ORIGINAL

Comparison between O-arm Navigation and Conventional Fluoroscopic Guidance in Corrective Posterior Fixation for Cervical Spinal Injury

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Abstract : Purpose : To compare the effectiveness of O-arm navigation with that of conventional fluoroscopic guidance in corrective posterior fixation for cervical spinal injury. Methods : This retrospective comparative study involved 11 consecutive patients who underwent corrective posterior fixation using O-arm navigation or conventional fluoroscopy for cervical spinal injury between February 2016 and May 2021. Patient-specific characteristics (age and sex), number of screws, number of pedicle screws, accuracy of pedicle screw insertion, number of vertebral bodies fixed, operating time, and length of hospital stay were analyzed using the *t*-test. A *P*-value <0.05 was considered statistically significant. Results : Corrective posterior fixation was performed under O-arm navigation in 5 patients and under conventional fluoroscopic guidance in 6. A significantly greater number of pedicle screws was used in the O-arm group (6.4 vs 2.7, P=0.046). According to the Neo classification for pedicle screw placement, there were no grade 2 or 3 breaches. No other items showed a significant difference between the groups (P>0.05). Conclusion : O-arm navigation can improve the accuracy of cervical pedicle screw insertion. Its introduction could expand the indications for use of pedicle screws in posterior fixation of cervical spinal injury beyond those that are possible using conventional fluoroscopy. J. Med. Invest. 69 : 273-277, August, 2022

Keywords : *Cervical spinal injury, O-arm navigation, pedicle screw*

INTRODUCTION

Cervical spinal injuries tend to have greater instability than nontraumatic congenital, infectious, inflammatory, cancer-related, or degenerative pathologies. Traumatic spinal injury often requires rigid internal fixation with cervical pedicle screws (CPS), lateral mass screws, or laminar screws. Biomechanical studies have established that CPS placement is superior to other techniques used for cervical spinal fixation (1, 2). However, CPS insertion is technically challenging because the cervical pedicle is small, narrow, and variable in shape and lies close to vital neurovascular structures. If a CPS were to breach the pedicle, the neural and vascular consequences could be catastrophic (3, 4). The intraoperative imaging modality generally used for transpedicular screw fixation is two-dimensional C-arm fluoroscopy, whereby the surgeon needs to insert the pedicle screw without three-dimensional (3D) visualization of the pedicle or navigation of screw placement. However, an O-arm navigation system has been developed for 3D intraoperative imaging. Several studies have reported that pedicle screw placement under O-arm navigation is more accurate than that under C-arm guidance (5-11). In this study, we evaluated the clinical impact of using the O-arm navigation system.

Received for publication April 4, 2022 ; accepted June 29, 2022.

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MATERIALS AND METHODS

Institutional review board approval was obtained before the start of this study. The approved number of IRB is 1402. Informed consent for publication was obtained from all the patients. The study retrospectively reviewed 11 consecutive patients in whom corrective posterior fixation of a cervical spinal injury was performed by three spine surgeons using O-arm navigation or conventional fluoroscopy at our institution between February 2016 and May 2021. Our institution acquired the O-arm multidimensional surgical imaging system (Medtronic, Minneapolis, MN) coupled with a StealthStation S8 surgical navigation system (Medtronic) in October 2020. Thereafter, this system was used whenever corrective posterior fixation was performed in patients with cervical spinal injury. Patients who underwent anterior fixation were excluded.

Data on patient-specific characteristics (age, sex and injury classification (12)), number of screws, number of pedicle screws, vertebral inserted level, pedicle size, accuracy of pedicle screw insertion, number of vertebral bodies fixed, operating time, and length of hospital stay were collected (Tables 1 and 2). The accuracy of CPS insertion was evaluated on postoperative CT scans (Figure 1a, 1b) and graded according to the Neo classification as follows (13) : grade 0, no screw breaches ; grade 1, minor breaches of <2 mm ; grade 2, breaches of 2–4 mm ; or grade 3, breaches >4 mm. Grades 0 and 1 are considered noncritical perforation and grades 2 and 3 are considered critical perforation (13).

Data were analyzed using the *t*-test for interval data on Microsoft Excel 2019. A *P*-value of 0.05 was considered statistically significant.

Table 1. Summary of patient-specific and treatment-related characteristics and screw-specific accuracy

Variables[a]	Total (n = 11)	O-arm group (n = 5)	Conventional fluoroscopy group (n = 6)	*P*-value*
Patient-specific				
Age, years[b]	73 (14.4)	71.2 (18.8)	74.5 (9.0)	0.739
Sex, male/female	8/3	5/0	3/3	0.074
Injury classification (AO spine subaxial classification)		C4 : A3, C6 : B1, C6-7 : C, C6-7 : C, C7-8 : C	C7 : A3, C7 : A3, C3 : B1, C6 : B1, C7 : B1, C2 : F4	
Treatment-related[b]				
Screws, n	8.3 (2.5)	8.2 (2.2)	8.34 (2.6)	0.937
Pedicle screws, n	4.4 (3.1)	6.4 (2.8)	2.7 (1.9)	0.047*
Cervical	2.2 (2.3)	4.4 (1.5)	0.33 (0.8)	0.00050*
C2	0.18 (0.6)	0.4 (0.8)	0 (0)	0.297
C3	0 (0)	0 (0)	0 (0)	-
C4	0.18 (0.6)	0.4 (0.8)	0 (0)	0.297
C5	0.45 (0.8)	1.0 (0.9)	0 (0)	0.035*
C6	0.72 (1.0)	1.6 (0.8)	0 (0)	0.0016*
C7	0.64 (0.9)	1.0 (0.9)	0.33 (0.7)	0.253
Thoracic	2.2 (1.8)	2 (1.8)	2.3 (1.8)	0.790
Pedicle size, mm				
C2	3.6 (0.4)	3.5 (0.4)	3.7 (0.3)	0.218
C3	3.7 (0.5)	3.6 (0.6)	3.8 (0.3)	0.332
C4	3.6 (0.4)	3.6 (0.5)	3.7 (0.3)	0.698
C5	3.8 (0.3)	3.8 (0.4)	3.7 (0.3)	0.471
C6	3.9 (0.4)	4.1 (0.4)	3.8 (0.4)	0.105
C7	4.4 (0.5)	4.4 (0.5)	4.5 (0.5)	0.684
Vertebral bodies fixed, n	4.5 (1.3)	4.2 (1.2)	4.6 (1.4)	0.600
Operating time, min	236.3 (75.0)	277 (69.9)	201 (60.1)	0.113
Length of hospital stay, days	35.1 (7.2)	32.6 (5.6)	37.17 (7.7)	0.341

[a]Comparison between O-arm and conventional fluoroscopy. [b]Mean (standard deviation) *Statistically significant, $P<0.05$)

Table 2. Distribution of screw positions

	Total (n = 11)	O-arm group (n = 5)	C-arm group group (n = 6)	*P*-value*
Accuracy of pedicle screw insertion	N (%)			
Neo grade 0	39 (92.9%)	25 (96.2%)	14 (87.5%)	0.968
1	3 (7.1%)	1 (3.8%)	2 (12.5%)	0.375
2, 3	0 (0%)	0 (0%)	0 (0%)	
Total	42 (100%)	26 (100%)	16 (100%)	

Comparison between O-arm and C-arm groups. *Statistically significant at $P<0.05$

SURGICAL TECHNIQUE

Corrective posterior fixation of a cervical spinal injury was performed with the patient positioned prone on a Jackson table and the head secured with a Mayfield skull clamp. Surgical exposure was achieved via a posterior approach. The reference frame was attached securely to one of the spinous processes at the relevant cervical levels. Next, CT data were obtained by the O-arm navigation system and the surgical instruments were registered. Additional lateral incisions were used in CPS insertion. The entry point and intended screw trajectory were identified and a high-speed drill with a diamond burr was used to make an entry hole. The navigated pedicle probe was inserted to the desired depth and the diameters were measured. The screw hole was checked, tapped, and rechecked using a ball-tipped probe. The CPS was then inserted under 3D navigation (Figure 2a, 2b). When using the O-arm, the StealthStation S8 surgical navigation system was used to insert cervical and thoracic pedicle screws based on 3D images obtained by the O-arm multidimensional surgical imaging system. When using the conventional fluoroscopy system, anatomic landmarks and specific entry sites were used to insert cervical and thoracic pedicle

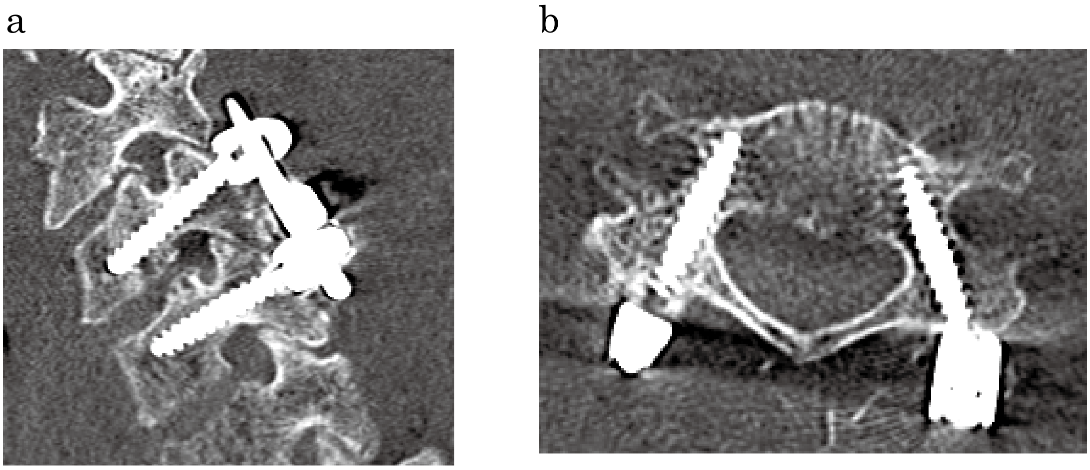

Figure 1. Postoperative computed tomography scans showing pedicle screws completely contained within the pedicle. (a) Sagittal view. (b) Axial view.

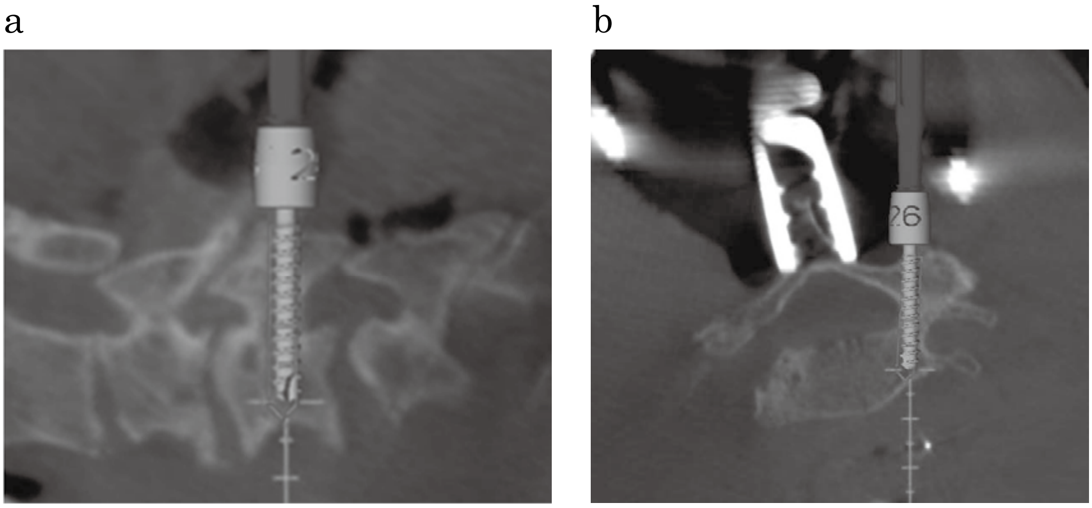

Figure 2. Images of the navigation screen showing insertion of cervical pedicle screws under O-arm navigation. (a) Sagittal view. (b) Axial view.

screws based on preoperative CT images and an intraoperative C-arm (OEC 9900 Elite ; GE Healthcare, Chicago, IL, USA). The position and approach were the same as those used in the O-arm group. The CPS was inserted without navigation. The entry point was determined using anatomic landmarks. The pedicle probe was inserted to the desired depth. The screw hole was checked, tapped and checked again using a ball-tipped probe before inserting the CPS. After the CPS was inserted, the surgeon assessed the accuracy of screw placement by reviewing the intraoperative C-arm. When the surgeon noticed CPS misplacement during surgery, the screws were reinserted. Neuromonitoring was performed in all surgeries in this series.

RESULTS

A total of 11 consecutive patients (8 male, 3 female ; mean age 73 years [range, 35–88]) were included in the study. O-arm navigation was used in 5 patients (the O-arm group) and conventional fluoroscopy in 6 (the conventional fluoroscopy group). There was no significant difference in age or sex between the two groups ($P>0.05$; Table 1). The number of screws used did not significantly differ between the O-arm group and the conventional fluoroscopy group (8.2 vs 8.3 ; $P>0.05$). A significantly greater number of pedicle screws was used in the O-arm group (6.4 vs 2.7 ; $P=0.046$). According to the Neo classification, there were three minor grade 1 lateral screw breaches (O-arm group, n=1 [3.8%] ; conventional fluoroscopy group, n=2 [12.5%]) but no grade 2 or 3 breaches. The accuracy of pedicle screw insertion was not significantly different between the groups ($P>0.05$; Table 2). There were 2 screws that were revised intraoperatively in O-arm group. There were no neurovascular sequelae and there was no need for revision surgery to correct a malpositioned pedicle screw. There was also no significant difference between the groups in the pedicle size, number of vertebral bodies fixed (O-arm group, n=4.2 ; conventional fluoroscopy group, n=4.6), operation time (277 min vs 201 min), or length of hospital stay (32.6 days vs 37.1 days ; $P>0.05$; Table 1).

Postoperative course

After surgery, cervical collar was used in all cases of the O-arm group and in 4 cases of the C-arm group. Halo vest was used in 2 cases of the C-arm group. No pseudoarthrosis and displacement and no loosening or fracture of screws were found in these two groups. There were no surgical adverse events and plain radiographs and CT showed that the sequence of vertebral body was good at the final follow-up.

DISCUSSION

Accuracy of CPS insertion under O-arm

A previous study reported that use of the O-arm system combined with a StealthStation navigation system could increase the accuracy of pedicle screw insertion (5-11). Chachan *et al*. and Ishikawa *et al*. reported an overall CPS breach rate of 7.1% and 11.1%, respectively (10, 11). In our present study, the overall breach rate in the O-arm group was only 3.8%, although some pedicle screws were inserted at the thoracic level. Our lower breach rate may reflect careful judgment on the screws used, such as screw diameter and length. As in previous reports (5-11), we found that use of the O-arm navigation system can improve the accuracy and safety of CPS insertion. O-arm is also useful for intraoperative evaluation after screw insertion. The postinsertion scan allowed for CPS reinsertion during the surgery and improved the accuracy of CPS insertion in this study.

Reason for CPS misplacement

The direction of pedicle breaches was consistently found to be through the lateral cortex, as in previous studies (9, 10, 14). This finding can be explained by the far lateral entry point and the high medial angulation required to achieve the desired screw trajectory. The surgeon needs to overcome the forces exerted by the paraspinal muscles without disturbing the cervical alignment. Minimally invasive cervical pedicle screw fixation using two lateral incisions should be considered as needed (15). Regarding to insertion of CPS, this lateral approach makes it easier because we do not have to overcome the medializing forces of the paraspinal muscles. The distance of the navigation probe from the reference frame may be a factor that could lead to errors in screw placement (16). Therefore, care is needed to avoid inadvertent loosening or dislodgement of the reference frame during surgery. Moreover, the fractured vertebrae could move slightly during insertion. Use of O-arm navigation does not provide superior benefits at the fracture level. In our study, the only instance of CPS misplacement when using the O-arm occurred in a patient with a lamina fracture (Figure 3). In spine instability, intersegmental shifts can lead to changes in spine alignment, which can affect the accuracy of navigation (17). The accuracy of navigation can be reconfirmed by touching an anatomical landmark with the probe. When a difference between the images obtained using the O-arm system and real landmarks is suspected, intraoperative data for navigation should be collected again.

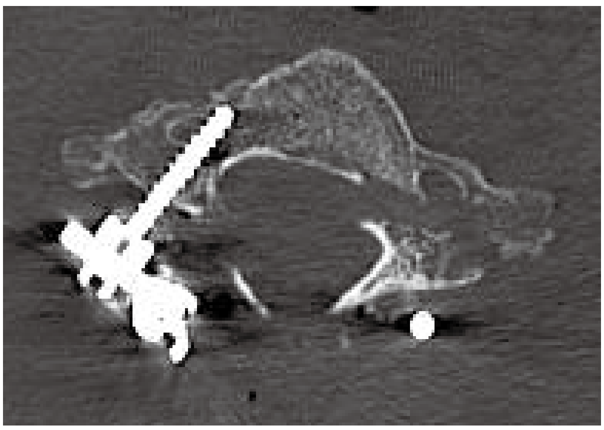

Figure 3. Postoperative computed tomography scan showing lateral minor breach of the pedicle in a patient with a laminar fracture.

Choice of CPS

In our study, a significantly greater number of pedicle screws was placed in the O-arm group than in the conventional fluoroscopy group. This finding suggests that introduction of O-arm navigation expands the indications for use of pedicle screws in posterior fixation of cervical spinal injury beyond what is possible when using the conventional fluoroscopic technique. Pedicle screws can be inserted more accurately and safely under O-arm navigation, and surgeons are likely to become more confident in their choice of pedicle screw. We think that cervical fixation using CPS can help to enhance the structural stability and reduce the correction loss in a follow-up period.

LIMITATIONS

This study has several limitations. First, the sample size was small, consisting of only 11 patients with 91 screws. A larger study is needed to confirm our findings. Second, there was some variation in the pathology of cervical spinal injury, which may have influenced the choice of surgical technique. Finally, the surgeons who performed the procedures had varying levels of experience and training. O-arm navigation is a novel technique, and there still may have been a learning curve that could have influenced our results.

CONCLUSION

O-arm navigation cannot completely prevent CPS misplacement. However, it can improve the accuracy of CPS insertion. Its introduction could expand indications for use of pedicle screws in the posterior fixation of cervical spinal injury beyond that currently possible using the conventional fluoroscopic technique.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest relevant to this manuscript.

ETHICAL APPROVAL

This study is a retrospective and based on patient data existing beforehand and dose not directly involve human participants. This study was approved our Institutional Review Boards. The approved number of IRB is 1402.

ACKNOWLEDGEMENTS

We would like to thank the staff of Tokushima Prefecture Naruto Hospital for helping to generate the records used in this study.

REFERENCES

1. Jones EL, Heller JG, Silcox DH, Hutton WC : Cervical pedicle screws versus lateral mass screws. Anatomic feasibility and biomechanical comparison. Spine (Phila Pa 1976)

22 : 977-9, 1997
2. Kothe R, Ruther W, Schneider E, Linke B : Biomechanical analysis of transpedicular screw fixation in the subaxial cervical spine. Spine (Phila Pa 1976) 29 : 1869-1875, 2004
3. Panjabi MM, Duranceau J, Goel V, Oxland T, Takata K : Cervical human vertebrae. Quantitative three-dimensional anatomy of the middle and lower regions. Spine (Phila Pa 1976) 16 : 861-869, 1991
4. Abumi K, Shono Y, Ito M, Taneichi H, Kotani Y, Kaneda K : Complications of pedicle screw fixation in reconstructive surgery of the cervical spine. Spine (Phila Pa 1976) 25 : 962-969, 2000
5. Verma SK, Singh PK, Agrawal D, Sinha S, Gupta D, Satyarthee GD, Sharma BS : O-arm with navigation versus C-arm : a review of screw placement over 3 years at a major trauma center. Br J Neurosurg 30 : 658-661, 2016
6. Knafo S, Mireau E, Bennis S, Baussart B, Aldea S, Gallard S : Operative and perioperative durations in O-arm vs C-arm fluoroscopy for lumbar instrumentation. Oper Neurosurg (Hagerstown) 14 : 273-278, 2018
7. Shin MH, Hur JW, Ryu KS, Park CK : Prospective comparison study between the fluoroscopy-guided and navigation coupled with O-arm-guided pedicle screw placement in the thoracic and lumbosacral spines. J Spinal Disord Tech 28 : E347-E351, 2015
8. Kim TT, Drazin D, Shweikeh F, Pashman R, Johnson JP : Clinical and radiographic outsomes of minimally invasice percutaneous pedicle screw placement with intraoperative CT (O-arm) image guidance navigation. Neurosurg Focus 36 : E1, 2014
9. Shimokawa N, Takami T : Surgical safety of cervical pedicle screw placement with computer navigation system. Neurosurg Rev 40 : 251-258, 2017
10. Chachan S, Bin Abd Razak HR, Loo WL, Allen JC, Kumar DS : Cervical pedicle screw instrumentation is more reliable with O-arm-based 3D navigation : analysis of cervical pedicle screw placement accuracy with O-arm-based 3D navigation. Eur Spine J 27 : 2729-2736, 2018
11. Ishikawa Y, Kanemura T, Yoshida G, Matsumoto A, Ito Z, Tauchi R, Muramoto A, Ohno S, Nishimura Y : Intraoperative, full-rotation, three-dimensional image (O-arm)- based navigation system for cervical pedicle screw insertion. J Neurosurg Spine 15 : 472-8, 2011
12. Vaccaro AR, Koerner JD, Radcliff KE, Oner FC, Reinhold M, Schnake KJ, Kandziora K, Fehlings MG, Dvorak MF, Aarabi B, Rajasekaran S, Schroeder GD, Kepler CK, Vialle LR : AOSpine subaxial cervical spine injury classification system. Eur Spine J 25 : 2173-84, 2016
13. Neo M, Sakamoto T, Fujibayashi S, Nakamura T : The clinical risk of vertebral artery injury from cervical pedicle screws inserted in degenerative vertebrae. Spine (Phila Pa 1976) 30 : 2800-5, 2005
14. Gan G, Kaliya-Perumal AK, Yu CS, Nolan CP, Oh JYL : Spinal Navigation for Cervical Pedicle Screws : Surgical Pearls and Pitfalls. Global Spine J Mar 11(2) : 196-202, 2021
15. Komatsubara T, Tokioka T, Sugimoto Y, Ozaki T : Minimally Invasive Cervical Pedicle Screw Fixation by a Posterolateral Approach for Acute Cervical Injury. Clin Spine Surg Dec 30(10) : 466-469, 2017
16. Mathew JE, Mok K, Goulet B : Pedicle violation and navigational errors in pedicle screw insertion using the intraoperative O-arm : a preliminary report. Internet J Spine Surg 7 : e88-e94, 2013
17. Miller CA, Ledonio CG, Hunt MA, Siddiq F, Polly Jr DW : Reliability of the planned pedicle screw trajectory versus the actual pedicle screw trajectory using intra-operative 3D CT and image guidance. Internet J Spine Surg 10 : 38, 2016