

Cervical osteotomies for neurological deformities

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Abstract

Purpose To report our experience and technique for performing cervical osteotomies under the setting of cervical deformity and myelopathy.

Methods Patients who underwent cervical osteotomies for CD with myelopathy were identified in a 10 year period from 2000 to 2010. Demographics, surgery type, osteotomy type, operative details, and radiographs were collected for pre-operative and ultimate post-operative time points. Cervical lordosis (CL) and basion plumb line were collected to assess angular and translational corrections.

Results In the study period, a total of 35 patients underwent a cervical osteotomy for fixed cervical deformity with a diagnosis of cervical myelopathy or myeloradiculopathy with an average follow-up of 3.4 years (range 1.0–6.3). The cohort was separated into two groups based on the type of surgical approach taken to correct their deformity. Anterior osteotomy with or without posterior instrumentation were performed in 31 patients (Group 1). Pedicle subtraction osteotomies were performed in 4 patients (Group 2). For Group 1, the mean angular correction achieved in this was 27.7° (range 9.0–66.0°) and the mean translational correction was 1.8 cm (range 0.1–2.4 cm). In group 2, the mean angular correction was 48.8° (range 38.4–68.3°) and the mean translational correction was 2.8 cm per PSO (range 0.1–5.6 cm). Similar improvements

in pre- and post-operative Neck Disability Index scores were achieved with either osteotomy technique.

Conclusions We present our series of patients with cervical myelopathy and/or radiculopathy and concurrent cervical deformity who were treated with cervical osteotomies. The re-alignment of the spine was a key step in preventing the progression of myelopathy and protecting the spinal cord from the continued injury.

Keywords Cervical kyphosis · Osteotomy · Cervical myelopathy · Spinal cord compression · Cervical deformity

Introduction

The presence of spinal cord compression in association with cervical deformities (such as cervical kyphosis) strongly predicts clinical progression of cervical spondylotic myelopathy and is negatively correlated with myelopathy scores (mJOA). [1, 2] Deformation of the spinal cord by anterior osteophytes or buckled/thickened ligamentum flavum can result not only in direct injury to the spinal cord, but also, injury in adjacent areas due to the shear/strain and stretch caused by the tethering effect of the local compression. This has been described as *Euler's Theorem* which is a concept describing local compression of a viscoelastic cylinder leading to tissue creep and tension forces directed perpendicular to the plane of compression [1]. Therefore, this results in local stretch injury to the spinal cord. This theory was demonstrated in a cadaveric model by Breig and colleagues who demonstrated that in the presence of ventral osteophytes and cervical stenosis, increased axial tension was seen in the dorsal columns [3, 4]. Clinically, this makes sense since many patients with cervical myelopathy demonstrate

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relatively normal static motor exams while their proprioception is severely altered (functions of the dorsal columns). This local injury from compression at one level is worsened with multilevel stenosis since the tethering effect of the cord is amplified from the adjacent areas of cord compression.

In cases of cervical deformities, the spinal cord is placed on even more stretch due to the cervical kyphosis increasing the effective distance the cord must stretch to accommodate the malalignment [1, 5, 6]. We present our series of cervical osteotomies performed for cervical deformity under the setting of cervical myelopathy and/or radiculopathy. We also briefly describe our technique for performing these osteotomies.

Materials and methods

All patients with cervical deformity who underwent either an anterior cervical osteotomy or a pedicle subtraction osteotomy of the cervical spine for cervical myelopathy or radiculopathy by the senior surgeon (KDR) during a 10 year period from 2000 to 2010 were identified and included in the study. Patients without a diagnosis of cervical myelopathy or myeloradiculopathy were excluded. Demographics (age, gender, and diagnosis), surgery type, osteotomy type, operative details, and radiographs were collected for pre-operative and ultimate post-operative time points. Two spine surgeons independently analyzed all the data. The cohort was separated into two groups. Group 1 had anterior osteotomy only with or without posterior instrumentation while Group 2 had a pedicle subtraction osteotomy of C7. Demographic information, operative details and alignment parameters were compared between groups.

Plain radiographic data was collected. Cervical lordosis (CL) and basion-C7 plumb line (B-C7PL) were collected to assess angular and translational corrections. The basion plumb line is a vertical plumb line drawn from the inferior tip of the basion and the distance between this line and the distance of the line drawn from the posterior superior aspect of the C7 vertebral body to this line was considered the B-C7PL. All lordotic measurements were reported as a negative angle while kyphotic alignment was considered positive. All basion plumb lines anterior to C7 were positive and posterior were negative.

Operative details collected included procedure, osteotomy type, level(s) where the osteotomies were performed, length of surgery (LOS), estimated blood loss (EBL) and intra-operative complications. Outcomes were assessed using the Neck Disability Index (NDI) at pre-operative and post-operative time points. Statistical analysis was performed using paired *t* tests with a *p* value of 0.05 as significant.

Table 1 Intra-operative details

Parameters/ groups	Anterior osteotomy group 1 (<i>n</i> = 31)	Pedicle subtraction osteotomy group 2 (<i>n</i> = 4)	<i>p</i> value
Length of surgery (min) ± SD	252.9 ± 100.2	353.3 ± 70.7	0.10
Estimated blood loss (cc) ± SD	215.9 ± 123.0	775.0 ± 556.0	<0.01
Intra-operative monitoring changes	0	0	
Neurologic complications	0	0	

SD standard deviation

Table 2 Radiographic and clinical outcomes from baseline to latest follow-up

Parameters/ groups	Anterior osteotomy group 1 (<i>n</i> = 31)	Pedicle subtraction osteotomy group 2 (<i>n</i> = 4)	<i>p</i> value
Radiographic parameters			
Pre-operative cervical lordosis (°)	24.8	4.3	0.73
Pre-operative basion PL (cm)	−1.5	4.6	<0.01
Post-operative cervical lordosis (°)	−5.0	−16.2	0.03
Post-operative basion PL (cm)	−1.6	2.4	0.02
Total angular correction (range)	27.7 (9.0–66.0)	48.8 (38.4–68.3)	0.03
Total translational correction (range)	1.8 (0.1–2.4)	2.8 (0.1–5.6)	0.56
Clinical outcome—Neck Disability Index (NDI)			
Pre-operative NDI	26.0	25.2	0.99
Post-operative NDI	21.5	20.5	0.99

Results

In the study period, a total of 35 patients underwent a cervical osteotomy for fixed cervical deformity with a diagnosis of cervical myelopathy or myeloradiculopathy with an average follow-up of 3.4 years (range 1.0–6.3). All

cases were revisions except for five, of which two were post-traumatic kyphosis, one post-laminectomy kyphosis, two with kyphoscoliosis.

There were 31 patients in Group 1 and 4 patients in Group 2. Group 1 had shorter LOS and significantly less EBL compared to Group 2 (LOS 252 vs. 353 min, $p < 0.10$; EBL 215 vs. 775 cc, $p < 0.01$) (Table 1). There were no intra-operative monitoring changes or neurologic complications.

Anterior osteotomy with or without posterior instrumentation were performed in 31 patients (Group 1). The mean angular correction achieved in this group was 27.7° (range 9.0 – 66.0°) and the mean translational correction was 1.8 cm (range 0.1–2.4 cm). Pedicle subtraction Osteotomies were performed in four patients (Group 2). The mean angular correction achieved was 48.8° (range 38.4 – 68.3°) and the mean translational correction was 2.8 cm per PSO (range 0.1–5.6 cm) (Table 2). The PSO was more effective at providing angular corrections compared to anterior osteotomy (48.8 vs. 27.7° , $p = 0.03$) while the translational corrections were similar. Similar improvements in pre- and post-operative NDI scores were achieved with either osteotomy technique (Table 2).

Surgical technique

Anterior osteotomy [7]

With the anterior osteotomy, placing the patient supine usually results in the head being suspended in the air due to the rigid kyphotic deformity. We support the head with sheets and/or a foam donut at the start of the case. Gardner-wells tongs are placed and 5 pounds are placed on the rope with another 20 lbs on standby. A Smith–Robinson approach is utilized. In cases where the chin is on or nearly on the chest, this can be difficult but in the vast majority of cases, one can still expose the anterior spine using this technique. If both vocal cords are functional, the approach can be on either side, although we prefer to utilize the side contralateral to the index operation to avoid scar tissue and to make the exposure less challenging. However, if the vocal cord is paralyzed, the approach should be performed on the ipsilateral side to avoid injury to the contralateral vocal cord. Exposing the apex of the kyphotic deformity can be challenging, since it is deep in the wound, even in thin patients. For patients with concomitant coronal plane deformities, we always approach from the convex side, as it is easier to expose.

To prepare for this osteotomy, a thorough examination of the vertebral arteries is also essential because the dissection often has to go lateral to the uncinates. During the operation, we utilize a Penfield 4 and/or 2 to perform a blunt dissection lateral to the uncinates and use the costal

process (the anterior ring of the foramen transversarium) as an anatomic landmark to identify the fused disc space. The disc space and uncinates is just medial to the cranial border of the costal process.

A Caspar pin is placed within the kyphotic segments above and below the level of where the osteotomy is desired. We place the pins perpendicular to the anterior plane of the deformed cervical spine, which for a kyphotic spine results in divergent pins. This means that the tips of the Caspar pins will be aiming away from each other and the proximal posts of the pins will be convergent. Pin placement in this manner can help to produce lordosis after the osteotomy is performed.

Once the area of osteotomy is identified, we can initiate the bony resection with a high speed 3 mm matchstick burr. The morphology of the resection is dependent on the type of deformity. For example, in purely kyphotic deformities, care must be taken to perform the resection perpendicular to the cervical spine and as much as possible in the same space as the former disc space, to prevent an iatrogenic coronal plane deformity. For those mixed coronal and kyphotic deformities, the bony resection can be asymmetrically made to result in proper alignment in the coronal plane once the osteotomy site is “closed” down. The osteotomy is performed deep in a kyphotic wound. Occasionally, it is so deep that one has to hold the burr at the very tip of the handle, which can be challenging for an inexperienced surgeon.

The bony resection is taken all the way posteriorly to the level of the posterior longitudinal ligament. The lateral aspect of the bony resection should always be performed with extreme caution as iatrogenic vertebral artery injury is possible during this step. To prevent this, we protect the vertebral artery by utilizing a Penfield 4 or 2 during the lateral bony resection. The Penfield identifies the lateral border of the uncinates where the vertebral artery lies. Alternatively, one can place a small paddy lateral to the uncinates to protect the artery. The burr never passes this point. Once the bone is resected to this border, the remaining thin shell of bone can be removed with the use of a microcurette. A foraminotomy is recommended at the levels where the bony resection is performed to prevent nerve root compression during extension.

The osteotomy is now complete. To correct the deformity, we ask the anesthesia team to remove the sheets under the head, one at a time while gently pushing on the forehead through the sterile drapes. Simultaneously, we distract the Caspar pins. In addition to helping to correct the deformity, the pins stabilize the correction. To distract the disc space, one can also rotate a Cobb within the osteotomy site to separate the bony edges while simultaneously distracting along the Caspar pins. In addition, one can use a vertebral body spreader. Of all of the above,

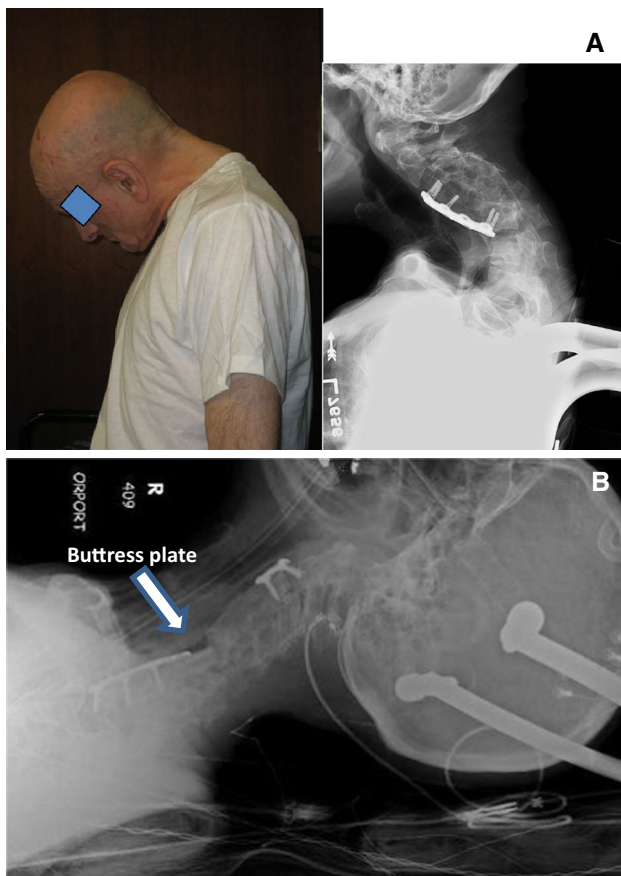


Fig. 1 **a** Clinical photograph demonstrating the Fixed Kyphotic Deformity with corresponding pre-operative X-ray. **b** Intra-operative X-ray demonstrating buttress plate with posteriorly recessed Strut graft. The graft is positioned posteriorly as to prevent the chances of graft kick out during the posterior osteotomy and correction

however, we believe that pushing on the forehead is the safest and the least likely to result in cutout of the pins or fracture of the vertebral body. Even in cases where there is a posterior fusion with instrumentation, one can usually get a partial correction of the deformity with this maneuver. This is because the force of pushing on the forehead utilizes a long lever arm such that, after anterior osteotomy, most rods will flex into less kyphosis. Once the occiput has been pushed back onto the table, the weight on the Gardner-Wells tongs is increased to 20–25# to maintain the correction, if needed.

We then place grafts into the osteotomy site. If the deformity has been completely corrected, we use fresh frozen iliac crest allograft that maximally fills the space and use an anterior plate with screws that penetrate at least 75 % of the vertebral body. If there is osteoporosis, we do not hesitate to use bicortical screws. Because the spine wants to spring back into its original kyphotic position, long screws and large grafts are necessary to prevent post-operative loss of correction. If the deformity has not been

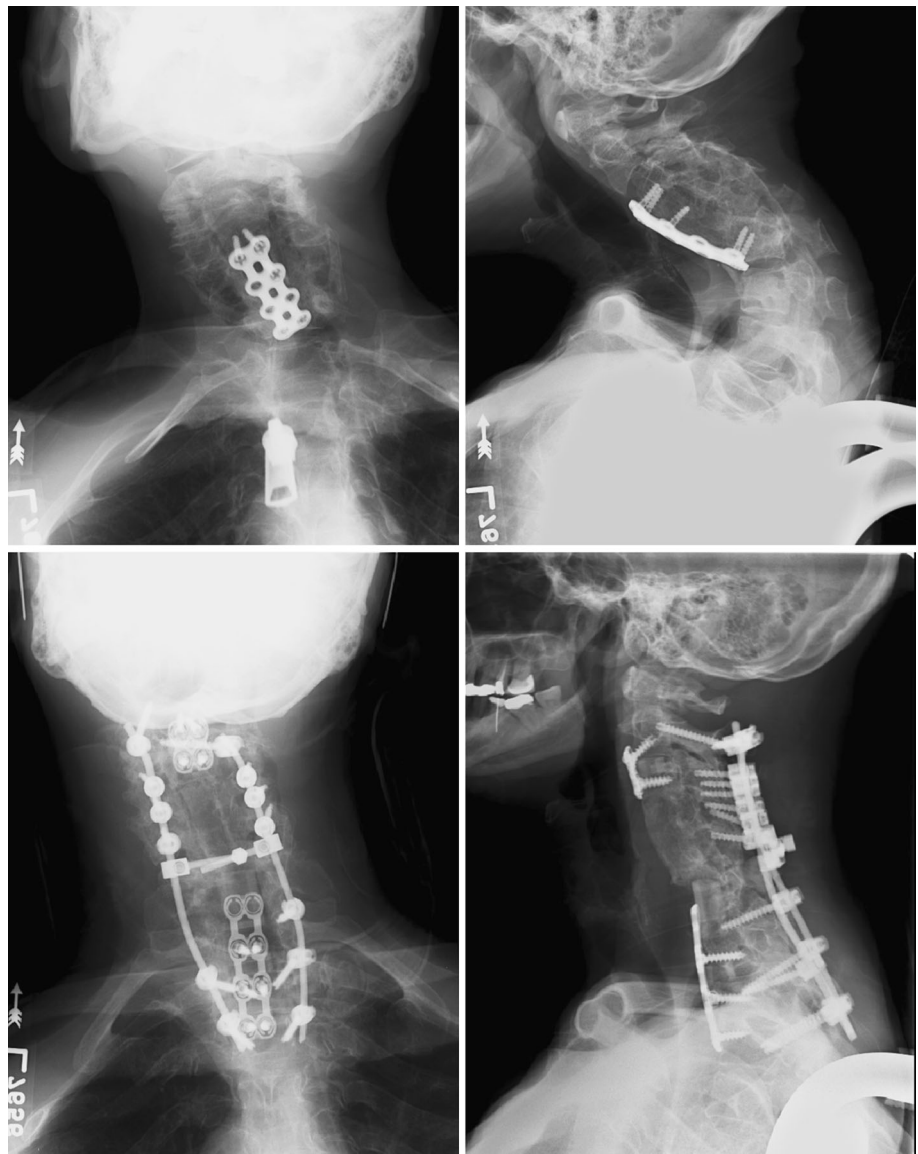
satisfactorily corrected, we prefer to use a lordotic cage-screw combination and only put in one screw so that we can get further correction posteriorly. If a corpectomy was performed, then we recess the graft as posteriorly as possible and put interference screws into the cranial and caudal endplates or a buttress plate to prevent graft extrusion during the posterior approach and correction. (Fig. 1) The patient is then turned to a prone position. If the deformity was completely corrected anteriorly, we lock it in with a posterior instrumented arthrodesis. If not, then we perform Smith–Petersen osteotomies followed by an instrumented arthrodesis. (Fig. 2).

Pedicle subtraction osteotomy [8]

Patients are positioned on a Jackson table in bivector traction previously described [8]. Briefly, Gardner-Wells Tongs are placed one fingerbreadth above the pinna of the ear. The patient is placed prone on an open Jackson table with the arms tucked at their sides and two traction ropes are placed through the Jackson Frame; one which is the flexion rope and the other which is placed over the H-attachment designated the extension rope. (Fig. 3) The bed is placed in as much Reverse Trendelenburg as possible to prevent venous pooling to the brain as well as to help decrease blood loss during the operation. After exposure, all screws are placed before the osteotomy. We recommend a minimum of six to eight fixation points above and below the osteotomy (usually at C7). We usually place screws into C2, 3, 4, and 5, skipping C6, and into the upper thoracic pedicles. If the patient is already fused to the skull, is osteoporotic and C2–5 fixation does not seem adequate, we extend the instrumentation up to the occiput. Alternatively, or in addition, if the posterior instrument purchase appears to be insufficient, we have a low threshold for going anteriorly to place a long anterior cervical plate with screws into each hole above and below the osteotomy.

The osteotomy commences with a complete C7 laminectomy, and partial laminectomies of the caudal half of C6 and cranial half of T1. The laminectomy is done with a high speed burr, just medial to the pedicles. We split the C7 spinous process in half in the sagittal plane and utilize it as bone graft. Care is taken to leave the C6 and T1 spinous processes intact. The entire lateral mass of C7, including its facets, the superior facet of T1 and the inferior facet of C6 is then removed bilaterally with a Leksell rongeur. The T1 pedicles must be well exposed and any overhanging facet cranial to the pedicle removed to prevent compression of the C8 root as the osteotomy is closed. The remaining stump of the C7 pedicle, along with the C7 and C8 nerve roots should now be visible. We use a Penfield 2 or 4 to retract the nerves and a 2 mm matchstick burr to core out

Fig. 2 (from upper Left, going clockwise) Pre-operative AP and lateral view with corresponding post-operative X-rays demonstrating adequate correction of the deformity with the anterior osteotomy followed by posterior instrumentation



the center of the C7 pedicle, thinning out its walls. Effort is made to maintain the medial and inferior wall of the pedicles since they are the only protection provided for the nerve roots. Therefore, we usually take down this portion as a last step. We burr through the pedicle and partially into the vertebral body to de-cancellate it. Pre-operatively, we check an MR-angiogram to make sure that the vertebral artery is not anomalously in the foramen transversarium at this level. If it is, then we protect it during the burring.

Following this, the thinned walls of the pedicle can be removed using a small curette and pituitary rongeurs. The pedicle has to be completely flush with the vertebral body to prevent injury to the C7 root, which will migrate into that space during the extension osteotomy. Reverse angle curettes are then used to remove and/or compact the cancellous bone in the posterior superior portion of the C7

vertebral body bilaterally to create the subtraction cavity. A Woodson or angled dural elevator is then used to implode the dorsal cortex of the body into the subtraction cavity. It is wise to check the ventral wall of the spinal canal multiple times with a Woodson at the end of the osteotomy, throughout the correction and after the correction to ensure no bony fragments are impinging on the spinal cord.

Next, the rods are pre-bent to a desired angle of correction and fixed to the thoracic pedicle screws. The surgeon then grasps the head using the Gardner-Wells tongs and the neck is gently brought up into extension. The anesthesiologist switches the weights from the flexion to the extension rope. If an adequate amount of bone has been resected at C7, little force is required to produce a controlled osteotomy. If one cannot easily extend the neck,



Fig. 3 **a** The bivector traction on the open Jackson Frame placed in as much reverse Trendelenburg as possible. **b** At the head of the bed is the flexion and extension ropes which allows for positioning the head during the operation without the surgeon breaking scrub

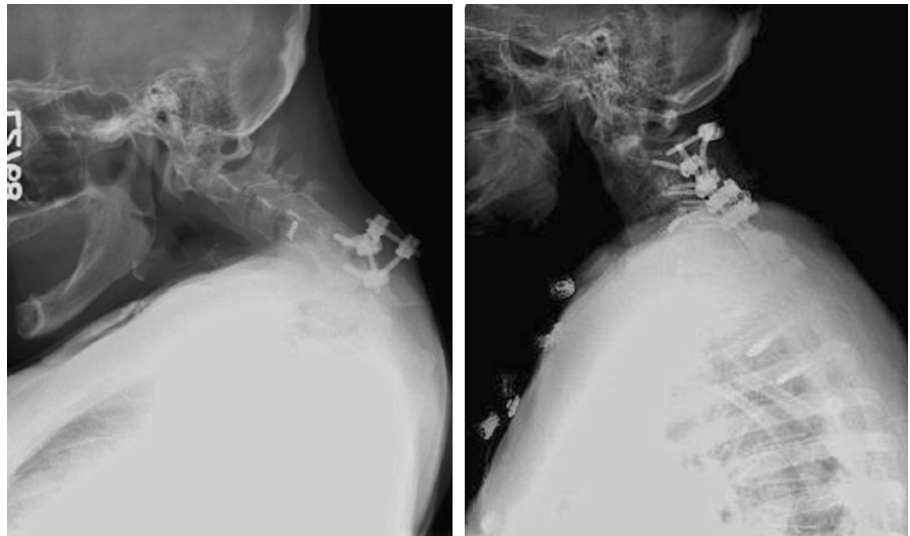
then more bone needs to be resected from the ventral portion of C7. During the extension maneuver, the C7 and 8 roots should be examined for any signs of impingement. If an adequate amount of bone has been resected, they should remain free and mobile. Further undercutting of the C6 inferior facet or removal of any overhanging T1 superior facet may be necessary.

As the head comes up, the cervical lateral mass screws will begin to capture the pre-bent rod. Set screws are placed into the tulips of the lateral mass screws as the head is extended. To ensure that this part of the operation goes as smoothly as possible, one must take care to place the

lateral mass screws in as straight a line as possible so that the rods easily fall into the tulip heads of the screws. At C2, if laminar screws have been utilized, a lateralizing connector will be necessary to capture the rod. All of the set screws are tightened and monitoring data is assessed to ensure that there are no changes.

Occasionally, the anterior column may open during the osteotomy. This happens commonly if there has been a fracture of the segment that the osteotomy is being performed at. It can also happen if inadequate bone has been removed via the pedicle subtraction procedure. If there is good fixation posteriorly, from the occiput to at least six

Fig. 4 Pre-operative and post-operative Lateral X-rays demonstrating the correction achieved with a C7 PSO



points of fixation distally, it may be adequate to leave the anterior gap alone, similar to what is done for a Simmons osteotomy. An alternative that we often prefer, however, is to turn the patient anteriorly and plate the segment with four screws above and below the osteotomy, placing in a graft if there is a large defect. (Fig. 4) This results in a stable construct that allows for a very short period of immobilization in a collar.

Conclusion

We present our series of patients with cervical myelopathy and/or radiculopathy and concurrent cervical deformity who were treated with anterior osteotomy or a pedicle subtraction osteotomy. The re-alignment and stabilization of the spine was a key step in preventing the progression of myelopathy and protecting the spinal cord from the continued injury resulting from segmental compression and tethering due to excessive cervical kyphosis.

Conflict of interest None.

References

- Henderson FC, Geddes JF, Vaccaro AR, Woodard E, Berry KJ, Benzel EC (2005) Stretch-associated injury in cervical spondylotic myelopathy: new concept and review. *Neurosurgery* 56(5):1101–1113 (discussion 1101–13. Review)
- Smith JS, Lafage V, Ryan DJ, Shaffrey CI, Schwab FJ, Patel AA, Brodke DS, Arnold PM, Riew KD, Traynelis VC, Radcliff K, Vaccaro AR, Fehlings MG, Ames CP (2013) Association of myelopathy scores with cervical sagittal balance and normalized spinal cord volume: analysis of 56 preoperative cases from the AO Spine North America Myelopathy study. *Spine (Phila Pa 1976)* 38(22 Suppl 1):S161–S170
- Breig A, Turnbull I, Hassler O (1966) Effects of mechanical stresses on the spinal cord in cervical spondylosis. A study on fresh cadaver material. *J Neurosurg* 25(1):45–56 (No abstract available)
- Breig A (1970) Overstretching of and circumscribed pathological tension in the spinal cord—a basic cause of symptoms in cord disorders. *J Biomech* 3(1):7–9 (No abstract available)
- Scheer JK, Tang JA, Smith JS, Acosta FL Jr, Protosaltis TS, Blondel B, Bess S, Shaffrey CI, Deviren V, Lafage V, Schwab F, Ames CP, International Spine Study Group (2013) Cervical spine alignment, sagittal deformity, and clinical implications: a review. *J Neurosurg Spine* 19(2):141–159 (Epub 2013 Jun 14. Review)
- Ames CP, Blondel B, Scheer JK, Schwab FJ, Le Huec JC, Massicotte EM, Patel AA, Traynelis VC, Kim HJ, Shaffrey CI, Smith JS, Lafage V (2013) Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. *Spine (Phila Pa 1976)* 38(22 Suppl 1):S149–S160
- Kim HJ, Piyaskulkaew C, Riew KD (2014) Anterior cervical osteotomy for fixed cervical deformities. *Spine (Phila Pa 1976)* [Epub ahead of print]
- Wollowick AL, Kelly MP, Riew KD (2012) Pedicle subtraction osteotomy in the cervical spine. *Spine (Phila Pa 1976)* 37(5):E342–E348