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Cervical Pedicle Screw Placement in Sawbone Models and Unstable Cervical Traumatic Lesions by Using Para-Articular Mini-Laminotomy: A Novice Neurosurgeon's Experience

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Objective: This retrospective study was conducted to analyze the novice neurosurgeon's experience of cervical pedicle screw placement by using the technique with direct exposure of pedicle via para-articular mini-laminotomy.
Methods: Fifteen sawbone models of subaxial spine were used (124 pedicles) to evaluate efficacy of repetitive training improving accuracy of cervical pedicle screw insertion. After that, we retrospectively reviewed 9 consecutive patients presented with traumatic cervical lesion. A total 38 cervical pedicle screws had been inserted. We analyzed the direction and grade of pedicle perforation on the postoperative computed tomography scan, and learning curve by using sawbone model.
Results: In sawbone model group, the correct position was found in 102 (82.3%) screws, and the incorrect position in 22 (17.7%) screws. The incidence of incorrect screw position was 26.9% in the initial 9 sawbone model, and 0% after that. Among the 38 screws inserted in 9 patients, the correct position was found in 36 (94.7%) screws, and the incorrect position in a 2 (5.3%) screw. There was no neurovascular complications related with cervical pedicle screw insertion.
Conclusion: *In vitro* training to insert pedicle screw by using sawbone models could improve an accuracy of cervical pedicle screw placement by using this technique. Preliminary result revealed that cervical pedicle screw placement would be feasible and provide good clinical results in traumatic cervical lesions. (Korean J Neurotrauma 2013;9:106-113)

KEY WORDS: Cervical pedicle screw · Laminotomy · Spinal instrumentation.

Introduction

Cervical pedicle screw has been shown to provide stronger fixation than other methods.[10,12,16,17] Due to these virtue of biomechanical characteristic, pedicle screw fixation can be used in a wide range of cervical spinal disorders, and excellent clinical results have been reported.[2,3,5,11,28-30] However, this procedure is technically demanding because of the great variation in pedicle dimension and angulations between cervical levels and patients, and generally criticized as being risky due to the proximity of the spinal cord, nerve roots, and vertebral artery.[4,13,18,20,21] Recently, the availability of image-guidance systems, e.g., computer-assisted navigation system based on CT or three-dimensional (3D) fluoroscope, has led to their use in spinal surgery to improve an accuracy of pedicle screw placement in cervical spine.[7,9,15,23,25,27]

However, its application could be limited due to its high cost and lengthy registration procedure. Moreover, there are some pitfalls using navigation system due to misregistration and motion of spine during the procedure.[27]

The objectives of this study were to present the cervical pedicle screw insertion technique, with direct exposure of the pedicle via para-articular mini-laminotomy, assess an efficacy of repetitive training by using saw-bone model improving accuracy of cervical pedicle screw insertion, and evaluate the accuracy of pedicle screw placement and validity of pedicle screw fixation in patients.

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Materials and Methods

Fifteen sawbone models (Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA) of subaxial spine harboring 150 pedicles were used to train of cervical pedicle screw insertion. Among of 150 pedicles, 124 pedicles of 15 sawbone models with a diameter, which was measured via axial computed tomography (CT) scan, of more than 4.0 mm were used to assess an efficacy of repetitive training by using saw-bone model improving accuracy of cervical pedicle screw insertion. After the training, from April 2012 to July 2013, a total of 9 consecutive patients (7 males and 2 females; mean age 56.1 years, range 42−67 years) presented with unstable cervical spinal injury underwent posterior spinal fusion with or without anterior spinal fusion. The type of fractures and dislocations were categorized according to the Allen's mechanistic classification.[6] Of the 9 cases, 4 were compressive extension (CE), 3 were distractive flexion (DF), and 2 was compressive extension (CE). The patients' neurological status was graded according to the ASIA classification system. There were 2 cases of ASIA A, 2 of AISA B, 2 of ASIA C, 2 of ASIA D, and 1 of ASIA E. Above all procedures were done by one neurosurgeon.

Pre-procedural radiographic evaluation

Pedicle morphology of sawbone model was fully evaluated preoperatively by 3D CT scan. On preoperative CT scans, the diameter of the pedicles, the convergence angle, and the caudal angle, e.g., between superior margin of pedicle and imaginary line on which pedicle screw would be placed, were measured for each cervical vertebra (Figure 1). The length of the screw was decided to reach the anterior one-third of the vertebral body on CT image. In cases of patient with unstable cervical spinal trauma, we performed preoperative plane radiography, CT, and magnetic resonance imaging (MRI). Pedicle morphology was fully evaluated on CT as described above. CT angiography was obtained in 3 of 9 cases to observe patency of vertebral artery.

Procedural technique

Sawbone was prepared with malleable metal wire to make lordotic curve simulating a real operative field. All patients planed to undergo posterior arthrodesis were placed in prone position with the head fixed by using a Mayfield clamp. A standard midline incision was made and paravertebral muscles were dissected and retracted laterally to expose facet joint.

Under the microscope, a para-articular mini-laminotomy was performed to expose the medial and superior wall of the pedicle by using 2.5 mm diamond burr (Figure 2A, B). The ligamentum flavum at each level was gently dissected free from medial edge of laminotomy by using microdissector, and removed by using 1.5 mm or 2.5 mm Kerrison punch. Thereafter, the entrance point for screw insertion and the convergence angle for screw placement were guided by direct determination of the superior and medial border of the pedicle by placing microdissector into the laminar window (Figure 2C, D). Measurements of pedicle morphology on preoperative 3D-CT scans were also considered to determine the entry point, convergence angle, and caudal angle for screw placement. After that, 2.5 mm diamond burr was used to remove the outer cortex of the lateral mass over the pedicle entrance (Figure 2C).

The pedicle was probed as close to the medial wall as possible by gentle manual pressure using the 2 mm-diameter Lenke probe with the curved tip oriented medially. In cases of sawbone, pedicle probing was not performed due to brittleness of sawbone. After probing about 20 mm in depth, lack of pedicle perforation was confirmed by using a ball-tip probe. Then sequential drilling by using tapper was performed. After that, lack of pedicle perforation was confirmed by using a ball-tip probe, again. If perforation was detected within the pedicle, the trajectory was changed or the segment was skipped. Thereafter, screw insertion was per-

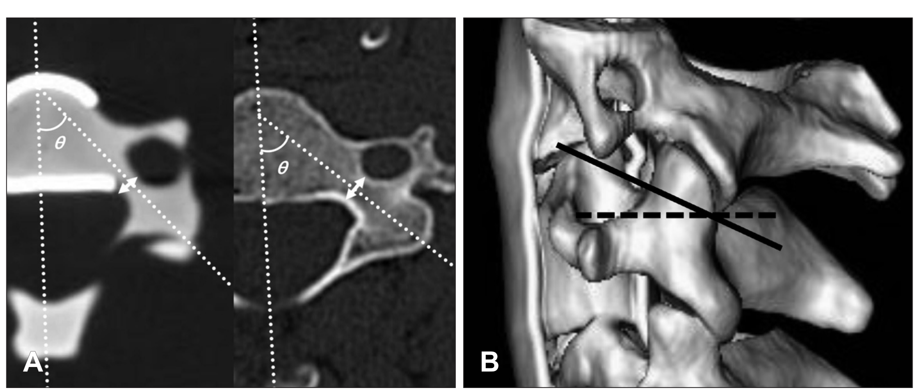

FIGURE 1. Preoperative axial CT images (A: left-sawbone, right-patient) showing the diameter (arrow) and the convergence angle (θ) of the pedicle, and 3D reconstruction image of sawbone (B) revealing the caudal angle between superior margin of pedicle (solid line) and imaginary line on which pedicle screw would be placed (dot line).

formed. During the pedicle screw insertion, retracting dural sac by using microdissector, the pedicle should be visualized under the microscope (Figure 3). We used a kind of cervical pedicle screw system (VERTEX®, Medtronic Sofamor Danek, Memphis, TN, USA) in all procedures. Anatomical lordosis was created by bending the rods. All procedures were performed manually so that the surgeon could acquire tactile feedback.

Post-procedural evaluation of screw placement

The accuracy of the placement of the pedicle screws was evaluated on 3D-CT scans in sawbone model and the patients. Medial and lateral wall of pedicle was evaluated on axial image of 2-mm slice, whereas superior and inferior pedicle wall was examined on coronal and sagittal reconstruction image of 3D-CT scan.

The degree of perforation was classified as grade 0 if the screw was located within the pedicle: grade 1, if perforation was made by the screw by less than 25% of the screw diameter; grade 2, if perforation was made by 25% to 50% of the screw diameter; and grade 3, if perforation was made by over 50% of the screw diameter (Figure 4). Grade 0 and 1 were classified as the correct position and the others, as the incorrect position. The direction of pedicle perforation was assessed: medial, lateral, cranial, and caudal. In cases of sawbone models, pedicle perforation can be directly visualized, and it is helpful to understanding geometrical relationship of cervical pedicle and inserted pedicle screw (Figure 5). Intraobserver and interobserver agreement rate and κ value were obtained to check errors between 2 observers in grade of the pedicle perforation.

Learning curve analysis

We analyzed the incidence of pedicle perforation of the chronologic group consisting of each 15 consecutive sawbone models. To analyze the learning curve, we compared the incidence of incorrect position of screw, mean pedicle diameter and convergence angle. Statistical analysis was performed with Student *t*-test or chi-square test, appropriately. Probability below 0.05 was considered statistically significant.

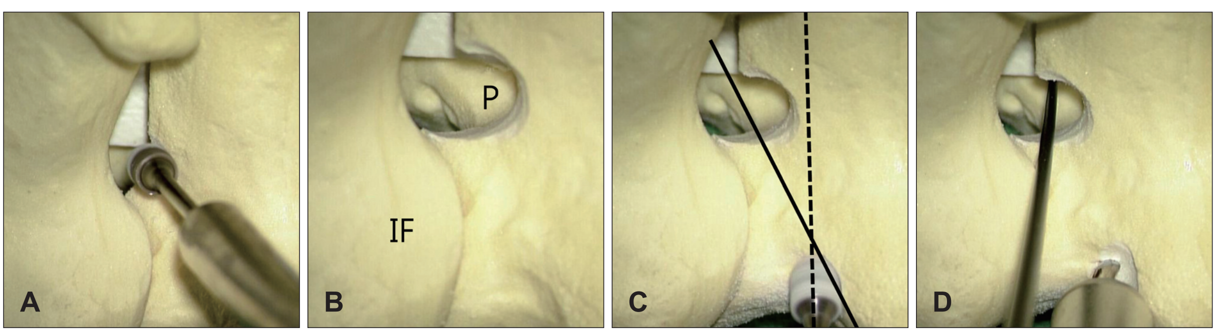

FIGURE 2. 2.5 mm diamond burr is used to perform para-articular mini-laminotomy (A). The laminotomy provides direct visualization of medial and superior wall of the pedicle (B). Burr is used to remove the outer cortex of the lateral mass over the entry point. The caudal angle (between solid and dot line) should be considered to determine the trajectory (C), and convergence angle should be determined under the direct visualization of the pedicle (D). P: pedicle, IF: inferior facet.

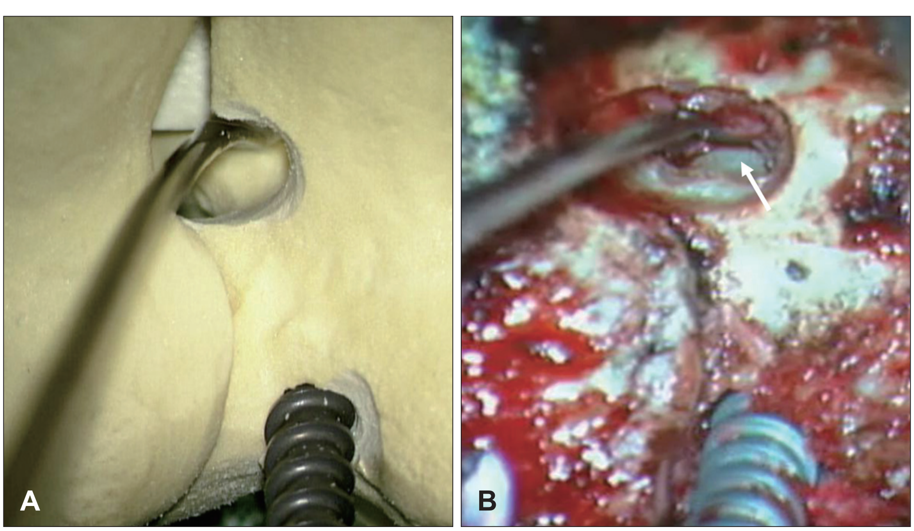

FIGURE 3. During the screw insertion, the pedicle should be visualized though the whole procedure (A). After the subperiosteal dissection of the pedicle, medial and superior wall of the pedicle (B, arrow) remained to be exposed by using a microdissector.

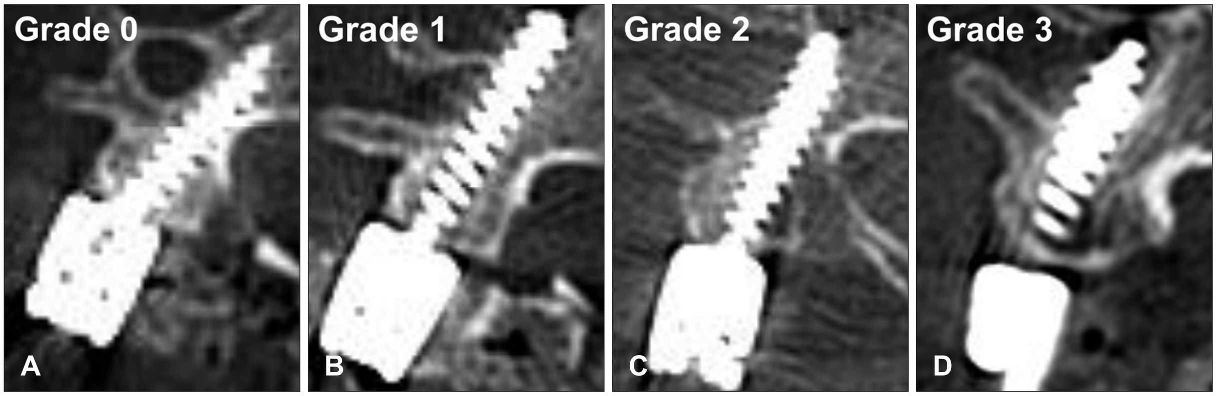

FIGURE 4. Grading system of the pedicle perforation. Grade 0: the screw is located within the pedicle (A). Grade 1: perforation less than 25% of the screw diameter (B). Grade 2: 25–50% of the screw diameter (C). Grade 3: over 50% (D).

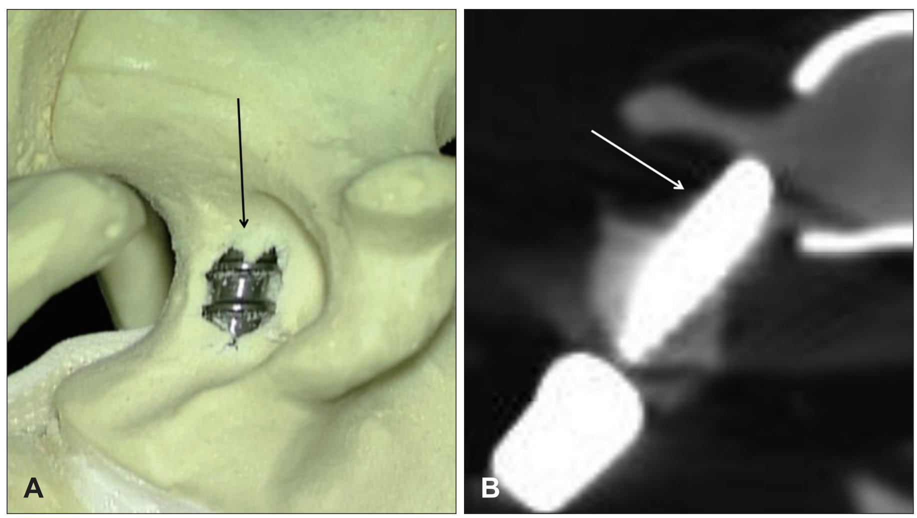

FIGURE 5. During the procedure, pedicle perforation (arrow) is directly visualized on sawbone model (A), and post-procedural CT of sa bone model shows grade 1 perforation (B).

Results

In sawbone model group. The mean axial diameter of subaxial cervical pedicles was 5.28±0.50 mm (range, 4.12–6.03 mm), and the mean convergence angle was 40.0±9.0 degrees (range, 31.0–54.3 degree). Screws of 3.5-mm in diameter were used in all cases. Perforation of cervical pedicles occurred in 58 screws (46.8%): grade 1 in 44 (35.5%), grade 2 in 18 (14.5%), and grade 3 in 4 (3.2%)(Table 1). The intraobserver agreement was 96.1% with a κ value of 0.83, and the interobserver agreement was 92.5% with a κ value of 0.78. Overall, the correct position (perforation of grade 0, 1) was found in 102 screws (82.3%) and the incorrect position (perforation of grade 2, 3) in 22 screws (17.7%). Incorrect position occurred in 6 screws (27.4%) at C3, 9 (40.9%) at C4, 5 (22.7%) at C5, 1 (4.5%) at C6, and 1 (4.5%) at C7. The direction of perforation was lateral in 59 (89.4%), followed by superior in 5 (7.6%), and medial in 2 (3.0%) screws. No perforation was directed toward inferior.

The learning curve showed a significant improvement according to the experience. The incidence of incorrect screws was 29.3% (17 of 58 screws) in the first 7 cases, and decreased to 6.1% (4 of 66 screws) in the last 8 cases (p=0.004, Fischer's exact test)(Figure 6). There was no significant difference between the initial and the last cases in terms of pedicle diameter and convergence angle.

In patients' group, the mean axial diameter of subaxial cervical pedicles was 5.68±0.75 mm (range, 4.33–7.58 mm), and the mean convergence angle was 44.4±7.8 degrees (range, 34.4–54.9 degree). The number of screws inserted was 8 at C3, 5 at C4, 8 at C5, 11 at C6, and 6 at C7. Screws of 4.0-mm in diameter were used for C3, C4, and C5 pedicle, and screws of 4.5-mm in diameter for C6, and C7. Anterior cervical discectomy/corpectomy and fusion in 7, cervicothoracic fusion in 2, and laminectomy with fusion was performed in 1 case respectively.

Perforation of cervical pedicles occurred in 9 (23.6%) screws: grade 1 in 7 (18.4%), grade 2 in 1 (2.6%), and grade 3 in 1 (2.6%). The intraobserver agreement was 96.1% with a κ value of 0.83, and the interobserver agreement was 92.5%

TABLE 1. Results of pedicle screw placement at each level

Level	Screws	Grade 0, n (%)	Grade 1, n (%)	Grade 2, n (%)	Grade 3, n (%)	Lateral malposition, n (%)	Superior malposition, n (%)	Medial malposition, n (%)
Saw bone (1st 7 cases)								
C3	14	0	8 (57.1)	6 (42.9)	0 (0)	12 (85.8)	1 (7.1)	1 (7.1)
C4	8	0	1 (12.5)	6 (75.0)	1 (12.5)	7 (87.5)	1 (12.5)	0
C5	8	0	5 (62.5)	1 (12.5)	2 (25.0)	7 (87.5)	1 (12.5)	0
C6	14	8 (57.2)	5 (35.7)	0	1 (7.1)	6 (100)	0	0
C7	14	11 (78.6)	2 (14.3)	1 (7.1)	0	2 (66.7)	0	1 (33.3)
Saw bone (2nd 8 cases)								
C3	14	9 (64.3)	5 (35.7)	0	0	5 (100)	0	0
C4	10	2 (20.0)	6 (60.0)	2 (20.0)	0	7 (87.5)	1 (12.5)	0
C5	12	2 (16.6)	8 (66.8)	2 (16.6)	0	9 (90.0)	1 (10.0)	0
C6	14	10 (71.4)	4 (28.6)	0	0	4 (100)	0	0
C7	16	16 (100)	0	0	0	0	0	0
Patients								
C3	8	6 (75.0)	2 (25.0)	0	0	2 (100)	0	0
C4	5	4 (80.0)	1 (20.0)	0	0	1 (100)	0	0
C5	8	5 (62.5)	2 (25.0)	1 (12.5)	0	2 (66.7)	1 (33.3)	0
C6	11	10 (90.9)	1 (9.1)	0	0	1 (100)	0	0
C7	6	4 (66.6)	1 (16.7)	0	1 (16.7)	2 (100)	0	0

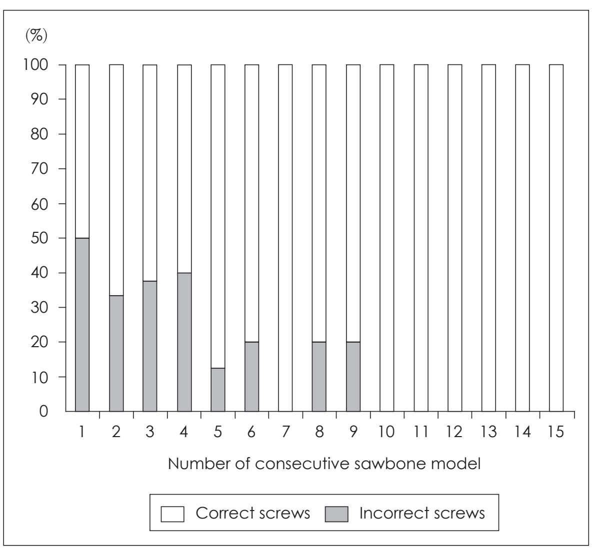

FIGURE 6. The number of total screws and screws showed incorrect position (>grade 2 perforation) in 15 consecutive cases of sawbone model. After initial 9 cases of sawbone model, there was no incorrect screw insertion.

with a κ value of 0.78. Overall, the correct position (perforation of grade 0, 1) was found in 36 (94.7%) screws and the incorrect position (perforation of grade 2, 3) in 2 screws (5.3%). Incorrect position occurred in at C5, and C7. The direction of perforation was lateral in 8 (88.9%), followed by superior in 1 (11.1%) screw. All 2 screws of incorrect position were laterally malpositioned due to an inadequate pedicle exposure leading an underestimation of convergence angle (Figure 7A). No perforation was directed toward medial and superior. Vertebral artery injury or nerve root irritation symptom was not observed in any case.

Discussion

Since Abumi et al.[2)] described first the cervical pedicle screw insertion technique, several techniques have been presented to improve convenience and safety inserting cervical pedicle screw.[11,14,19)] However, the definite methodology determining the entry point and trajectory were not confirmed. Recently, various spinal image-guided techniques have been introduced to facilitate cervical pedicle screw insertion.[8,9,15,24-27)] With 3D-image guidance, the rate of significant violation rate of pedicle has been was 0.7−6.2% in several independent studies.[16,24-27)] Considering methods of registration, however, the screw misplacement rate increased up to 23.4%, and navigation errors can develop due to mobility of adjacent cervical vertebrae during the procedure.[27)] Despite the higher rate of screw misplacement with non-guided technique, the incidence of neurovascular complication remains low.[4,11,29)]

The usefulness of repetitive training using sawbone model reducing learning curve

The present study showed that repetitive training by using sawbone model could improve the accuracy of cervical

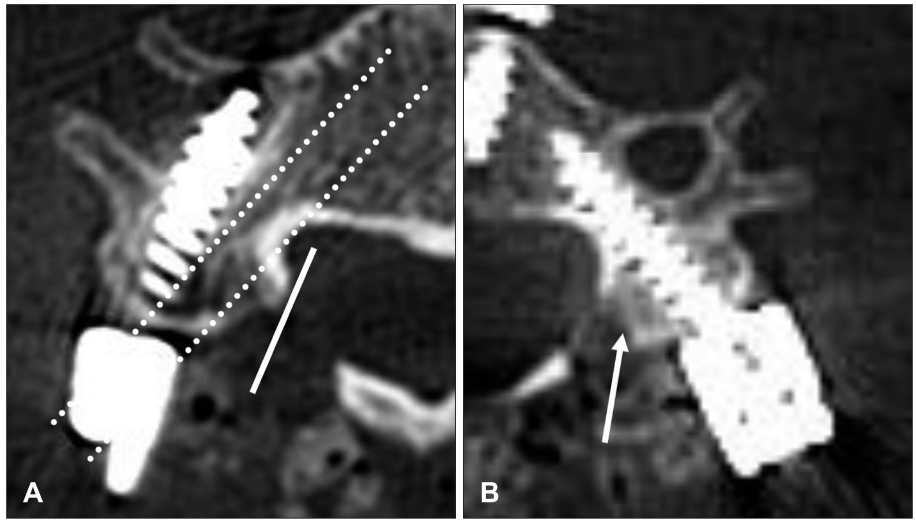

FIGURE 7. Post-operative axial CT showing grade 3 perforation (A). Trajectory of the pedicle screw placement was indicated with dot lines. Due to an inadequate laminotomy, convergence angle underestimated along the lateral margin of the foraminotomy site (solid line). About 1–2 mm drilling of medial wall of lateral mass might be helpful to fully expose a proximal segment of pedicle (B).

pedicle screw insertion with direct exposure of the pedicle by using para-articular mini-laminotomy. After the repetitive training by using sawbone model, we achieved 94.7% of correct screw placement in 9 consecutive patients without any neurovascular complications. Recently, without any image guidance, the rate of significant breaches of pedicle has been decreased up to 8.7% in several independent studies.[11,19] The sawbone model provides similar tactile feel during drilling, punching and screw insertion. Of course, cadaver model can provide a more realistic operative milieu. However, it can be used under limited conditions. Compared with cadaveric model, the sawbone model had no limitation on its use. The morphology of sawbone model can be analyzed via CT scan before and after the pedicle screw insertion. During the procedure, any direction of perforations can directly be revealed, and it provides an immediate feedback of the procedural failure. On the contrary to these advantages, the pedicle of sawbone, during the screw placement, tended to fracture when pilot hole was not optimally centered within the pedicle due to its brittleness. Moreover, pedicle diameter of sawbone usually smaller than human's cervical pedicle. Considering these characteristics of sawbone model, we did not probe the pedicle. Instead of probing, meticulous drilling by using tapper was done as accurate as possible. Sawbone models provide more strict tolerance range of cervical pedicle screw insertion, and it seems be helpful refining of the procedure.

Practical considerations inserting cervical pedicle screw insertion

In the present study, there was no medial direction perforation in 9 consecutive patients' series. Under the microscope, the medial wall of pedicle can directly be visualized during whole procedure. According to dimension of pedicle, the operator usually determined the convergence angle and entry point, and the medial wall perforation could be significantly low. However, most of pedicle violations were directed laterally, and it can cause catastrophic vascular complications due to the vertebral artery injury. Medial wall of cervical pedicles are significantly thicker than lateral wall.[13,22] Due to the anatomical characteristics, screws tend to deviate laterally. Considering the internal morphology of the cervical pedicle, the tapper and screws should be introduced somewhat medially more than estimated trajectory. In addition, inappropriate laminotomy would cause an inadequate exposure of pedicle's medial wall. It leads to underestimate the convergence angle, and trajectory could be determined more laterally than the pedicle axis (Figure 7A). Laminotomy should be performed to expose a full length of pedicle. About 1–2 mm drilling of medial wall of lateral mass might be helpful to a full expose proximal segment of pedicle (Figure 7B). In addition, inadequate navigation of pedicle's medial wall could induce an underestimation of convergence angle. Meticulous dissection of medial wall using microdissector would make possible to expose the junction of pedicle and posterior wall of vertebral body. It leads to visualize a full-length of medial wall under a microscope, and more accurate convergence angle could be estimated (Figure 2D). Medial wall of cervical pedicles are usually concave laterally. If the distal segment of medial wall is not exposed, convergence angle could be underestimated due to its lateral concavity.

Superior direction perforation was the second most common pedicle violation. During the procedure, inferior wall of pedicle could not be visualized in the operative field. Unconsciously, the trajectory could be determined along the medial and proximal segment of superior margin of the pedicle. Using the 3D-CT, the direction of screw placement in the sagittal plane could be determined. The superior margin of pedicle usually concave inferiorly, full-length of the pedicle should be visualized to determine an accurate superior margin. The caudal angle could be measures on 3D-CT (Figure 1A), and it should be considered during the procedure (Figure 3B). Anatomic variation of the cervical pedicle is considerable.[13,21] Therefore, it is important to analyze the anatomical structure carefully, and entry point and trajectory of screw placement should be individually customized via preoperative CT.

During exposure of pedicle's medial wall, subperiosteal dissection would be helpful to reduce bleeding from the epidural venous plexus. When the medial retraction of dural sac was done in the epidural space, epidural venous plexus are usually damaged. Bleeding control through mini-laminotomy might be laborious, and interrupt a full exposure of the pedicle's medial wall. Subperiosteal dissection could compress the epidural venous plexus during the pedicle navigation, and it make possible to expose of pedicle to the junction of pedicle and posterior wall of vertebral body without significant interruption of blood. As a result, a clearer operative filed with less blood loss could be obtained during the procedure.

Despite the high rate of pedicle perforation, especially lateral malposition, the significant vertebral artery injury has been rarely reported. The present study revealed that overall 23.6% of pedicle perforation rate, e.g., 77.8% of lateral, 11.1% of superior and medial perforation rate, with no neurovascular complications. It had been explained through several reports that laterally deviated screws which are placed in the transverse foramen do not necessarily cause vertebral artery perforation or obstruction due to the relatively large space of the transverse foramen between bone and artery.[1,20] Considering the possibility of catastrophic results caused by vertebral artery injury, the operator should do the best effort to avoid the lateral deviation of the pedicle screw.

Conclusion

In vitro training by using sawbone model seem to be useful to improve the surgical technique of cervical pedicle screw insertion with direct exposure of the pedicle by using para-articular mini-laminotomy. After the repetitive training, we performed cervical pedicle screw insertion in patients suffered from unstable cervical trauma, and with 94.7% correct position without clinical complications. This technique seems to be feasible and provide good clinical results in traumatic cervical lesions.

■ The authors have no financial conflicts of interest.

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