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Original Article

Intraoperative three-dimensional fluoroscopy after transpedicular positioning of Kirschner-wire versus conventional intraoperative biplanar fluoroscopic control: A retrospective study of 345 patients and 1880 pedicle screws

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Abstract

Study Design: Retrospective study. **Objective:** The aim was to find out whether intraoperative three-dimensional imaging after transpedicular positioning of Kirschner wire (K-wire) in lumbar and thoracic posterior instrumentation procedures is of benefit to the patients and if this technique is accurately enough to make a postoperative screw position control through computer tomography (CT) dispensable. **Patients and Methods:** Lumbar and thoracic posterior instrumentation procedures conducted at our department between 2002 and 2012 were retrospectively reviewed. The patients were divided into two groups: group A, including patients who underwent intraoperative three-dimensional scan after transpedicular positioning of the K-wire and group B, including patients who underwent only intraoperative biplanar fluoroscopy. An early postoperative CT of the instrumented section was done in all cases to assess the screw position. The rate of immediate intraoperative correction of the K-wires in cases of mal-positioning, as well as the rate of postoperative screw revisions, was measured. **Results:** In general, 345 patients (1880 screws) were reviewed and divided into two groups; group A with 225 patients (1218 screws) and group B with 120 patients (662 screws). One patient (0.44%) (one screw [0.082%]) of group A underwent postoperative screw correction while screw revisions were necessary in 14 patients (11.7%) (28 screws [4.2%]) of group B. Twenty-three patients (10.2%) (28 K-wires [2.3%]) of group A underwent intraoperative correction due to primary intraoperative detected K-wire mal-position. None of the corrected K-wires resulted in a corresponding neurological deficit. **Conclusion:** Three-dimensional imaging after transpedicular K-wire positioning leads to solid intraoperative identification of misplaced K-wires prior to screw placement and reduces screw revision rates compared with conventional fluoroscopic control. When no clinical deterioration emerges, a postoperative CT seems to be dispensable using this intraoperative three-dimensional control method.

Key words: Accuracy, intraoperative imaging, pedicle screw, spine surgery, transpedicular instrumentation

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INTRODUCTION

Various techniques of transpedicular lumbar and thoracic stabilization were introduced and steadily developed during the past decades and have become the mainstay of spinal instrumentation.[1-15] Subsequently, various methods of intraoperative control of the implanted screws are currently practiced.[7,15-35]

In this study, we examine and compare two main methods of intraoperative fluoroscopic control. On one hand, the intraoperative three-dimensional imaging after transpedicular positioning of Kirschner-wire (K-wire); on the other hand, the conventional intraoperative biplanar fluoroscopic control solely. Another aspect, which we want to enlighten, is whether intraoperative three-dimensional imaging after transpedicular positioning of K-wire is accurate enough to make a postoperative computer tomography (CT) dispensable. We were further encouraged by the fact that, to the best of our knowledge, there is no published study at the time comparing these two intraoperative control methods or giving evidence based answer to that question, but multiple studies reporting mainly on CT-and three-dimensional-based navigation systems.

PATIENTS AND METHODS

Three hundred forty-five consecutive patients, 174 female and 171 male, were treated in our department between January 2002 and December 2012 by open and percutaneous posterior transpedicular instrumentation for thoracic and lumbar disorders; 212 patients (120 female, 92 male) for nonscoliotic spinal disorders without fractures (spondylolisthesis, spondylolysis, failed back syndrome) and 133 patients (49 female, 84 male) for instable traumatic and pathologic fractures.

The 345 patients (1880 screws) were retrospectively reviewed and divided into two groups: Group A, including patients who underwent intraoperative three-dimensional scan after transpedicular positioning of the K-wire and group B including patients who underwent conventional intraoperative biplanar fluoroscopic control solely. In our analysis, we did not distinguish between open and percutaneous techniques. To evaluate postoperative screw positions, early postoperative CT of the instrumented spinal section was done in all cases.

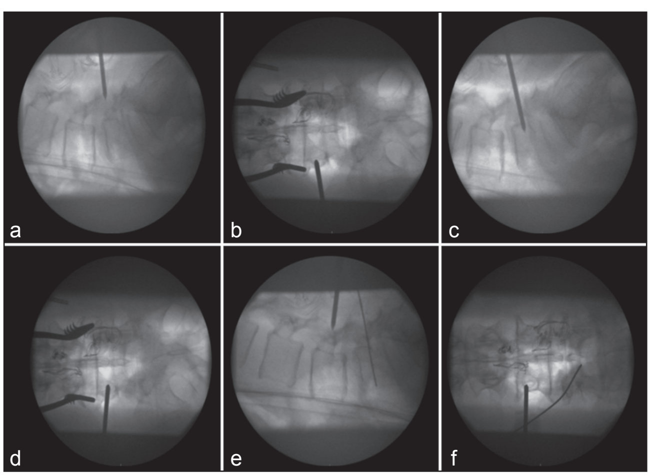

Figure 1: Pedicel probing technique used in group A: (a) Lateral view of the Jamshidi needle docked onto the entry pint of the pedicle; (b) anterior/posterior (AP) view of the needle checking the lateral aspect; (c) lateral view after inserting the needle into the vertebral body; (d) AP control view (e) lateral view checking the depth of the Kirschner wire and the entry point of the next pedicle; (f) AP control view

In both groups, the pedicles were initially localized using biplanar fluoroscopic control. In group A, the probing of the pedicles was performed via Jamshidi needle, followed by inserting 1.6 mm K-wire down the Jamshidi needle into the vertebral body depending on biplanar fluoroscopy without using image-guided navigation systems. After transpedicular intracorporeal positioning of all K-wires, intraoperative three-dimensional scan with an isocentric mobile C-arm was performed keeping the sterile conditions of the surgical field unaffected; position and angulation of the K-wires were evaluated, and the appropriate screw length and diameter were measured. Afterwards, self-tapping, cannulated screws were inserted using biplanar fluoroscopic control. Figure 1 shows the used technique of pedicle probing.

In group B, the pedicles were opened under biplanar fluoroscopy control using a probe after perforating the entry point with a sharp awl. Afterwards, the pedicle tract was palpated with a ball-tipped feeler probe. Based on preoperative measurements of screw length and diameter, the self-tapping screws were then placed in free hand style using only biplanar fluoroscopic control.

In cases of screw misplacement, pedicle screw revisions were done in both groups after evaluation of the clinical condition of the patient and the possible implant instability.

RESULTS

A total of 345 patients (1880 screws) were reviewed and divided into group A and B as aforementioned. Two hundred twenty-five patients (1218 screws) were in group A and 120 patients (662 screws) were in group B. Among group A, 23 patients (10.2%) (28 K-wires [2.2%]) were intraoperatively detected with primary false placement of K-wires and subsequently corrected during the same procedure. The replacement was confirmed by a second three-dimensional imaging [Figure 2]. In those cases, screw false placements as well as possible revisions could be primary avoided through intraoperative three-dimensional control. None of the intraoperative corrected K-wires resulted in a corresponding neurological deficit or screw misplacement.

Postoperative CT of the instrumented level was obtained in all patients. Screw revisions due to inaccurate positioning were

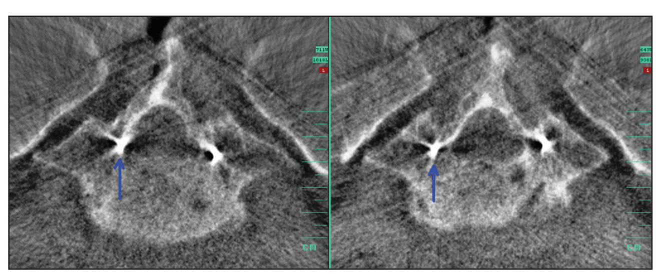

Figure 2: Left - axial view of intraoperative three-dimensional-scan showing a medially misaligned Kirschner wire (K-wire) at the right-sided S1 (arrow); (right) after appropriate K-wire correction (arrow)

encountered in one patient (0.44%) (one screw [0.082%]) of group A versus 14 patients (11.7%) (28 screws [4.2%]) of group B. The revised screw among group A showed a lateral and cranial misplacement at the right-sided L5 level and was corrected due to the possible implant instability in spite of not resulting in neurological deficit [Figure 3].

The majority of revised screws in group B were at T6, T7, and T9 levels (4 screws each), followed by T4 level (3 screws). Table 1 shows the levels of revised screws, as well as the misplacement positions in group B. Among group B, 2 screws out of 28 corrected screws, resulted in sciatica (L5 and S1) after the primary surgery due to medial pedicle violation and were, therefore, revised. The rest of the revised screws in Group B (26 screws) were corrected due to the possible implant instability [Figure 4]. Adequate clinical examination of five patients, who underwent screw revision among group B, couldn't be achieved due to initial coma conditions and paralysis.

Table 1: Level, number and misplacement position of the revised screws in Group B

Level	Number of revised screws	Screw misplacement position	
		Medial	Lateral
T1	2	1	1
T2	2	2	
T4	3	2	1
T6	4	3	1
T7	4	2	2
T8	1	1	
T9	4	3	1
T10	1		1
T12	2	2	
L1	2	1	1
L5	2	1	1
S1	1	1	

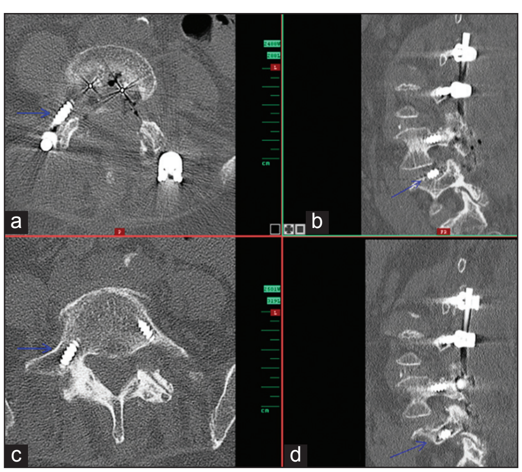

Figure 3: Postoperative computer tomography of the revised case in group A showing: (a) The misaligned screw (arrow) at the right-sided L5 in axial view; (b) sagittal view before screw correction (arrow); (c) axial view after screw correction (arrow); (d) sagittal view after screw correction (arrow)

In both groups, the diameters of the inserted screws ranged between 4 mm and 7.5 mm; mainly 6.5 mm screws were inserted (506 screws [41.5%] in group A and 254 screws [38.4%] in group B). The screw length ranged from 30 mm to 60 mm in group A and from 25 mm to 65 mm in group B; mainly screws of 50 mm length were used (544 screws [44.7%] in group A and 302 screws [45.6%] in group B) [Table 2].

Overall, there was no major statistical difference between both groups concerning the distribution of instrumented levels, screw diameter or length.

Table 2: Overview of screw diameter and length in both groups

Group A		Group B	
Diameter/number of screws	Length/number of screws	Diameter/number of screws	Length/number of screws
4 mm/12		4 mm/16	
	30 mm/6		25 mm/1
4.5 mm/108		4.5 mm/82	
	35 mm/42		30 mm/23
5 mm/36		5 mm/32	
	40 mm/90		35 mm/28
5.5 mm/168		5.5 mm/188	
	45 mm/280		40 mm/92
6 mm/198		6 mm/64	
	50 mm/544		45 mm/110
6.5 mm/506		6.5 mm/254	
	55 mm/234		50 mm/302
7 mm/68		7 mm/8	
	60 mm/22		55 mm/96
7.5 mm/122		7.5 mm/18	
			60 mm/8
			65 mm/2

Figure 4: Axial view of a postoperative computer tomography detecting a lateral screw misplacement (arrow) among group B at the left-sided T4, which was corrected due to possible implant instability

In group A, up to 4 vertebral levels could be registered during a single three-dimensional scan varying due to anatomical differences. Scanning time was 60 s for 100 images and the whole procedure, from scanning to evaluation, required between 6 and 9 min, depending on image quality and the number of instrumented levels.

DISCUSSION

The accuracy of pedicle screw placement remains a major concern of spine surgeons and has been the subject of several studies.[11,25,28,29,34,36-39] Conventionally, transpedicular instrumentation was performed based on preoperative radiographs and anatomical landmarks controlled using intraoperative two-dimensional-fluoroscopy devices.[3,22,25,31] In the course of years, there has been a shift toward much progressive intraoperative safety-related control methods. In this field, significant improvements were achieved.[7,24,26,27,30,35,40,41]

An obvious disadvantage of performing just a conventional fluoroscopic control is the lack of coronal, axial, and sagittal views, which give the surgeon an optimal feedback regarding instrumentation position. These views can be obtained using three-dimensional imaging as a control tool prior to screw implantation revealing the option of revision during the same procedure [Figure 5]. In our study, a primary screw false placement was avoided through intraoperative three-dimensional control in 10.2% of the patients among group A. This considerable percentage demonstrates our control method as a useful strategy in improving the accuracy of screw placement.

A numerous of studies, using solely biplanar fluoroscopy, are found in the literature; among others, Vaccaro *et al.* reported a misalignment rate of 41% of 90 screws placed in the T4-T12 pedicles.[32] Weinstein *et al.* inserted 128 screws in the T11-S1 pedicles of 8 cadaver specimens and reported a screw misalignment rate of 21%.[42] Castro *et al.* reported a pedicle wall perforation rate of 39.8% of 123 pedicle screws in the lumbar vertebra also using biplanar fluoroscopy alone.[36]

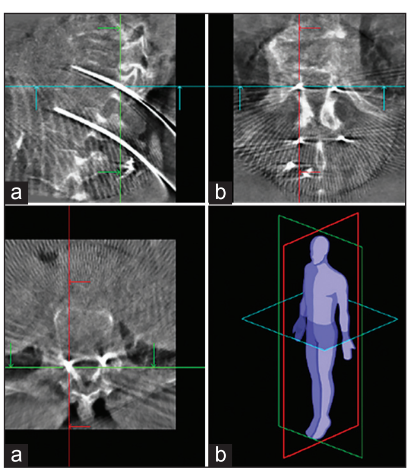

Figure 5: Three-dimensional Kirschner wire control in: (a) Sagittal, (b) coronal and (c) axial views. (d) Diagram showing body plans

To improve the accuracy of screw placement, navigation systems have been developed utilizing CT, C-arm, and O-arm devices. In 1998, Merloz *et al.* reported a misplacement rate of 8% in nonscoliotic patients using CT-based navigation versus 42% without navigation; in the same study, a misplacement rate of 14% was reported in scoliotic patients utilizing the same navigation system.[7] Two years later, Laine *et al.* reported a pedicle perforation rate of 4.5% using CT-based navigation versus 13.4% with conventional fluoroscopic control.[38] In 2010, Tormenti *et al.* reported a rate of merely 1.2% misplaced screws using CT-based navigation versus 5.2% in the fluoroscopy group.[41] Other studies utilizing C-arm-based navigation systems reported misplacement rates of 1.7-9.1%.[19-21] Park *et al.* reported a misplacement rate of 7.5% of 52 screws using O-arm-based navigation and Patil *et al.* published on a misplacement rate of 2.6% utilizing the same system.[26,27] In a recent systematic literature review, 20 studies (8539 pedicel screws) were analyzed by Shin *et al.* in a comparison between navigated (two-dimensional and three-dimensional navigation computer-assisted surgeries) and nonnavigated screw placement; the overall pedicle screw perforation risk was 6% using navigation and 15% for nonnavigated insertion.[40]

Neurological deficit due to screw misplacement was shown by Castro *et al.* to be up to 16.6% (5 out of 30 patients);[36] a lower incidence (1-3%) of neurological injury associated with misplaced screws was reported by Esses *et al.* and Lonstein *et al.*[43,44] Moreover, the papers of Schulze *et al.* and Wiesner *et al.* showed that even most eccentric screws must not result in acute neurological complications.[33,39] Nevertheless, the biomechanical strength of the construct and subsequently the spinal stability provided by the instrumentation was shown to be impacted when pedicel screws are primary mal-positioned despite early correction, as Açikbas *et al.* reported.[45] Thus, inserting a 1.6 mm-thick K-wire down a 3 mm-thick Jamshidi needle seems, at least theoretically, to be less harming to the pedicles in case of mal-positioning than the commonly used screws and could minimize the possible spinal instability. This issue makes the findings of Beck *et al.*, which show the ideal point of time for an intraoperative three-dimensional imaging to be directly after pedicle screw insertion, debatable.[17] In this field, biomechanical studies investigating the effect of smaller cortical pedicel breaches due to misplacements of Jamshidi needle or K-wires in comparison to screw misplacements are missing yet and strongly needed to provide an evidence-based proposition. We hope to make this a focus of future analyses.

In terms of screw revision rates, Zdichavsky *et al.* reported a revision rate of 5% of 278 pedicle screws using biplanar fluoroscopy alone.[46] In the aforementioned literature review by Shin *et al.*, the overall revision rate per screw insertion was 1.44% for navigated surgery and 2.03% for nonnavigated.[40] In comparison to our study (0.082% revision rate in group A giving an accuracy of 99.918%), a significant reduction was achieved using the intraoperative three-dimensional control of K-wire position. An important issue missed yet, is a direct comparison between intraoperative three-dimensional control after positioning of K-wires and navigated screw placement performed by the same surgical team. Our coming study will focus on that issue and will seek the evaluation of utilizing spinal navigation systems in addition to the control method used in group A.

However, the role of the various intraoperative control methods in minimizing the risk of screw misplacements is divisive. Usually, the surgeons are able to feel and redirect the screw.[3] Schizas *et al*. inserted 60 pedicle screws in 13 nonscoliotic spine patients in the upper thoracic spine based only on anatomical landmarks without using fluoroscopy or any image guidance method and reported a very acceptable accuracy of 88.3%.[11] Nevertheless, they concluded that the possible danger of inserting transpedicular screws should not be underestimated, and every effort should be made to develop safer guidance techniques. As for us, we also share that notion and see the meticulous control during the whole procedure as essential whether using anatomical landmarks, conventional fluoroscopy, navigation systems or control methods like ours used in group A.

As our study shows, the rate of screw revision is significantly reduced using intraoperative three-dimensional imaging control (99.9% of appropriate screw placement in the group A vs. 88.4% in group B). Nevertheless, the possibility of screw mal-positions requiring revision can't be absolutely excluded. Therefore, if the patients complain relevant clinical deficits after the procedure, a CT control should be done. Yet, a routine postoperative CT control is not necessary in patients who are free of complaints; in these cases, conventional radiographs appear in our opinion sufficient enough as standard follow-up. In addition, waiver of routine postoperative CT-control leads to a reduction of costs and radiation exposures. Nevertheless, a CT-scan could be indicated in cases of patients, who can't be adequately examined whether they have neurological deterioration, such as coma or paralysis patients. In the interests of transparency, Berlemann *et al*.'s study of 119 pedicle screws comparing between postoperative pedicle screw assessment with plain radiographs and CT reconstruction is worthy of particular mention; the authors concluded that plain antero-posterior and lateral radiographs taken postoperatively and at 3 months' follow-up insufficiently assess pedicle screw placement.[47]

In cases of severe osteoporosis or obese patients, image quality can become problematic; thus, three-dimensional scans as well as the conventional fluoroscopy generally need to be performed with higher energies to achieve acceptable radiographs. According to Deinsberger *et al*., a standard 100-image three-dimensional C-arm capture is equivalent in radiation to 40 s of standard fluoroscopy.[48] Analyzing this finding, in relation to our two methods of intraoperative control, the patients' exposition to radiation dose in group A will surely be more than in group B, but it's similar for surgeons who normally step back from the C-arm during three-dimensional-scanning; a direct statistical comparison between both data could not be done in our study.

The three-dimensional C-arm has commonly a bigger size than conventional biplanar devices, but their handling differs marginally. Furthermore, the cost of acquiring an intraoperative three-dimensional C-arm could be seen as a criticism of this control method, in comparison to the minor cost of conventional C-arm, but it seems to be affordable and economically sustainable compared to the cost of reoperations in patients with misplaced screws. A limitation of our study is the inability of giving a statistical cost-benefit analysis as adequate financial calculations are missed. Another limitation is that we didn't measure the screw perforation rate of the pedicels as we mainly focused on screw mal-positions requiring revision. In addition, our study does not classify spinal procedures by complexity, since no standardized complexity score was found in the literature.

CONCLUSION

When compared with standard fluoroscopy control, intraoperative three-dimensional imaging control of K-wire position prior to screw placement improves the accuracy of instrumentation and reduces the screw revision rate significantly. Furthermore, this method assists in selecting an appropriate screw length and immediate correction which helps minimizing the possible damage of neurovascular structures, as well as the feasible spinal instability in case of screw mal-position.

The use of three-dimensional scans, as in our study, helps to improve patient safety without impinging the intraoperative workflow. A postoperative CT seems to be dispensable after using such an intraoperative control method if there is no deterioration of the clinical status.

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