy via multi-slice CT reconstructions in surgical cases, comparing the results with conventional X-rays and axial CT slices, and to evaluate the diagnostic value of multi-slice CT in complicated pedicle screw cases.

Materials and Methods

This study was planned as a prospective and blinded comparison of multi-slice CT accuracy in determining pedicle screw trajectory in patients undergoing lumbar fusion surgery. All of the patients had posterior transpedicular fusion procedures because of spondylolisthesis, severe lumbar instability, spinal stenosis, and failed spinal surgery. We used a midline skin incision over the segments requiring fusion and bluntly dissected the paravertebral

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muscles subperiostally, after which the transverse processes were exposed. Using the entry point in the lumbar spine as the intersection of the two lines marking the midline of the transverse processes and the lateral border of the superior articular processes, the screws were inserted into the vertebral body. Under real-time image intensifier use, insertion was completed at an angle of 30° to the sagittal plane.[1-3] Preoperative vertebral body diameters were measured and the screw length required to penetrate 80% of the vertebral body diameter was selected. Both final sagittal and anteroposterior images of the implanted system were received by the image intensifier before completion of the operation.

After surgical intervention, all patients underwent conventional radiography within 48 hours. There were no screw misplacements identified in this stage. The same patients received multi-slice CT between the first and eighth day postoperatively. The patients' complaints of pain and neurological status were scanned and recorded by an independent neu-

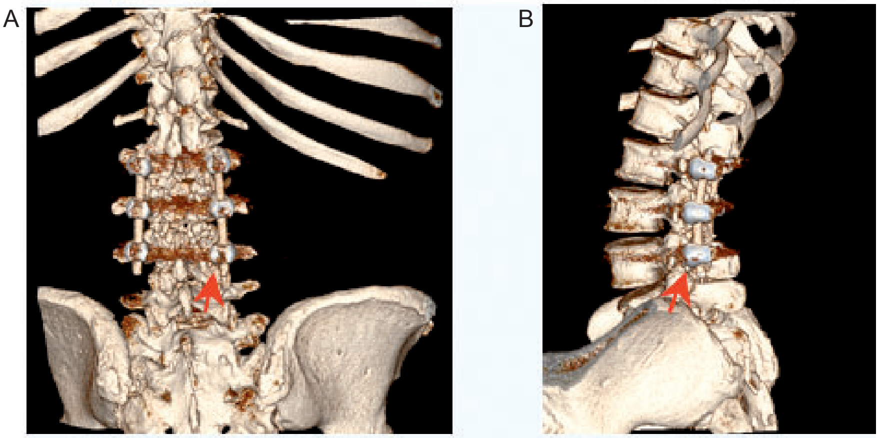

Figure 1. (A) and (B) show excellent views of both skeletal anatomy and architecture of implanted material on reformatted three-dimensional images. The arrows show the correct insertion of screws into the pedicles.

Table 1. Patient demographic characteristics.

Age	48.4 ± 14.7
Sex (F/M)	52/32
Pathology	
Spondylolisthesis	47
Failed back surgery	16
Spinal stenosis	13
Traumatic fracture	8

rologist both pre- and postoperatively (Table 1). The CT scans with 0.6 mm thick slices were performed in a standardized way (Somatom Sensation 40 detector multislice, Siemens Germany). Reformatted images were done using computer software to obtain 3D images. Metal artifacts were cleared in a reformatted window so that the screw trajectory was clearly visible after the multi-slice CT (Figure 1).

A total of 458 pedicle screws (84 patients) was evaluated. The two blinded radiologists (RG and ACY) reported the final position of all screws, the screw trajectory, and cortical and neural perforations by conventional radiography, axial CT slices (including artifact), and 3D images of the multi-slice CT. All results were compared at the end of the study. Statistical analyses were performed using the Student *t*-test. Data are presented as the mean ± standard deviation, statistical significance set at $p<0.05$.

Table 2. Pedicle screw characteristics and inserted vertebra levels.

Vertebral level	Screw length (mm)	Screw diameter (mm)	Total
L2	8 (45), 4 (50)	6 (4.5), 6 (5.2)	12
L3	16 (45), 12 (50)	18 (4.5), 10 (5.2)	28
L4	124 (45), 38 (50)	124 (4.5), 38 (5.4)	162
L5	144 (45), 60 (50)	144 (4.5), 60 (5.4)	204
S1	32 (45), 20 (50)	28 (4.5), 24 (5.2)	52

Table 3. Summary of location and perforation severity of 458 screws; comparison of axial and reformatted three-dimensional studies.

	Axial images			Three-dimensional reformatted images				
	Lateral	Medial	Total	Lateral	Medial	Caudal	Cranial	Total
Encroachment	7	8	15	12	9	5	3	29
Pedicle penetration								
Minor (<3 mm)	1	0	1	1	1	0	0	2
Moderate (3-6 mm)	0	1	1	0	1	1	0	2
Severe (>6 mm)	2	1	3	3	1	2	1	7
Endplate penetration	1	0	1	2	2	3	2	9
Vertebral extrusion	2	0	2	6	0	3	2	11
Total	13	10	23	24	14	14	8	60

Table 4. Visual analog scores for postoperative pain in cases with pedicle or endplate perforation.

	Low back pain		Leg pain	
Group	Preop	Postop	Preop	Postop
Correct placement^{47}	9.1±2.7	4.6±2.1*	8.4±3.7	3.1± 2.4*
Endplate or pedicle perf^{2}	8.7±2.3	7.2±4.3*	8.6±2.1	1.8± 0.9*

Postoperative values are the means of five consecutive examinations. No statistically significant between-group differences were found ($p>0.05$). *Significantly lower than preoperative values ($p<0.05$)

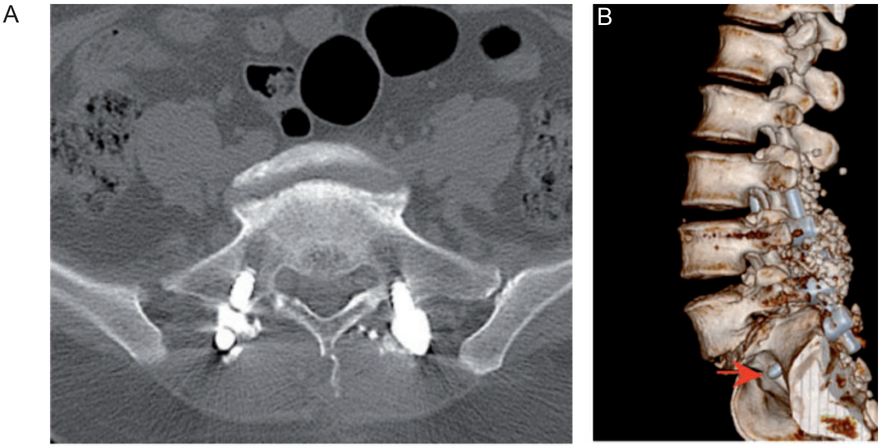

Figure 2. (A) Axial CT slice showing full bone insertion of screws without intra-neural insertion. (B) Clearly visualized vertebral anterior wall perforation (arrows) in the same patient.

Results

The screw lengths, diameters, and inserted vertebral levels were documented (Table 2). At the final decision there were no screw misplacements at the insertion points into the pedicles. However, after insertion there were 60 screws in 27 patients that showed different degrees of cortical perforations along the trajectory in multi-slice reformatted images. Eleven screws showed vertebral body extrusions at the tip of the implant, and nine screws showed endplate perforation (Table 3). Only 23 of the 60 cases of malpositioning could be verified in axial CT slices. Thus, the diagnostic power of multi-slice CT was three times higher than that of the axial slices.

The postoperative pain according to the visual analog scores (VAS) was higher in the cases having endplate or pedicle perforation, but no statistical difference was observed (Table 4). The increased postoperative neurological deficit associated with pedicle perforation via medial cortical damage was shown in three cases. In two cases these perforations could not be observed in CT axial slices but were obvious in multi-slice reconstructions. Similarly, the majority of endplate perforations could not be observed in the axial slices (Figures 2 and 3).

There was no difference between the results of the two neuroradiologists who evaluated the postoperative images. Overall, the rate of pedicle cortical perforation was 8.7%, screw extrusion from the cortical wall of the vertebral body was 2.4%, endplate perforation was 1.9%, and the total misplacement rate was 13.1%. There was no foraminal insertion or direct penetration of the dural sac observed.

Discussion

Although there are more improved surgical techniques and increased real-time use of the image intensifier, the wrong placements of pedicle screws may occur. Moreover, some screws may show cortical or endplate penetration or vertebral body extrusion, even with correct engagement into the pedicle.[4,14,15,18-20] The expected complications were minimized with the Roy-Camille technique and simultaneous use of the image intensifier in spinal stabilization; nevertheless, screw misplacements have not been reduced yet.[1-3,10,21,22] Although plain X-rays are helpful, postoperative CT scanning has been accepted as the gold standard to evaluate screw location.[6,11,16,17,23] However, the CT slices can show the proximity between the screw and bony or neural elements only in two dimensions. Moreover, metallic artifacts and the difficulty of following the screw trajectory between the slices are problematic in axial CT images.[6,14-16] The difference between axial and multi-slice images illustrates the inadequacy of the axial images. These results strongly suggest the requirement for multi-slice imaging.

There are other techniques for ensuring proper screw placement into the pedicle. Xu *et al.* compared the Roy-Camille with the open lamina technique in ten cadaveric spines using 189 pedicle screws. They found more cortical violations (55%) by using the Roy-Camille than open-lamina method without the aid of fluoroscopy.[24] Hertlein *et al.* also described the insertion of the pedicle screws from an anterior approach.[25] In the last decade, the use of robotics technology and computer-based stereotaxic screw placement have gained in popularity.[5,26-28] The lack of the stereotaxic system and intraoperative use of the CT scanner are limitations of our study.

To date, the Roy-Camille technique is the most widely accepted procedure by spinal surgeons worldwide. The insertion point is the midpoint of the line between the transverse processes as it crosses the top of the pedicle. Under visualization with the biplanar image intensifier, the taps were used with gradually increasing diameter along the isthmus of the pedicle. For safe placement the insertion angle was 10° for the thoracic vertebrae, 20° for the lumbar vertebrae, and 25° for the fifth lumbar vertebra.[1,2,3] This technique, which we used in the present study, is also called the Funnel Technique and can be used with both somatosensorial evoked potentials and electromyography for neurophysiological monitoring.[29-31]

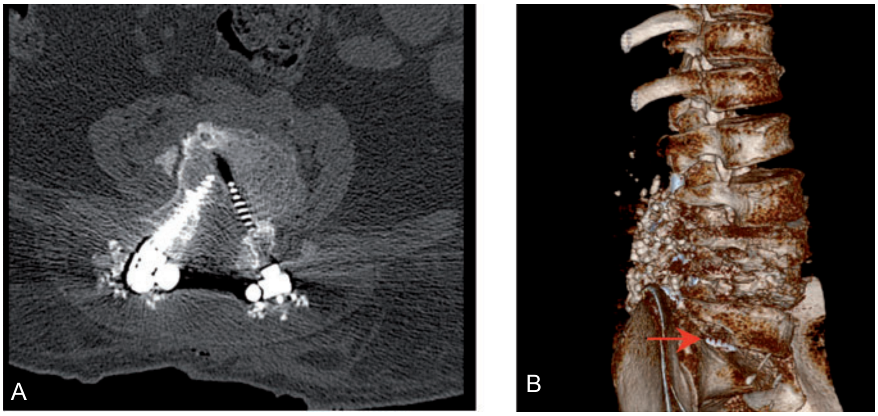

Figure 3. (A) Axial CT slice showing normal anatomic insertion of both screws in vertebral bone in a severely osteoporotic and rheumatoid patient. (B) The endplate extrusion of the right-side screw (arrow) was visualized by multi-slice CT.

The postsurgical evaluation of the screw position has evolved with time. The first reports used X-rays to control the final screw position. After the initial experience, CT scans were used to assess screw placement. CT slices were found to be more accurate with better visualization of the screw position than conventional X-rays.[4,14-18,20] Guven *et al.* investigated the accuracy of in vivo CT scanning in the placement of pedicle screws in thoracic and lumbar spines. The screws were inserted according to the Roy-Camille technique without fluoroscopy. The authors classified the screw position according to cortical perforation or horizontal and lateral misplacement. There were 3% medial, 5% lateral, and 2% superior cortical misplacements observed without serious screw-related complications.[11]

Sapkas *et al.* graded thoracic and lumbar pedicle screw placement as either "in" or "out" according to postoperative CT scans and plain radiographs obtained in 35 patients. The investigators concluded that CT scanning depicted screw misplacements more clearly than did plain radiography.[23] In their study, Heary *et al.* described a simplified grading system based on the evaluation of postoperative CT scans. They suggested, on evaluating pedicle screw placement with the use of plain radiography, that investigators are likely to underestimate the number of misplaced screws.[15] The results of our study correlated strongly with previous reports. Both axial CT and multi-slice CT could visualize misplacement of pedicle screws more easily than could normal, plain X-rays.

However, the nerve root interaction or neurological damage cannot be excluded even if the accuracy of pedicle screw placement is perfect.[14] The Scoliosis Research Society reported a 3.2% rate of neural deficit in all procedures involving correct pedicle screw placement.[21] In a cohort study of spinal fusion operations, Yuan *et al.* concluded that 5% of the patients had intraoperative events associated with the use of pedicle screws.[32] The neurological injury rates were reported to be 4-7%.[10,22,33] The vascular or other neighboring tissue damage were reported in less than 1% of cases.[32]

In the context of this article, we tried a more realistic and accurate verification of implanted materials by multi-slice CT reconstruction. In the results, multi-slice CT has shown a more accurate picture of the screw's trajectory than either axial CT or X-rays. Moreover, the architecture of the whole implants can be evaluated easily in 3D reformatted images. This radiological modality helps the surgeon to visualize the final relationship between the implanted instruments and neural and bony architecture, especially in the presence of postoperative kypholordotic changes and screw foraminal proximity. The minimized metallic artifacts also help the surgeon to observe the bony channel of the screw in multi-planar images. In conclusion, 3D multi-slice CT can verify postoperative screw position more accurately and is of more value than conventional CT slices. The future use of intraoperative multi-slice scanners will increase the precise placement of screws and it will limit the requirement for revision surgery. Both intraoperative neurological monitoring and refinements in image modalities will shorten the operating time, increase the surgical success, and enhance the patient's quality of life in the near future.

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