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Review Article

Subaxial Cervical Pedicle Screw in Traumatic Spinal Surgery

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Conflict of Interest
The authors have no financial conflicts of interest.

ABSTRACT

In cases of unstable cervical traumatic lesions, the biomechanical superiority of the cervical pedicle screw (CPS) allows the lesion to be stabilized effectively. In this study, we review and summarize the indications, technical guidelines, and potential neurovascular complications and their prevention of the use of the CPS for trauma. For patients with fractured lamina or lateral mass, a CPS is reliable for stabilization. In addition, the CPS can penetrate through a linear cervical spinal pedicle fracture gap and could stabilize three-column injury. CPS reduce the range of surgical approach and preserve the motion segment using short-segment fixation. Fluoroscopy-guided CPS insertion is popular and cost-effective. Image-guided navigation systems improve accuracy. Three-dimensional template-guided CPS placement is simple to use. Most spine surgeons can perform laminoforaminotomy easily. Freehand technique that can be performed quickly without heavy equipment is suitable for emergency situation. Possible complications due to screw misplacement are vertebral artery injury owing to a laterally misplaced screw, dural sac or spinal cord injury from a medially misplaced screw, and nerve root injury caused by a superiorly or inferiorly misplaced screw. To prevent neurovascular complications, meticulous preoperative anatomical evaluation and following the five steps are most important.

Keywords: Cervical pedicle screw; Technique; Complication; Navigation; Trauma; Accuracy

INTRODUCTION

Abumi et al.[1,5,15] first reported subaxial cervical pedicle screw (CPS) placement for traumatic lesions to stabilize an unstable motion segment. In three-column fixation, use of the CPS has a lower screw loosening rate and greater strength in fatigue testing than other fixation procedure.[4,14,15,18] In cases of unstable cervical segments caused by traumatic lesions, the biomechanical superiority of the CPS allows the lesion to be stabilized effectively even with posterior fixation alone and short-segment fixation. However, no recent literature reviews are available regarding CPS placement for traumatic lesions. In this study, we review and summarize the indications, technical guidelines, and potential neurovascular complications and their prevention of the use of the CPS for trauma.

USEFULNESS OF THE CPS IN CERVICAL TRAUMATIC DISEASE

In patients with cervical instability caused by trauma, controversies remain regarding the best surgical approach -anterior, posterior, or combined -according to bony changes, neural compression, and neurological symptoms. For patients with cervical trauma who have fractured and fragile posterior bony elements such as a lamina or lateral mass, a CPS is reliable for stabilization versus use of a lateral mass screw or lamina screw.[4,15] For severely injured patients with a lateral mass and lamina fracture, lateral mass screw fixation is impossible, but CPS stabilization might be possible (**FIGURE 1**). In addition, the CPS can penetrate through a linear cervical spinal pedicle fracture gap and could stabilize three-column injury, which might be unstable with posterior-column fixation using a lateral mass screw alone (**FIGURE 2**). The greatest advantages of the CPS are reduction in the range of surgical approach and preservation of the motion segment using short-segment fixation. Abumi et al.[1,15] reported 13 cases of middle or lower cervical spine injuries treated using transpedicular screw fixation. All patients achieved solid fusion without loss of correction and had satisfactory outcomes. Park et al.[8,15,17,25] demonstrated the safety and efficacy of the single-stage posterior approach with open reduction and CPS placement for severe traumatic cervical injuries including cervical facet dislocation, vertebral body fracture with ankylosing spondylitis, and cervical spondyloptosis (**FIGURE 3**).

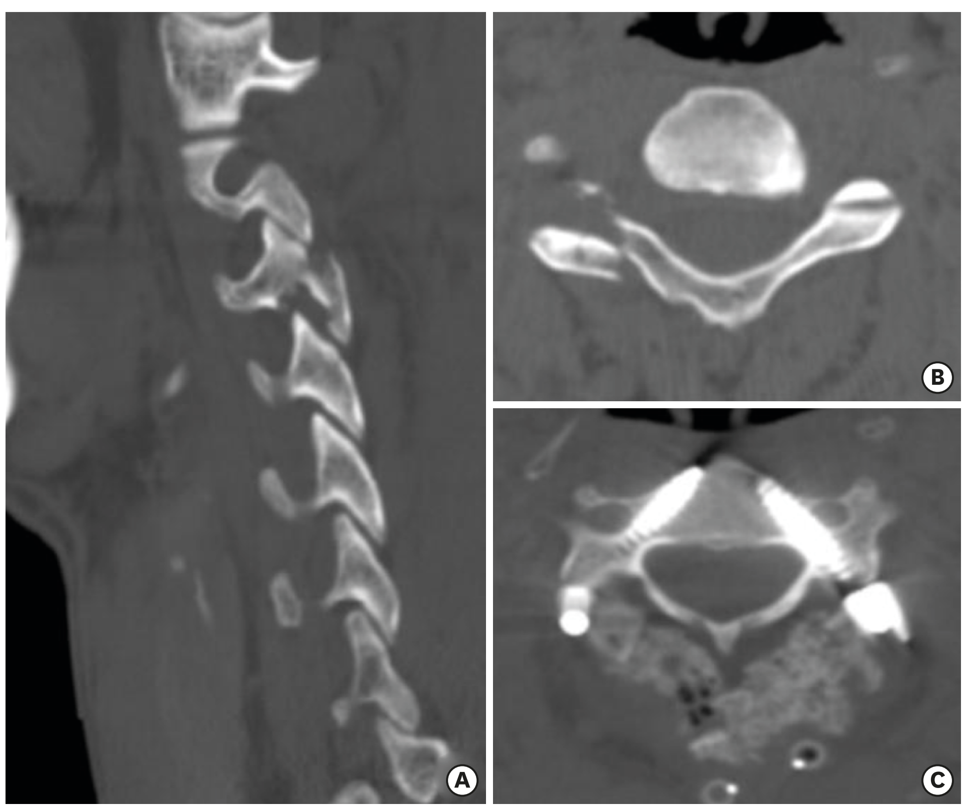

FIGURE 1. CPS fixation in patient with fractured lateral mass of right C3. (A) Sagittal image of preoperative CT scan shows fractured inferior articular process of right C3. (B) Axial image of preoperative CT scan shows fractured lateral mass of right C3. (C) In postoperative CT scan, fractured vertebrae was stabilized by CPS effectively. CPS, cervical pedicle screw; CT, computed tomography.

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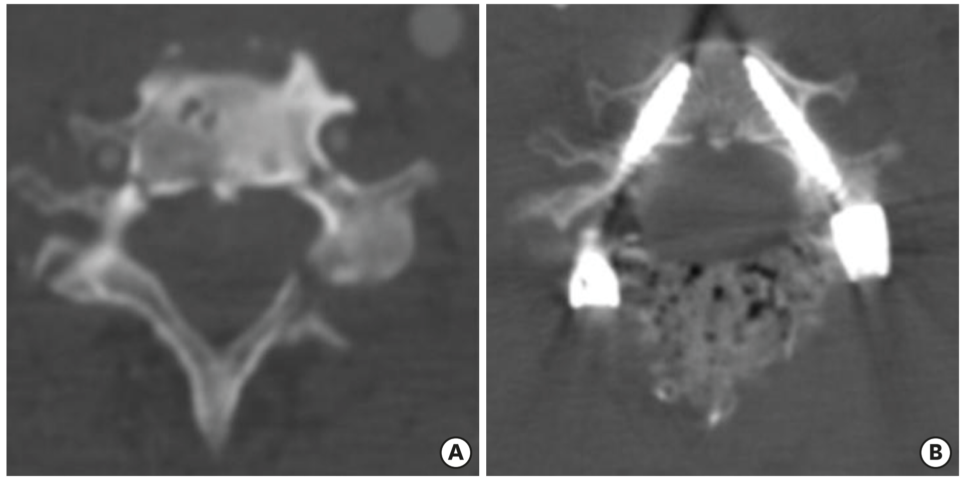

FIGURE 2. Three column fixation of cervical pedicle screw by penetrating gap of fractured pedicle. (A) Preoperative CT scan shows fracture of both pedicle. (B) In postoperative CT scan, the gap of fractured pedicle was stabilized by cervical pedicle screw.
CT, computed tomography.

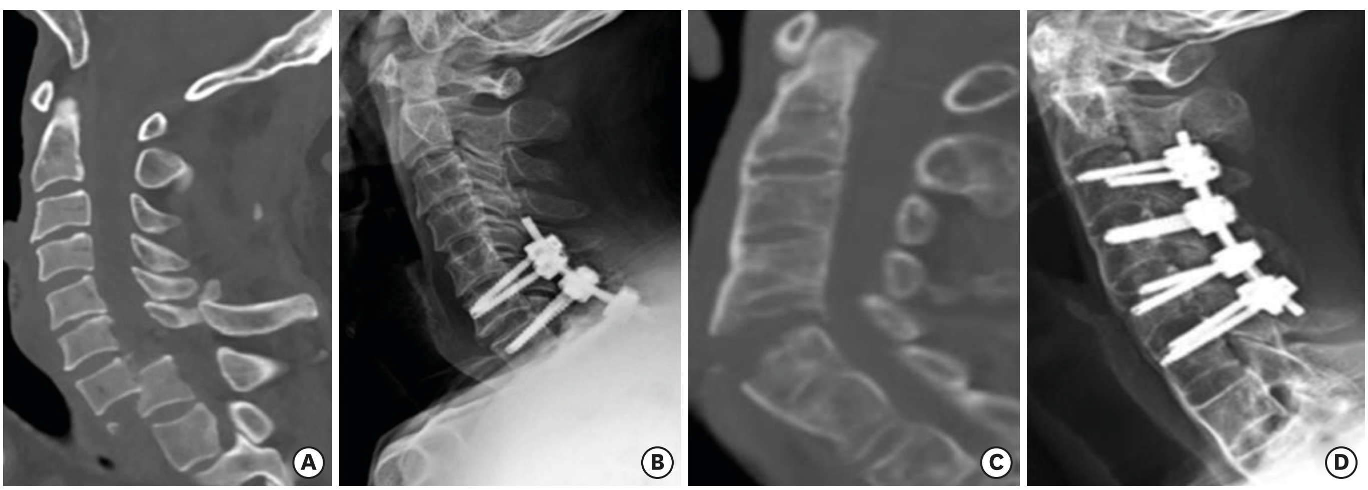

FIGURE 3. A single-stage posterior approach with open reduction and cervical pedicle screw placement for severe traumatic cervical injuries. (A) Preoperative CT scan shows traumatic spondyloptosis at C7-T1 level. (B) The spondyloptosis was corrected and stabilized by only posterior short segment fixation of cervical pedicle screw at the C6-T1 level. (C) Preoperative CT scan shows a fractured C5 bamboo spine with ankylosing spondylitis. (D) Postoperative simple lateral radiograph of the lesion shows a successful correction using short segment instrumentation of cervical pedicle screw.
CT, computed tomography.

If cervical lateral mass screws and thoracic pedicle screws are used for the stabilization of cervicothoracic junction pathology, a rod connecter is necessary to bridge the different screws. However, in this situation, one level of screw insertion should be omitted to allow space for a rod connecter between the pedicle screw and lateral mass screw; consequently, long level fixation is unavoidable. In addition, the lower biomechanical fixation power of the lateral mass screw leads surgeons to fixate longer levels. In this situation, if CPS is placed, it can be connected using a thoracic pedicle screw with a single rod. This makes the lesion more biomechanically stable, even with posterior-only fixation; this also secures the screw insertion space at each level, shortening the fixation level and thereby preserving the mobile segment (**FIGURE 4**).

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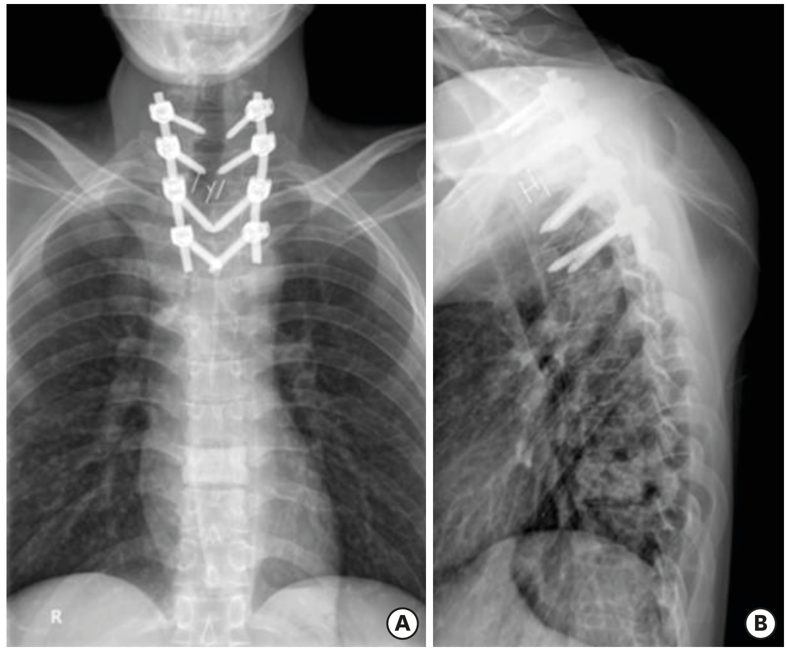

FIGURE 4. Advantage of pedicle screw for the stabilization of cervicothoracic junction pathology. A-27-year old male patient developed myelopathy after sliping down while skateboarding. Diagnosis was T2 bursting fracture due to lung cancer bone metastasis. Posterior decompression and both side C7, T1, T3, T4 pedicle screw fixation connected with 5.5 mm sized single rod was performed and it made lesion biomechanically more stable. It also shortened fixation level and thereby preserving the mobile segment. (A) Anteroposterior view of postoperative simple radiograph. (B) Lateral view of postoperative simple radiograph.

THE CPS IN OTHER NON-TRAUMATIC CERVICAL SPINE DISEASE

In cervical spondylotic myelopathy without kyphosis, laminoplasty is a useful method for decompression of stenotic lesions. However, posterior decompression alone is inadequate for cervical spondylotic myelopathy with local kyphosis exceeding 13°.[15,26] In this case, anterior decompression and fixation or simultaneous posterior decompression with CPS fixation can restore cervical lordosis.[5,15] Simultaneous posterior decompression and CPS fixation can be applied in cases of unstable cervical spondylotic myelopathy requiring posterior decompression or in salvage operations for previous anterior or posterior surgery to treat cervical spondylotic myelopathy requiring posterior decompression and stabilization.[2,5,15]

According to Abumi et al.[3,15], the goals of surgery for the treatment of cervical kyphosis are correction of the deformity and decompression of the neural elements. In principle, a combination of lengthening the anterior column and shortening the posterior column is required for effectively correcting kyphosis and minimizing spinal cord damage. Although circumferential osteotomy and shortening of the posterior portion of the cervical spinal column using a CPS are necessary in cases of fixed kyphosis with bony ankylosis, flexible kyphosis with segmental motion can be effectively corrected using independent posterior-only CPS placement. The CPS can restore the physiological sagittal alignment of the cervical spine.[4,15]

In addition, the CPS is useful for treating cervical spine metastasis. Although most cervical spine metastatic lesions involve the middle column of the vertebral body, the anterior cervical approach is the most popular for neural decompression and stabilization.[6,9,10,15] However, this

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anterior approach has several limitations, including excessive bleeding in corpectomy, risk of local recurrence from remnant tumor tissue, and weak biomechanical power even for palliative requirements. Since 1991, Oda et al.[15,23] have conducted palliative spine reconstruction for neural decompression and stabilization in patients with metastatic lesions. They have suggested several advantages of pedicle screw fixation for metastases of the cervical spine: 1) biomechanical superiority, 2) capability of kyphosis correction without anterior procedures, 3) simplified or no requirement of external support, and 4) possible simultaneous posterior decompression. Recently, Gallazzi et al.[10,15] reported satisfactory results using posterior-only fixation for cervical spine metastases, including postoperative pain relief, and improved quality of life. They also suggested that CPS placement can preserve a greater number of mobile cervical spine segments and can achieve stronger biomechanical stability.

USEFULNESS OF VARIOUS CPS INSERTION TECHNIQUES IN A TRAUMATIC SITUATION

Fluoroscopy-guided insertion

The lateral fluoroscopy-assisted manual procedure reported by Abumi el al.[4,15] is considered the conventional technique for subaxial CPS placement. After determining the screw entry points and resecting the outer surface of the articular mass to create a funnel-shaped hole, a small specially designed pedicle probe, a tap, and screws are inserted serially into the pedicle under lateral fluoroscopic image guidance to confirm the direction and insertion depth. Fluoroscopy is popular and cost-effective; however, it is insufficient for identifying fractured bony anatomy, especially in a lower cervical traumatic lesion, which might be obscured by the overlying shoulders.

Image-guided navigation system

The newest-generation image-guided navigation techniques include three dimensional (3D) fluoroscopy navigation systems such as the O-Arm System with Stealth Navigation based on intraoperative computed tomography (CT) scans with 3D image guidance. According to Chachan et al.[7,15], after exposing the posterior elements of the cervical spine, a reference array is clamped onto one of the spinous processes. Two-dimensional anteroposterior (AP) and lateral fluoroscopic images are first acquired to center the subsequent 3D scan; the actual 3D scan takes less than 17 seconds. The datasets, together with the sagittal and coronal reconstructions, are automatically transferred and registered in the Stealth Station navigation platform. A simple verification of the auto-registration process is performed using landmarks, such as the tip of the spinous process and facet joints. The starting point, trajectory, and the length of pedicle screw are planned by the surgeon using the navigated pointer together with axial, sagittal, and coronal images on the navigation platform. The pilot hole for screw placement is made using a high-speed drill, after which the cervical pedicle is probed using a navigated pedicle finder. This is followed by tapping and screw placement. After placement of all screws, another O-Arm-based scan is acquired to confirm proper screw position. Although surgeons can identify the exact fractured bony anatomy in traumatic lesions and can improve accuracy using these navigation systems, the procedure is time-consuming from preparation to use in an emergency situation for patients with trauma.

3D template-guided CPS placement

According to Lu et al.[15,21], numerous commercial software packages for making 3D models of the template are available, but the manufacturing processes are similar. First, CT images of the surgical region are obtained and exported as digital imaging and communications in medicine (DICOM) files. Next, the DICOM files are imported into multiplanar imaging software and a 3D model of the target spine segment is constructed. This 3D model is then imported into a reverse engineering program. The optimal position of the drill guide is designed, and the partial surface of the lamina and spinous process on the 3D model of the target spine segment is extracted. Finally, a 3D model of the template is created based on the drill guides and extracted bony structures. Using a rapid prototyping machine, a physical model of the template is created. During surgery, after complete removal of the corresponding soft tissue to securely fit the template onto the bony structure, pedicle screws are inserted under template guidance. On average, only about 80 seconds are required from fixation of the template to the lamina to insertion of the pedicle screws. Fluoroscopy can be used once only after screw insertion. 3D template systems are patient-specific, customized instruments. However, the long time required to make a template (about 1-7 days) limits application of the CPS in emergency situation for patients with trauma.

Direct exposure of the pedicle via laminoforaminotomy

According to Ludwig et al.[15,22], the ligamentum flavum at each targeted interlaminar space is gently dissected free from the lamina using a small curved curette. Thereafter, the inferior aspect of the superior lamina and the superior aspect of the inferior lamina are removed in varying amounts using a 3 mm burr followed by 1 mm and 2 mm Kerrison punches. After identifying the medial, superior, and inferior walls of the pedicle, drilling, probing, tapping, and screw insertion are performed. Although laminoforaminotomy can be easily performed in an emergency situation for patients with trauma, the accuracy of the procedure is controversial.[15,22,28]

Free-hand technique

Park et al.[15,19,24] reported freehand subaxial CPS placement using a curved pedicle probe without creation of funnel-like hole. After determining the entry point, a small pilot hole was made with a 1.8 mm diameter matched head-type burr, and a small curved pedicle probe (2.5 mm in diameter) was inserted. The tip of the pedicle probe was placed at the thick medial cortical pedicle wall and pushed medially using upward and downward movements to locate the cancellous channel of the pedicle, which is at an insertion depth of approximately 30 mm. After forming a track with the curved probe, ball-tip probe palpation was performed. Next, a straight pedicle probe (2.5 mm in diameter) was inserted to make the track wider and straighter, and the depth of the ball-tip probe was measured. During ball-tip probe palpation, feedback suggestive of malpositioning of the screw led to abandonment of the CPS procedure and conversion to insertion of a lateral mass screw. After tapping with a 3.5 mm diameter tap, a screw (diameter range from 3.5 to 4.0 mm) was inserted. After screw insertion, portable AP and lateral radiographs were obtained. A cortical defect in the lateral mass by the hole will cause screw instability.[15,30] However, as no funnel-shaped hole was created on the cervical lateral mass, they could use a longer screw (28 to 30 mm in length as opposed to the 20 to 22 mm screws used by Abumi et al.[4,15,19,24] Thus, CPS placement facilitated a longer bone and screw engagement, which increased screw stability. In surgery for patients with trauma, a freehand insertion technique is useful because it can yield shorter operation time and less soft tissue injury. With use of cumbersome equipment such as image-guided navigation, it may not always be possible to perform emergency surgery without a delay because the time, location, staff, or other factors may be unsuitable. Therefore, the simple free-hand pedicle screw insertion technique is useful in emergency surgery. Park et al.[8,13,15,17,24,25] proved the accuracy of freehand subaxial pedicle screw placement in patients with traumatic injury; however, it is difficult to become proficient in this technique.

PITFALLS OF THE CPS AND THEIR PREVENTION

Despite the biomechanical superiority of the CPS, possible neurovascular complications including injury to the vertebral artery (VA) and nerve root have limited the routine application of subaxial CPS placement.[11,15] Possible complications due to screw misplacement are VA injury owing to a laterally misplaced screw, dural sac or spinal cord injury from a medially misplaced screw, and nerve root injury caused by a superiorly or inferiorly misplaced screw.

Most pedicle perforation of CPS occurs in the lateral direction, which might cause injury to the VA.[15,19,29] Although the lateral cortex of the cervical pedicle is usually thinner than the medial cortex and perforation of the lateral cortex is more frequent than perforation of the medial cortex, VA injury is still rare.[15,16,24,30] Because most cortical breaches are minor, the VA occupies only 35% of the foramen, on average, and the distance from the VA to the lateral pedicle wall increases from C2 to C7, a misplaced CPS does not necessarily cause severe VA injury and catastrophic complications.[12,15,27] The reported incidence of ischemic brain complications caused by unilateral VA obstruction is also low, due to collateral circulation from the contralateral VA.[4,15] However, if an anomalous or unilaterally dominant VA is injured, catastrophic complications can occur. To prevent such adverse events, preoperative magnetic resonance angiography or CT angiography should be conducted to reveal the precise morphology of the VA. If an abnormality or unilateral predominance of VA is detected, alternative and safer techniques such as lateral mass screw insertion should be considered (**FIGURE 5**). Other potential complications of screw misplacement are injury to the spinal cord or dural sac if the CPS perforates the medial cortex; however, such cases are also rare because the medial cortex is thicker than the lateral cortex and the dural sac is 2.4 to 3.1 mm away from the medial cortex.[15,27]

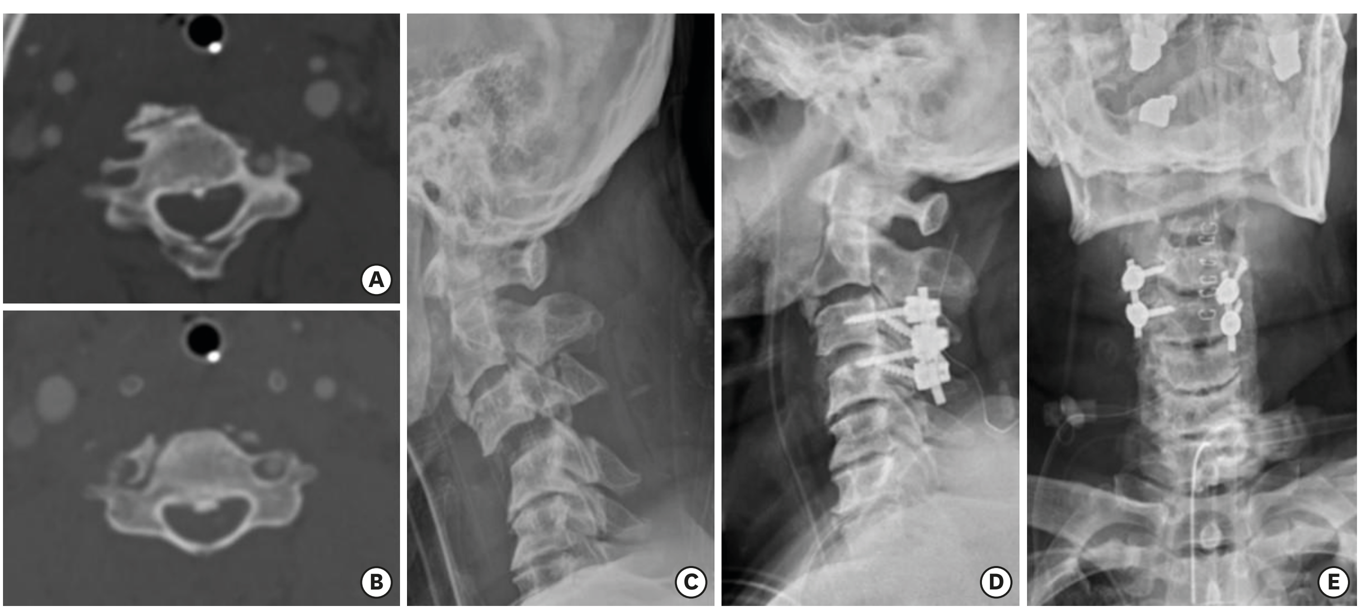

FIGURE 5. Conversion to lateral mass screw because of unilaterally dominant vertebral artery.
A 60-year-old male patient was diagnosed with cervical subluxation of C3-C4 in simple lateral radiograph (C). The right side vertebral artery is invisible and the left side VA is dominant (A, axial CT of C3 vertebrae; B, axial CT of C4 vertebrae). Therefore, right C3-C4 were stabilized by cervical pedicle screw and left C3-C4 were primarily stabilized by lateral mass screw instead of cervical pedicle screw(D, lateral view of postoperative simple radiograph; E, anteroposterior view of postoperative simple radiograph).
CT, computed tomography.

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To avoid neurovascular complications, Park et al.[15,19,20,24] proposed five steps to be followed during the initial learning period. First, screw entry points should be determined based on preoperative CT scans. Second, small-sized and curved pedicle probes can be used to ensure a proper medial angle for screw insertion. Third, a pedicle breach can be detected using a ball-tip probe. Fourth, a CPS should be changed to lateral mass screw when a breach is detected. The final step is the ability to interpret intraoperative AP radiographs after screw insertion. By following these five steps, surgeons can insert a CPS more accurately and safely.

CONCLUSIONS

In patients with a cervical traumatic lesion, three-column fixation and biomechanical superiority of the CPS enable stabilization of the lesion effectively even with posterior fixation alone and short segment fixation. Among the various insertion techniques, considering accuracy and simplicity under traumatic emergency conditions, freehand technique could be useful, after receiving systematic training under an expert surgeon. The most important neurovascular complication is injury to the VA owing to a laterally misplaced screw because of a thinner lateral pedicle wall than medial wall. To prevent neurovascular complications, meticulous preoperative anatomical evaluation of anomalous pedicles and the VA, and following the five steps proposed by Park et al.[15,19,20,24] are most important.

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