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ORIGINAL PAPER

Improved accuracy of screw implantation could decrease the incidence of post-operative hydrothorax? O-arm navigation vs. free-hand in thoracic spinal deformity correction surgery

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Abstract

Purpose The purpose of this study was to analyze the occurrence of PE after intra-operative O-arm navigation-assisted surgery and determine whether the post-operative PE incidence could be decreased by using O-arm navigation as compared to conventional free-hand technique.

Methods A cohort of 27 patients with spinal deformity who were operated upon with an O-arm navigated system (group A) between 2013 and 2016 were enrolled in the study. A total of 27 curve-matched patients treated by conventional free-hand technique were included as the control group (group B). Whole spine posterior-anterior and lateral radiographs, and CT scans were taken pre and post-operation. Radiologic parameters and volume of PE were measured and compared between the two groups.

Results There were no significant differences in age, Cobb angle, and sagittal contour between the two groups pre-operatively. The mean total volume of post-operative PE was significantly larger in the free-hand group ($p < 0.001$). In the O-arm group, 59 malpositioned screws were identified in 22 patients. In the free-hand group, 88 malpositioned screws were found among 26 patients. The screw perforation rate was higher in the free-hand group than in the O-arm group ($p = 0.007$). In the O-arm group, the mean volume of PE was significantly larger among patients with malpositioned screws than those without malpositioned screws ($p < 0.001$), as well as in the free-hand group.

Conclusion The volume of PE after correction surgery can be significantly decreased by application of O-arm navigation system as compared to conventional free-hand technique. We ascribed the improvement to the accuracy of screw implantation navigated by O-arm.

Keywords O-arm navigation · Pleural effusion · Scoliosis · Screw malposition

Introduction

Surgery for severe scoliosis by anterior and/or posterior spinal fusion are effective but extensive. Peri-operative complications such as pleural effusion (PE) are quite common [1–4]. Hayashi et al. [5] reported that PE was observed in 71% of the patients who underwent posterior corrective spinal fusion for adolescent idiopathic scoliosis. Although varying degrees of PE was observed in many asymptomatic patients, pulmonary function may deteriorate due to large volume of PE immediately after surgery in some cases.

During surgical procedures, aggressive manipulation of the thorax related to cavum pleurae may result in post-operative PE. Ogura et al. [6] reported a massive post-operative haemothorax related to thoracic pedicle screw placement in an AIS patient. Liang et al. [7] found that 24 patients with spinal deformity in their study suffered from haemothorax, and PE was thought to be related to the pedicle screw misplacement in two patients. Various literature [7–9] indicated that screw malposition is an important risk factor for PE after posterior correction surgery.

Taken together, these findings suggest that correct insertion of the thoracic pedicle screws may reduce the risk of PE. With

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the advent of 3D O-arm navigation system, which is the newest intra-operative imaging platform, real-time multi-dimensional images are optimized for pedicle screw insertion procedure. Many studies have affirmed the accuracy of O-arm navigation system [9–12]. However, given the relationship between PE and screw misplacement, it is necessary to determine the incidence and the volume of PE while the system is being used. We examined whether the O-arm navigation system could help the surgeons to better manipulate the correction surgery, and the occurrence of PE could be avoided.

In this study, we described the volume of PE among patients with thoracic scoliosis who underwent intra-operative O-arm navigation-assisted surgery, and compared them with that of patients treated by free-hand technique. The purpose of this study was to analyze the occurrence of PE after intra-operative O-arm navigation-assisted surgery and determine whether the post-operative PE incidence could be decreased by using o-arm navigation as compared to conventional free-hand technique.

Material and methods

Patients and radiological assessment

A cohort of 27 patients with spinal deformity who underwent intra-operative O-arm navigation-assisted surgery (group A) between 2013 and 2016 at our institution were enrolled in the study. A total of 27 curve-matched patients treated by a conventional free-hand technique were included as the control group (group B). The following inclusion criteria were applied: (1) surgically treated by posterior instrumentation and fusion, (2) Cobb angle > 60°, (3) no previous spinal or/and cardiothoracic surgery, (4) no pre-operative PE. Patients who had undergone thoracoplasty or high-grade (> 3°) [13] osteotomies were excluded. Group A included eight males and 19 females with an average age of 14.2 years (range 10–20 years), while group B included nine males and 18 females with an average age of 14.8 years (range 11–19 years). There were 14 type 1 neurofibromatosis (NF 1), 10 congenital scoliosis (CS), and two idiopathic scoliosis (IS) patients in group A, and 14 NF 1, nine CS, and three IS patients in group B. Whole spine posterior-anterior and lateral radiographs were taken pre and post-operation and included Cobb measurements of the frontal and sagittal curves (Figs. 1 and 2).

Post-operative CT scans were performed the day after surgery to figure out pedicle screw violation on axial views. Post-operative CT scan images were also used to quantify the volume of PE. Images were taken using a 64-slice CT scanner (Flash Definition, Siemens, Forchheim, Germany). Tube voltage was 120 kVp. All scans were performed using the automatic dose modulation software (CARE Dose 4D, Siemens, Forchheim, Germany). Collimation was 256 mm × 0.6 mm. All image reconstructions were performed with a slice thickness of 1.0 mm in increments of 1 mm using the soft tissue kernel. The volume-rendering technique [14] of the AW workstation was used for image processing.

Surgical procedure

All patients were positioned prone on a radiolucent table. After midline exposure, a stealth navigation tracker was placed on a proper spinous process of the vertebrae, after which the O-arm was brought in. The 3D image series was automatically performed and then transferred to the Stealth Station Treon plus system (Medtronic). Based on the real-time 3D images shown on the monitor, the pedicle screws were carefully inserted. Another CT scan was not performed when all the screws were inserted, and the incision was closed.

Pedicle screw violation

Post-operative CT scans were reviewed for screw placement. All instrumented pedicle screws were evaluated for any violation of the cortices including medial, lateral, and anterior breach on axial views. The degree of violation was graded by the classification of Jeswani et al. for thoracic spine [15]. In this study, grades 0 and 1 were considered satisfactory, while grades 2 and 3 were regarded as perforation.

Grade 0: screws completely within the pedicle medullary canal and not penetrating the corresponding pedicle cortex. Grade 1: violated or penetrating the corresponding pedicle cortex by less than 1 mm. Grade 2: screws violated any cortices of the corresponding pedicle by 1–3 mm. Grade 3: screws with more than 3-mm penetration through any of the cortices.

Statistical analysis

Statistical analysis was performed using SPSS for Windows (version 17.0.1; SPSS Inc., Chicago, IL, USA). Malposition rates and directions were statistically analyzed using Chi-squared and Fisher exact tests. A p value < 0.05 was statistically significant.

Results

The mean age was 14.2 (range 10–24) and 14.8 (range 11–21) years in groups A and B, respectively. The pre-operative Cobb angle of the major curve was 71.9° in the O-arm group and 68.7° in the free-hand group, with an average curve correction rate of 74.2 and 71.6%, respectively ($p = 0.031$) (Table 1). There were no significant differences in sagittal contour between the two groups. The mean intra-operative blood loss was 824.1 mL in group A and 866.3 mL in group B, with a mean intra-operative infusion volume 3780 and 3800 mL respectively ($p = 0.542$).

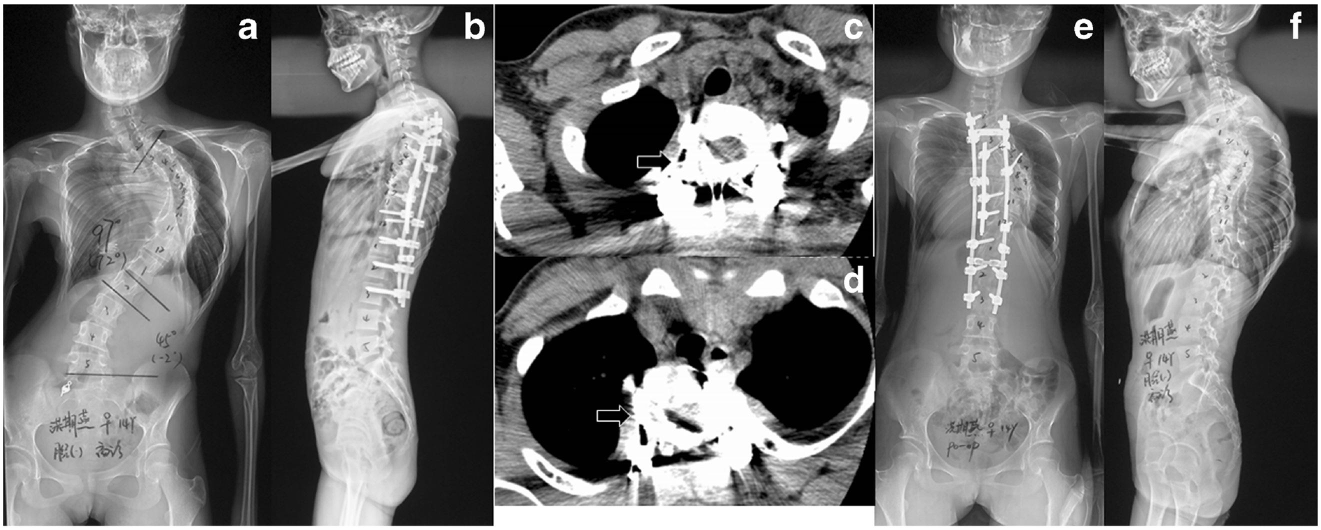

Fig. 1 **a**, **b**, **e**, and **f** A 14-year-old girl in group A with congenital scoliosis underwent posterior instrumentation from T2 to L4 assisted by O-arm navigation system. **a** The Cobb angle was 97° before surgery and 41° immediately after surgery. **c**, **d**, **e**, and **f** Two malpositioned screws (grade 2) were identified in postoperative CT scan, and the volume of pleural effusion located at convex side of the curve was 21.3 and 14.4 mL in the concave side, as measured by the volume-rendering technique of the AW workstation

All the surgeries were performed by the last two authors. A standard operating procedure in surgeries was followed by the other staff associated with surgeries. No significant difference between two groups in mean temperature recovery time (group A 2.3 days vs. group B 2.4 days) of post-operation. The mean C-reactive protein (CRP) of group A was 87.2 ± 24.4 mg/L in group A and 91.0 ± 31.4 mg/L in group B at 1 day after surgery. There was no significant difference in plasma levels of acute-phase proteins after surgery.

Volume of pleural effusion

The mean total volume of PE was significantly larger in the free-hand group (group A 53.9 ± 13.5 mL vs. group B 221.8 ± 81.4 mL, $p < 0.001$) (Table 2). The PE volume was significantly larger in the free-hand group than in the O-arm group on the convex side (group A 41.2 ± 8.3 mL vs. group B 139.8 ± 70.6 mL, $p < 0.001$), as well as on the contralateral side (group A 19.4 ± 11.7 mL vs. group B 89.3 ± 43.1 mL, $p < 0.001$). There were two (6.7%) patients without PE by CT scan after surgery in group A, and one (3.3%) patient in group B. Bilateral PE was observed in 23 (76.7%) patients in the O-arm group, and 24 (88.9%) patients in the free-hand group.

In the O-arm group, 59 malpositioned screws were identified in 22 patients (81.5%). Of these, 37 (37/59, 63%) malpositioned screws were identified on the concave side. In the free-hand group, 88 malpositioned screws were found in 26 patients (96.3%). Of these, 52 (52/88, 59%) malpositioned screws were identified on the concave side. However, all of

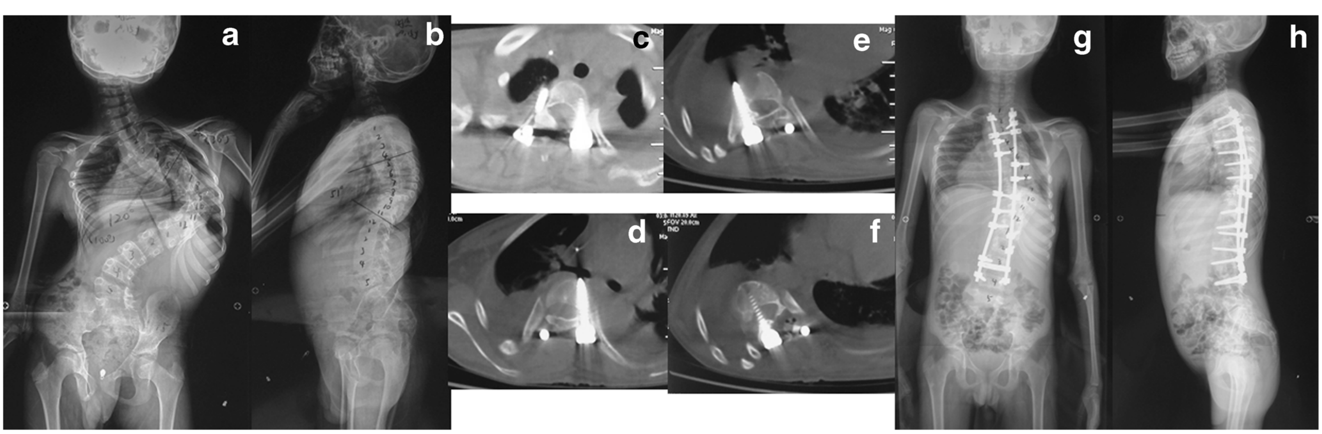

Fig. 2 **a**, **b**, **g**, and **h** A 16-year-old boy in the group B (free-hand group) with congenital scoliosis underwent posterior instrumentation from T2 to L4. **a** The Cobb angle was 120° before surgery and **g** 46° immediately after surgery. **c**, **d**, **e**, and **f** Four malpositioned screws (grade 2 and 3) were identified in post-operative CT scan, and the volume of pleural effusion located at convex side of the curve was 212.4 and 102.4 mL in the concave side

Table 1 Evaluation of demographic data and radiological measurements of the entire series

	O-arm group	Free-hand group	p
Gender (M/F)	8 M/19F	9 M/18F	n.s
Age (years)	14.2 ± 2.3	14.8 ± 2.1	n.s
Preoperative main thoracic Cobb (°)	89.4 ± 22.7	84.7 ± 21.1	0.144
Postoperative main thoracic Cobb (°)	26.0 ± 7.4	27.2 ± 8.1	0.075
Right thoracic curve	20/27 (74%)	19/27 (70%)	n.s
Preoperative kyphosis (T5-T12) (°)	20.4 ± 8.1	19.6 ± 10.7	0.448
Postoperative kyphosis (T5-T12) (°)	23.7 ± 6.1	22.4 ± 5.3	0.320
Fusion levels	13.5 ± 2.2	14.3 ± 1.9	0.034

n.s not significant

them eventually healed without adverse effects (Table 3). The perforation rate was higher in the free-hand group than in the O-arm group (group A 59/484 12.2% vs. group B 88/478 18.4%, $p < 0.001$). In the O-arm group, the mean volume of PE was significantly larger among patients with malpositioned screws than those without malpositioned screws (53.6 ± 12.9 mL vs. 33.7 ± 10.4 mL, $p < 0.001$), as well as in the free-hand group.

Complications

Dural tear occurred in one patient during the operation in group B. The pedicle screw was not inserted due to gel sponge usage to manage the leakage. The patient recovered, and no sequela was found during follow-up. No screws were intra-operatively revised, and no screw-related neurological or vascular complications were observed in either group. No other fatal complications or neurological injuries were observed in the present case series.

Respiratory dyspnea including pant and chest congestion were found in 24 patients with PE after surgery. All of these patients achieved remission of symptoms at discharge. Some pleural effusion was asymptomatic. None of the patients with post-operative PE received chest tube drainage treatment. No apparent radiological signs of PE were found in 86% (44/51) of the patients in whole spine posterior-anterior and lateral radiographs seven days after surgery. In the other seven patients, costophrenic angle blunting was found.

Discussion

Posterior correction surgery for spinal deformity is relatively safe and effective. However, high incidence of peri-operative complications [1, 2, 16] is risky for patients with severe spinal deformity. PE is one of these complications which is quite common. PE is intimately associated with cardiopulmonary disorder [17] in scoliosis patients and may lead to extended length of hospital stay [18] after spinal correction surgery. According to our experience, varying degrees of PE were very common post-operation. In this study, the incidence of PE in patients who underwent posterior instrumentations was about 86.7% (52/60). Hayashi et al. found that 71% (54/76) of the patients who underwent posterior corrective spinal fusion for adolescent idiopathic scoliosis developed PE, which was similar to our findings. In contrast, Liang et al. [8] reported that the incidence of post-operative PE in spinal deformity correction surgery was approximately 0.84% (28/3325). This major discrepancy between our study and Liang et al.'s report can be explained by the negligence of the asymptomatic patients who were not treated with chest tube drainage, and the quantitative analysis by 64-slice CT scanner in our study.

Table 2 Volume of pleural effusion in the two groups (mL)

	O-arm group (group A)			Free-hand group (group B)		
	Convex side	Concave side	Total	Convex side	Concave side	Total
Malpositioned	57.6 ± 11.9	25.4 ± 10.9	73.6 ± 12.9	149.8 ± 69.4	45.3 ± 18.1	242.7 ± 81.0
Positioned	26.7 ± 6.8	17.7 ± 14.1	33.7 ± 10.4	134.4	0	134.4
Total	41.2 ± 8.3	19.4 ± 11.7	53.9 ± 13.5	139.8 ± 70.6	89.3 ± 43.1	221.8 ± 81.4
$p_1 < 0.001$*		$p_2 = 0.025$*		$p_3 < 0.001$*		

p_1, the total volume of PE was compared between groups A and B; p_2, the volume of PE in group A was compared between the convex side and concave side; p_3, the volume of PE was compared between the malpositioned group and positioned group. *Statistically significant if $p < 0.05$

Table 3 Malpositioned screws in the two groups

	O-arm group			Free-hand group		
	Concave side	Convex side	Total	Concave side	Convex side	Total
Grade 0	108	119	227	105	101	206
Grade 1	104	94	198	88	96	184
Grade 2	26	16	42	36	29	65
Grade 3	11	6	17	16	7	23
Total	249	235	484	245	233	478
$p_1 = 0.007$*		$p_2 = 0.066$		$p_3 = 0.048$*		

p_1, the overall accuracy rates were compared between the two groups; p_2, the accuracy rates on the concavity were compared between the two groups; p_3, the accuracy rates on the convexity were compared between the two groups. *Statistically significant if $p < 0.05$

During the posterior correction surgery, though the pleural cavity is not theoretically affected, misplaced pedicle screws may cause perforation directly involving the pleura. Sarwahi et al. [6] reported misplaced pedicle screws near the pleura after posterior spinal fusion. Ogura et al. [7] reported a massive haemothorax related to thoracic pedicle screw placement in an AIS patient. Liang et al. [8] reported that 24 patients suffered from haemothorax, of which two were thought to be related to the pedicle screw misplacement. Taken together, these findings indicated that misplaced pedicle screw is a high-risk cause of post-operative PE.

Several studies have shown that radiographs alone do not reliably demonstrate the position of pedicle screws [19–21]. CT scanning is the gold standard for assessment of pedicle screw position. O-arm-assisted spinal navigation produces high-quality images that are comparable to conventional CT scans, representing the current highest accuracy achieved by a combination of spinal navigation and intra-operative imaging system [10]. Ling et al. [22] had documented that 98.7% pedicle screws were accurately placed with O-arm navigation. Tow Bp et al. [12] reported an accuracy of 85.5% for pedicle screw placement in treating degenerative scoliosis by O-arm navigation. Liu et al. [23] reported that the accuracy of screw placement in extremely small pedicles was 84.3% in the O-arm group and 62.7% in the free-hand group. In the present series, the accuracy of all pedicle screws was 84.7% (147/962), and 87.8% in the O-arm group, significantly higher than the free-hand group, which was in agreement with the findings of Liu et al. [23].

In the present series, the volume of PE in the free-hand group was five times more than that of the O-arm group (group B 221.8 ± 81.4 mL vs. group A 49.9 ± 12.6 mL, $p < 0.001$). The improved accuracy from O-arm navigation helps in placing the pedicle screws on a more medial trajectory than conventional techniques [24]. Prior studies have suggested that wider diameter screws, as well as screws placed on a more medial trajectory have greater construct stability [22, 25]. Thus, less lateral violation and indirect irritation to pleura significantly decreased the volume of PE. Besides, unnecessary distraction was avoided owing to the intra-operative real-time images and accurate trajectory, which contributed to the lower volume of PE than the conventional free-hand technique. Additionally, a misplaced screw was also an attendant risk factor. In both groups, misplaced screws increased the volume of PE (Table 2). The volume of PE after correction surgery can be significantly decreased by the application of O-arm navigation system as compared to the conventional free-hand technique. We noticed that some PE was asymptomatic, while some patients might have obvious symptoms such as pant and chest congestion. We cannot attribute these symptoms to post-operative PE, as a variety of factors may result in these symptoms. As for the cause, according to our data, no evidence of infection was found after surgery. Our hypothesis was that screws outside the pedicles cause pleural effusion either because the screws are irritating the pleura or fluids and blood products from the posterior surgery are falling into the pleural cavity through the pedicle track perforations. For PE found in these patients, it is more of a response to mechanical disturbance or injury.

The present findings should be interpreted within the context of their limitations, including the retrospective nature of this study and non-randomization of the patients. However, the two groups of patients in this study were well matched. Moreover, this is the first study to quantitatively analyze the volume of PE in patients after posterior correction surgery for spinal deformity. Additionally, the liquid property of PE was unavailable for appraisal because of conservative treatment in the current series.

Conclusion

In this study, the volume of PE was significantly decreased by O-arm navigation system as compared to conventional free-hand technique, with no adverse effect on the final results. This new intraoperative navigation technique provides an ideal option for scoliosis patients with poor pulmonary function.

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Compliance with ethical standards

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors declare that they have no conflict of interest.

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