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CASE REPORT

Asymmetric C7 pedicle subtraction osteotomy for correction of rigid cervical coronal imbalance secondary to post-traumatic heterotopic ossification: a case report, description of a novel surgical technique, and literature review

Alexander A. Theologis[1] · Kate D. Bellevue[1] · Erion Qamirani[1] · Christopher P. Ames[2] · Vedat Deviren[1]

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Abstract
Purpose Deformities of the cervical spine are uncommon in the coronal plane. In this report, a unique case of a 31-year-old male with a fixed, 30° left coronal deformity due to heterotopic ossification 3 years status post polytrauma was treated with an asymmetric C7 pedicle subtraction osteotomy (PSO).
Methods Case report.
Results Pre-operatively, the patient had a fixed 45-degree left tilt of his neck and radiographs demonstrated a rigid 30° scoliosis, 7 cm coronal imbalance, and 4 cm negative sagittal balance, diffuse bridging bone between the spinous processes and the facet joints of C5 to T1 bilaterally. An asymmetric C7 PSO with C2–T3 posterior spinal fusion was completed without complication. There was residual 9° coronal deformity, 2.9 cm left coronal imbalance, and 2.3 cm sagittal imbalance. He had a marked improvement in his function, as assessed by the SF-36 physical component score (pre-op 31.1; post-op 44.7) and mental component score (pre-op 46.0; post-op 66.8). Post-operatively, neck disability index scores also improved (pre-op 38; post-op 16). Although the patient passed away from a drug overdose 14 months post-operatively, he did not report neck pain, he had not sought evaluation from another physician for his neck, and he had not undergone a subsequent neck operation before his passing.
Conclusion In this one patient, an asymmetric C7 PSO was performed safely. While it was effective in addressing a fixed cervical coronal imbalance, its efficacy and safety profile should be confirmed in larger cohorts.

Keywords Coronal imbalance · Cervical deformity · Pedicle subtraction osteotomy · Heterotopic ossification

✉ Alexander A. Theologis
alekos.theologis@ucsf.edu

[1] Department of Orthopaedic Surgery, University of California-San Francisco (UCSF), 500 Parnassus Avenue, MU325W, San Francisco, CA 94143-0728, USA

[2] Department of Neurological Surgery, UCSF, San Francisco, CA, USA

Introduction

Post-traumatic heterotopic ossification (HO) of the cervical spine is uncommon. Nevertheless, it may cause restricted range of motion, nerve impingement, pain, soft tissue ulceration, and joint ankylosis [1–3]. Resultant deformity in the sagittal or coronal planes may adversely affect one's quality of life [4]. While deformity of the cervical spine often occurs in the sagittal plane, coronal plane deformity is also recognized [5–7]. Cervical kyphotic deformity has been successfully and safely treated with a pedicle subtraction osteotomy (PSO) at the cervicothoracic junction [8–10]. To the best of our knowledge, we detail the first successful use of an asymmetric PSO at C7 to correct a rigid coronal cervical deformity due to post-traumatic heterotopic ossification.

Case report

History, physical examination, and imaging

A 31-year-old male presented to the outpatient spine clinic with a chief complaint of neck tilting and pain. Three years prior, he had suffered a motorcycle crash that resulted in a traumatic brain injury, a right upper extremity amputation,

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a left lower extremity amputation, and prolonged intubation. After his discharge, he developed torticollis that was progressive despite physical therapy and Botox injections and caused functional impairment of his vision, voice, and ambulation. Additional information regarding the extent of his vision, voice, and ambulatory dysfunction is not available. Clinically, he was noted to have a fixed 45-degree tilt of his neck to the left. Imaging demonstrated 7 cm of coronal imbalance to the left and a 4 cm negative sagittal imbalance (Fig. 1). Standing radiographs of the spine were not able to be obtained given his previous left lower extremity amputation. Diffuse bridging bone between the spinous processes and the facet joints of C5 to T1 bilaterally was noted (Fig. 1). This bridging bone was presumed to be heterotopic ossification given its extent throughout the subaxial cervical spine and the patient's traumatic brain injury [4]. There was no facet dislocation, as sagittal images demonstrated all facets were well aligned and there was no anterolisthesis at any level (Fig. 1). To address the multi-planar, fixed cervical deformity, he was scheduled for a C2 to T3 posterior spinal fusion and C7 PSO. The correction was planned based on the pre-operative coronal malalignment and negative sagittal alignment of the cervical spine. The goal of correction was to align the patient's head between his two shoulders without significantly changing his sagittal alignment. Given that the

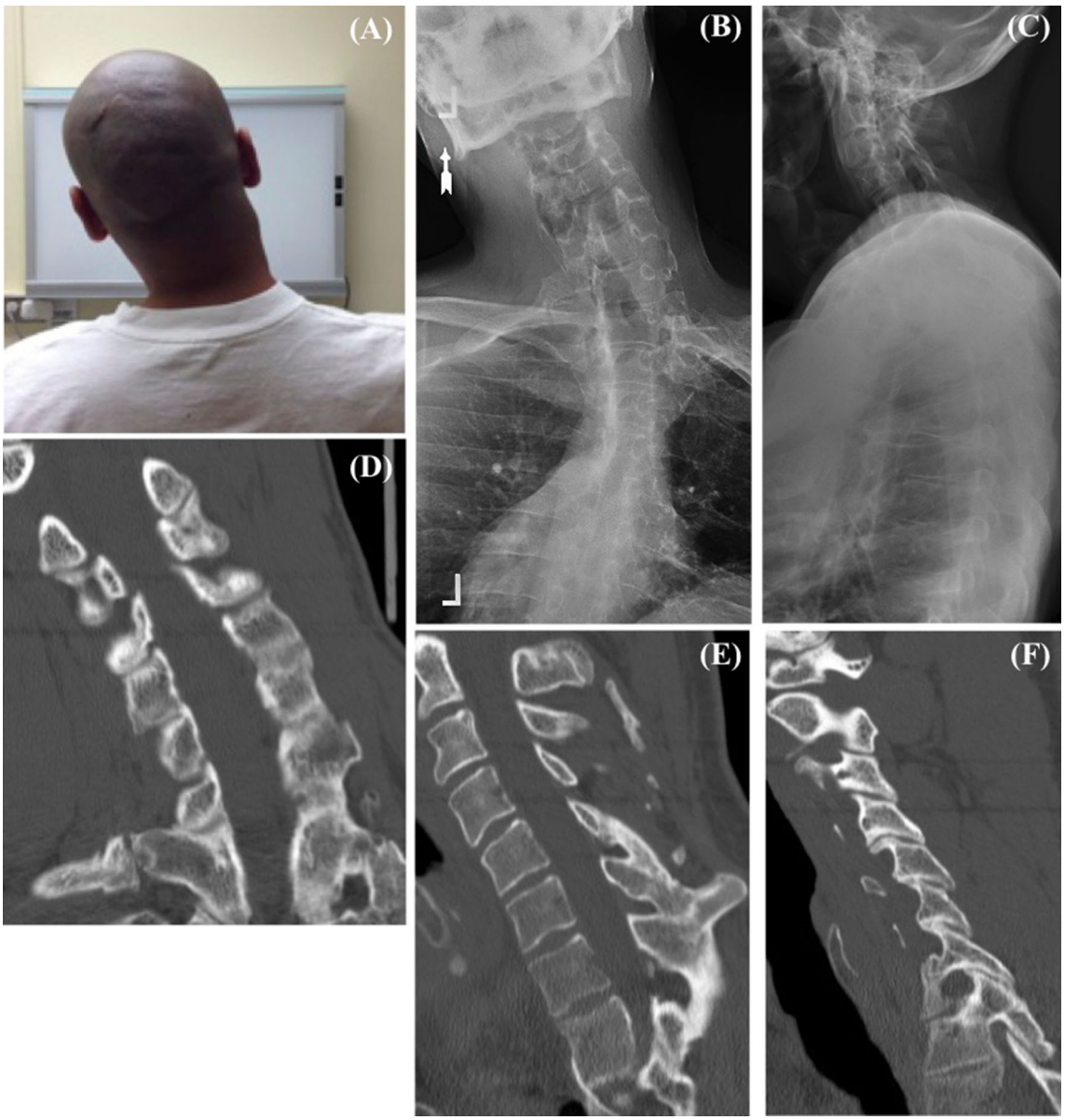

Fig. 1 Preoperative clinical and radiographic images of the cervical spine. Note the fixed coronal deformity (**a**, **b**, **d**) and bony bridging of the cervical facets (**d**, **f**) and spinous processes (**e**) from C5 to T1

deformity was rigid, a three-column osteotomy was deemed necessary. As adequate fixation after a PSO in the thoracolumbar spine has been proposed to be three levels above and below the PSO site, the distal extent of our construct was at T3. While the proximal extent of the construct could have been terminated in the subaxial spine (i.e., C4), we chose to extend the fusion and instrumentation proximally to C2 with pedicle screws given their better screw purchase compared to lateral mass screws.

Surgical technique

In the operating room, the patient underwent general anesthesia and endotracheal intubation while supine. This was then followed by placement of a halo. The patient was then turned prone onto a flat OSI table with a Jackson four-post frame. The halo was subsequently attached and stabilized to a connection at the head of the operating room table. Given the patient's rigid coronal deformity, the position of the halo before correction was dictated by the position of the head relative to the body. A midline incision extending from C2 to T3 was then performed and the spine was exposed in a subperiosteal manner. Pedicle screws were placed bilaterally at C2, T1, T2, and T3 and lateral mass screws were placed bilaterally at C3, C4, and C5. The inferior and superior articular processes at C6, C7, and T1 were found to be autofused due to significant heterotopic ossification. The C7 level was identified and confirmed by first identifying the ribs at T1 bilaterally and then dissecting the vertebra one level proximal. Laminectomies were performed at C6, C7, and T1. The C7 and C8 nerve roots were identified and followed out each foramen.

Attention was then turned to performing the osteotomy. The C7 pedicle was skeletonized and its transverse processes were removed bilaterally. The C7 pedicles were then tapped sequentially with increasing sizes of lumbar taps to decancellate the vertebral body. A Penfield No. 1 retractor was then used to dissect and prepare the lateral wall of C7. The lateral wall was removed with needle-nose rongeurs and osteotomes via the pedicle hole reamed out previously by the lumbar taps. The middle column was then removed using down-pushing curettes to create an asymmetric closing wedge resection (30° right-sided). No provision stabilization to prevent translation was used at this point, as the head was stabilized rigidly to the table via the halo. After the osteotomy was completed, the coronal deformity was gradually corrected by manually moving the halo. This was accomplished by having one physician from the surgical team detach the halo from the head of the operating room table while a second physician from the surgical team held the halo. The halo was then very slowly translated to the right while the scrubbed surgeons visualized the closure of the asymmetric PSO site. As the closure of the PSO was done only in the coronal plane, sagittal alignment was not changed appreciably. The extent to which the PSO site was closed and overall deformity correction was achieved was determined by trunk alignment and neuromonitoring signals. While the goal was to position the patient's head equally between the patient's shoulders, the ultimate goal was to avoid a neurologic injury. In this case, we were able to achieve desired deformity correction without encountering any changes in the neuromonitoring signals. After the head position was in the desired location, the halo was then reattached and stabilized to the head of the operating room table. Two rods were then placed from C2 to T3. Decortication was performed from C2 to T3 and allograft bone was placed posterolaterally. No bone graft was placed in the osteotomy site, which admittedly increased the risk of nonunion at the PSO level, especially with only two rods crossing the PSO site. To decrease the risk of developing pseudarthrosis at the PSO site, the authors have employed four-rod constructs across PSO sites to more rigidly stabilize the segment.

Post-operative course

The patient tolerated the procedure well and was discharged on post-operative day 7 with an intact neurologic examination. At the 6-week post-operative visit, he had improved and adequate head balance, level shoulders, and vocal and ambulatory function (Fig. 2). Additional information regarding the extent of his post-operative vocal and ambulatory function is not available. Radiographs demonstrated residual coronal deformity of 9°, a left coronal imbalance of 2.9 cm, and sagittal imbalance of negative 2.3 cm (Fig. 2). He had a marked improvement in his function, as assessed by the SF-36 physical component score (PCS—pre-op 31.1; post-op 44.7) and mental component score (MCS—pre-op 46.0; post-op 66.8). Post-operatively, the neck disability index also improved (pre-op 38; post-op 16). The patient did not return for further follow-up, as he moved out of the state as a member of the military. He then passed away 14 months after the operation due to a drug overdose. Before his death, the patient did not report neck pain or any difficulty with his neck, he had not sought evaluation from another physician for his neck, and he had not undergone a subsequent neck operation.

Discussion

Fixed coronal cervical deformity is a rare entity. Although mild coronal cervical deformity rarely results in functional impairment, severe deformities present a challenge to both the patient and treating surgeon. Current literature on

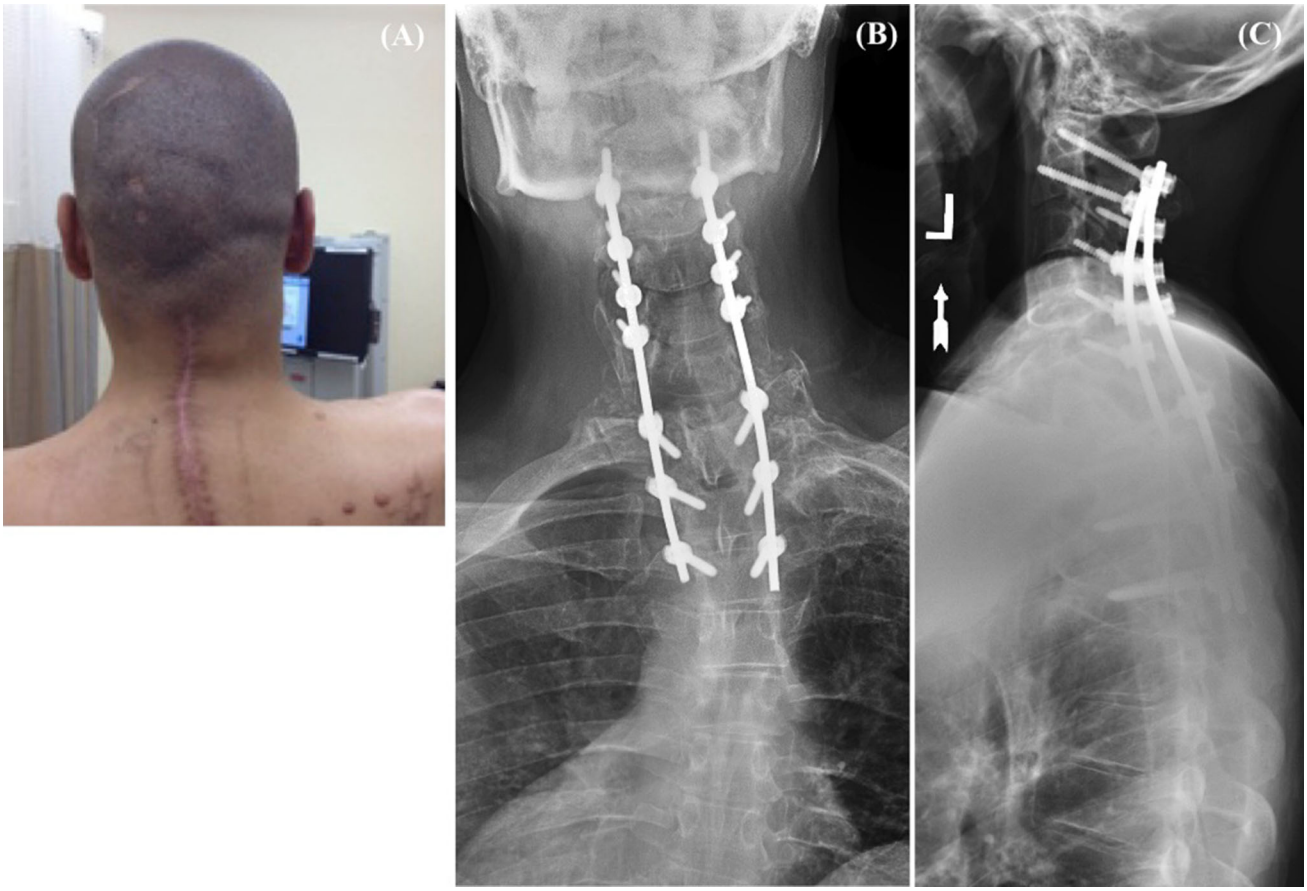

Fig. 2 Clinical and radiographic images of the cervical spine after an asymmetric C7 pedicle subtraction osteotomy. Note the significant improvement of the coronal deformity (**b**, **c**)

cervical deformity focuses primarily on management of deformities in the sagittal plane and case reports of hemivertebra resections (11, 12). To the best of our knowledge, there are no reports on the treatment strategy of fixed cervical coronal imbalance in adults. Thus, the case presented herein is the first to detail the use of an asymmetric C7 PSO for correction of a cervical coronal deformity.

Our technique is a variant of previously published reports of cervicothoracic PSOs for correction of cervical sagittal imbalance [8–10]. Similar to previous reports, we found that a cervical PSO is a safe and effective technique for the correction of cervicothoracic deformities in adults [8–10]. In our patient, the osteotomy resulted in improved patient posture, mobility, and quality of life. Other techniques described for correction of cervical deformity are limited to two previous case reports and pertain to children with cervical scoliosis due to congenital hemivertebra [11, 12]. Zhang et al. presented a 14-year-old male with progressive torticollis, cervical scoliosis (60°), and thoracic scoliosis (90°) due three semi-segmented hemivertebrae at C4, C5, and C6 [11]. After undergoing a staged operation (posterior, anterior, posterior) to remove the three hemivertebrae and a T6 PSO 6 months later, the patient was noted to have an excellent correction of his cervical scoliosis (residual 23°), thoracic curve residual (30°), and occipital tilt [11]. Ruf et al. treated three children each with a single cervical hemivertebrae and associated cervical scoliosis with a combined posterior–anterior (–posterior) surgical approach [12]. He noted improvements in the segmental Cobb angle (pre-op 29°; post-op 5°) and head tilt (pre-op 17°; post-op 1°) as well as no pseudarthrosis. Of note, there was one case in which a facet screw caused an acute C5 palsy and associated deltoid weakness, which resolved completely after revision of the screw [12].

Despite the novelty of our case report, it has limitations. It is a retrospective review of a single case performed at a single institution, which introduces bias into the results. It additionally limits our assessment of the surgical impact on certain aspects of the patient's life. For example, the extent of the patient's pre-operative and post-operative vocal and ambulatory dysfunction was unknown. We also did not have access to imaging at the time of his initial injury and cannot comment on the nature of his cervical spine before

his traumatic motorcycle crash. We were also not able to accurately assess the patient's full spine coronal and sagittal alignment given his previous lower extremity amputation. Having this information would have provided important insight into how the cervical deformity impacted his overall alignment and other compensatory mechanisms [13]. Furthermore, while the operation was performed safely and demonstrated good acute deformity correction, the clinical follow-up with associated health-related quality of life outcome scores was limited to 6 weeks. In turn, effectiveness of the operation can neither be evaluated nor endorsed. Although we were not able to assess radiographically or clinically the long-term effects of the osteotomy in this patient as he passed away, he had no neck problems more than 1 year after the operation.

In conclusion, proper patient selection, adequate patient education and pre-operative planning are essential requirements for a successful outcome following cervicothoracic junction PSO for rigid coronal deformity correction. As this is an isolated case, its efficacy and safety profile should be confirmed in larger cohorts.

Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest.

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