CASE REPORT

Nagoya J. Med. Sci. **82**. 799–805, 2020 doi:10.18999/nagjms.82.4.799

An intraoperative 3D image-based navigation error during cervical pedicle screw insertion

Hiroaki Nakashima, Yoshimoto Ishikawa, Kei Ando, Kazuyoshi Kobayashi, Naoki Ishiguro and Shiro Imagama

Department of Orthopedic Surgery, Nagoya University Graduate School of Medicine, Nagoya, Japan

ABSTRACT

A 67-year-old man underwent posterior cervical decompression surgery for ossification of the posterior longitudinal ligament (OPLL) with fixation using cervical pedicle screws (CPSs) guided by intraoperative 3D image-based navigation. Intraoperatively, while creating the screw hole using the navigation probe, the virtual trajectory on the intraoperative navigation screen showed a 10-degree angle discrepancy in the axial plane depending on whether a probing force was or was not applied for making the hole. This was potentially caused by vertebra rotation and a bent probe. Consequently, the CPSs were placed more laterally than the ideal trajectory, which resulted in <2 mm lateral perforation to the foramen transversarium. There were no screw insertion-related perioperative complications. Based on this case, we conclude that navigation error during CPS insertion can occur even with intraoperative 3D image-based navigation. The risk of a bowed navigation probe caused by posterior cervical muscle and vertebra rotation should be considered, even with use of a navigation reference frame.

Keywords: cervical pedicle screw, navigation, O-arm™, 3D fluoroscopy, navigation error

This is an Open Access article distributed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. To view the details of this license, please visit (http://creativecommons.org/licenses/by-nc-nd/4.0/).

INTRODUCTION

Cervical pedicle screws (CPSs) are used to treat cervical lesions and instability caused by conditions such as rheumatoid arthritis, trauma, degenerative diseases, and tumors, owing to their rigid biomechanical stability.¹⁻³ However, significant malpositioning of CPSs can evoke catastrophic vascular or neural injuries, including injuries to the vertebral artery (VA); therefore, insertion of CPSs requires high accuracy and safe techniques.⁴ The rate of CPS malpositioning ranges from 3.9% to 15%, ^{1-3,5-7} with computer-assisted surgery having been effective in improving the accuracy of CPS insertion.⁸⁻¹⁴

Use of navigation-based intraoperative three-dimensional (3D) images is a relatively new technique that offers accurate and safe intraoperative navigation in spine surgery.^{8,10,11} However, current navigation systems cannot completely prevent malpositioning of the CPS, and herein, we

Corresponding Author: Shiro Imagama, MD, PhD

Received: February 4, 2020; accepted: May 19, 2020

Department of Orthopedic Surgery, Nagoya University Graduate School of Medicine, 65 Tsurumai-cho, Showa-ku, Nagoya 466-8550, Japan

Tel: +81-52-741-2111, Fax: +81-52-744-2260, E-mail: imagama@med.nagoya-u.ac.jp

report a case of malpositioning due to a navigation error. Cervical vertebral rotation is a common cause of 3D image-based navigational error in a vertebra without a navigation reference,¹⁶ but little is known about other reasons for navigation errors. We recently experienced a case of serious navigation error during CPS insertion in the vertebra with an attached navigation reference. We analyzed this navigation failure using intraoperative images, and we discuss management of this process for safe CPS placement.

CASE REPORTS

A 67-year-old man presented with gait disturbance and numbness in the bilateral upper and lower limbs 1.5 years ago. Due to worsening of these symptoms, he visited his local hospital for a medical examination, and cervical disorder due to ossification of the posterior longitudinal ligament (OPLL) was diagnosed. He was transferred to our hospital for a surgical procedure.

At the time of arrival at our hospital, his gait ability was severely compromised and he had paralysis (manual muscle test: 3-4/5) of the bilateral upper and lower limbs, without clear rectal disturbance. Hyperactivity of the deep tendon reflex in the lower extremities was present. His Japanese Orthopedic Association (JOA) score for cervical myelopathy was 7/17.¹⁵

An X-ray examination of the cervical spine and computed tomography (CT) showed OPLL at C3-6. Magnetic resonance imaging (MRI) showed canal stenosis and compression of the spinal cord due to OPLL (Fig. 1A-C). Thus, the patient was diagnosed with myelopathy due to cervical OPLL, and posterior cervical decompression surgery with fixation was performed. Preoperative CT angiography of the cervical spine revealed VA laterality, with the left-side VA being larger than the right-side VA. Therefore, we chose CPSs for the right and lateral mass screws for the left side as the fixation implants.



Fig. 1 Preoperative images

(A, B) Ossification of the posterior longitudinal ligament (OPLL) at C3-6. Computed tomography axial image at C6 showing a large ossification in the cervical spinal canal. (C) Compression of the spinal cord due to OPLL.

The patient was placed in a prone position under general anesthesia on a Jackson table. A carbon fiber, 4-point-cranial fixation device was used and, as an additional safety measure, we performed intraoperative spinal cord monitoring for detecting any serious damage from the operative procedures. After a posterior approach with a midline incision, the navigation reference frame was attached to the C5 spinous process of the vertebra and intraoperative 3D image data were obtained using O-arm[™] (Medtronic, Minneapolis, MN, USA). Spinal implants were placed before laminectomy using the StealthStation[™] navigation system (Medtronic). As soon as the system was ready, we reconfirmed the screw trajectory using a navigation probe, and started creating the primary screw hole using a navigation pedicle probe. After making the hole, threading was created for the screws, which were subsequently inserted. During this process, the intraoperative navigation screen was recorded repeatedly. Next, we inserted CPSs at C5 and C6, after which lateral mass screws were inserted in the contralateral side using the navigation system and cervical laminoplasty for decompression of the spinal cord was performed.

Intraoperative navigation screen images

Intraoperative navigation screens are shown in Fig. 2. Images taken during probing and making of the screw hole by the navigation probe with and without a probing force are shown in Figs. 2B and 2C, respectively. A comparison of these images indicates that the navigation trajectory was more medial with a probing force (a better trajectory to ensure safety of the foramen transversarium and VA), with a difference of about 10° (Fig. 2D). The same phenomenon was also recorded during C6 CPS insertion.

Accuracy of screw insertion

The accuracy of all screw placements (CPSs and lateral mass screws) was evaluated by postoperative CT. The C5 and C6 CPSs showed lateral perforations of <2 mm (i.e., less than half of the screw diameter) to the foramen transversarium (Fig. 3A). The CPS trajectories on postoperative CT were almost the same as the trajectory shown on the intraoperative navigation screen images without a probing force. The lateral mass screws were not perforated.

Postoperative Management

There were no perioperative complications, including neurovascular complications, related to the screw insertion. On postoperative day 2, the patient was able to get up from bed with a soft neck collar. Ten days postoperatively, he could walk with a T-cane and his gait disturbance was improved. At the time of discharge, 2 weeks after the operation, his JOA score had improved to 13/17. Postoperative MRI showed sufficient decompression (Fig. 3B, C). After one year postoperatively, he had stable gait with a T-cane and there was no worsening of neurological disorder in the upper and lower limbs.



Fig. 2 Navigation screens during surgery

(A) Intraoperative navigation screen showing the 3D trajectory constructed by intraoperative O-arm 3D images. (B, C) Magnified intraoperative navigation screens in the axial view, showing trajectories of the probe with and without probing force, respectively. The trajectory in (B) is more medial than that in (C). (D) The 10-degree discrepancy between the trajectories in (B) and (C).





Fig. 3 Postoperative images

(A) Left-side cervical pedicle screws (CPSs) displayed small lateral perforations of <2 mm (i.e., less than half of the screw diameter) to the foramen transversarium at C5. (B) Decompression of the spinal cord, showing expansion of the dura mater.

DISCUSSION

CPSs provide significantly stronger stabilization than other cervical posterior instrumentation, and stronger pullout strength than lateral mass screws.² These properties indicate their utility for severe deformities of the cervical spine, short segment fixation surgery, and surgery requiring rigid stability.^{1,3,5} However, significant CPS malposition may cause neurovascular injury, such as spinal cord, nerve root, or VA injury,^{3,4} indicating the need for accurate positioning and improved insertion techniques.

Cervical pedicle diameters are smaller than those in the thoracic or lumbar spine, and differences in intervertebral anatomic relationships between preoperative CT and intraoperative findings are potential problems in navigation surgery.^{3,9} Moreover, intraoperative 3D image-based navigation offers automatic registration, which does not require free hand registration by surface matching using anatomical landmarks.³ Thus, intraoperative 3D image-based navigation may be more appropriate for cervical spine procedures and may provide better accuracy. However, CPS malpositioning cannot be prevented completely, even with use of such systems.^{8,10,11}

Using intraoperative 3D-based navigation, cervical intervertebral anatomic relationships and alignment can change by probing or force during screw insertion. Hence, the accuracy of CPS insertion at a vertebra without a navigation reference frame is lower than that at a vertebra with an attached navigation reference frame.^{8,10,11} Sugimoto et al reported that an average cervical rotation of 10.6° occurs during CPS insertion, and this vertebral rotation could be a main cause of CPS misplacement even in 3D-based navigation.¹⁶ Thus, vertebrae with a reference frame provide the best accuracy. Nevertheless, our case highlights the risk of navigation error even with a reference frame (at C5). This error was difficult to predict, and CPSs were placed based on the error. Fortunately, there was no catastrophic malposition evoking neurovascular injury. However, this phenomenon should be considered during CPS insertion with 3D-based navigation.

Hiroaki Nakashima et al

In this case, each vertebra (C5 with a reference frame and C6 without a reference frame) showed navigation errors (Fig. 4A, B), suggesting that this phenomenon might not be related to the position of the reference frame or due to intervertebral movement. Instead, the error occurred when force was added to the probe during CPS insertion, leading us to hypothesize the following reasons for this finding: first, force on the probe during creation of the screw hole may have caused vertebra rotation¹⁶ (Fig. 4A). Second, the trajectory of the probe tip may have moved laterally (Fig. 4B). Finally, in correspondence to the rotation, the operator may have added more force and an increased angle to ensure a correct trajectory. As a result, only the navigation antenna of the probe would move to the ideal point for CPS placement, while the tip of the probe would be left in the lateral trajectory, causing a bowed navigation probe (Fig. 4B). Thus, a navigation error may occur even if the vertebra has an attached navigation frame. To reduce navigation errors after experiencing the current case, we changed to create CPS holes using a newly developed power drill tool that can be navigated. This navigated drill makes it possible to create CPS holes by drilling without pressing the cervical spine. Since the bone cortex might be perforated by using this power tool, we use this drill with a very low rotation. The accuracy of CPS placement has become better, and the results will be reported in a near future paper.

In conclusion, based on the present case, we believe that a surgeon inserting CPSs using a navigation system should keep in mind the possibility of probe flexure due to restrictions of the cervical posterior muscle and rotation of vertebrae. To ensure safe and accurate CPS insertion, percutaneous insertion of screws using a navigation system might reduce the risk of CPS malposition by the posterior cervical muscles.^{7,9,12} Nevertheless, navigation error during CPS insertion can occur even with intraoperative 3D image-based navigation. Even for vertebrae with a navigation reference frame, the risk of posterior cervical muscle restrictions and vertebra rotations should not be ignored to ensure safe CPS insertion.



Fig. 4 Mechanism of malposition during cervical pedicle screw insertion

(A) During creation of the screw hole by the navigation probe, the vertebra is rotated (arrow). (B) The stronger the probing force, the more the vertebra is rotated like a curved arrow, resulting in probe bending (block arrow). As a result, the tip of the probe is directed more laterally, towards the vertebral artery. On the other hand, the handle and antenna of the probe are positioned laterally due to the probe bending; hence, this phenomenon creates the ideal trajectory for the probe on the navigation screen.

DISCLOSURE STATEMENT

None of the authors have a conflict of interest to declare. Funding was from institutional sources only.

REFERENCES

- 1. Abumi K, Kaneda K. Pedicle screw fixation for nontraumatic lesions of the cervical spine. *Spine*. 1997;22(16):1853–63.
- Jones EL, Heller JG, Silcox DH, Hutton WC. Cervical pedicle screws versus lateral mass screws. Anatomic feasibility and biomechanical comparison. Spine. 1997;22(9):977–82.
- 3. Abumi K, Itoh H, Taneichi H, Kaneda K. Transpedicular screw fixation for traumatic lesions of the middle and lower cervical spine: description of the techniques and preliminary report. *J Spinal Disord*. 1994;7(1):19–28.
- 4. Neo M, Sakamoto T, Fujibayashi S, Nakamura T. The clinical risk of vertebral artery injury from cervical pedicle screws inserted in degenerative vertebrae. *Spine*. 2005;30(24):2800–5.
- 5. Hojo Y, Ito M, Suda K, Oda I, Yoshimoto H, Abumi K. A multicenter study on accuracy and complications of freehand placement of cervical pedicle screws under lateral fluoroscopy in different pathological conditions: CT-based evaluation of more than 1,000 screws. *Eur Spine J.* 2014;23(10):2166–74.
- Nakashima H, Yukawa Y, Imagama S, et al. Complications of cervical pedicle screw fixation for nontraumatic lesions: a multicenter study of 84 patients. J Neurosurg Spine. 2012;16(3):238–47.
- 7. Yukawa Y, Kato F, Yoshihara H, Yanase M, Ito K. Cervical pedicle screw fixation in 100 cases of unstable cervical injuries: pedicle axis views obtained using fluoroscopy. *J Neurosurg Spine*. 2006;5(6):488–93.
- Ito Y, Sugimoto Y, Tomioka M, Hasegawa Y, Nakago K, Yagata Y. Clinical accuracy of 3D fluoroscopyassisted cervical pedicle screw insertion. J Neurosurg Spine. 2008;9(5):450–3.
- 9. Richter M, Cakir B, Schmidt R. Cervical pedicle screws: conventional versus computer-assisted placement of cannulated screws. *Spine*. 2005;30(20):2280–7.
- Ishikawa Y, Kanemura T, Yoshida G, Ito Z, Muramoto A, Ohno S. Clinical accuracy of three-dimensional fluoroscopy-based computer-assisted cervical pedicle screw placement: a retrospective comparative study of conventional versus computer-assisted cervical pedicle screw placement. J Neurosurg Spine. 2010;13(5):606– 11.
- 11. Ishikawa Y, Kanemura T, Yoshida G, et al. Intraoperative, full-rotation, three-dimensional image (O-arm)based navigation system for cervical pedicle screw insertion. J Neurosurg Spine. 2011;15(5):472–8.
- Kotani Y, Abumi K, Ito M, Minami A. Improved accuracy of computer-assisted cervical pedicle screw insertion. J Neurosurg. 2003;99(3 Suppl):257–63.
- 13. Takahashi J, Shono Y, Nakamura I, et al. Computer-assisted screw insertion for cervical disorders in rheumatoid arthritis. *Eur Spine J*. 2007;16(4):485–94.
- 14. Uehara M, Takahashi J, Ikegami S, et al. Screw perforation features in 129 consecutive patients performed computer-guided cervical pedicle screw insertion. *Eur Spine J*. 2014;23(10):2189–95.
- 15. Hirabayashi K, Satomi K. Operative procedure and results of expansive open-door laminoplasty. *Spine*. 1988;13(7):870–6.
- 16. Sugimoto Y, Ito Y, Tomioka M, et al. Vertebral rotation during pedicle screw insertion in patients with cervical injury. *Acta Neurochir (Wien)*. 2010;152(8):1343–6.