Multi-level Anterior Cervical Discectomy and Fusion (ACDF) with expandable cages for fixed kyphotic spondylotic myelo-radiculopathy obviating a posterior reconstruction.

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Introduction – Anterior cervical discectomy and fusion (ACDF) is one of the most widely used treatments for cervical myelopathy and spondylosis. In addition to its success in clinical history, one primary advantage of the anterior surgical approach is that it allows for easier cervical lordosis restoration, which has statistically significant correlation with regional and global spinal sagittal balance[1]–[3]. ACDFs that achieved a significant amount of cervical lordosis were consistently associated with improved clinical outcomes[4][5], while ACDFs that failed to correct pre-operative kyphosis reported worse scores in multiple clinical outcome assessments such as Neck Disability Index (NDI) and Visual Analogue Scale (VAS)[6][7]. A study done by Hu *et al.* in 2015 with 104 multi-level ACDF patients showed a 35% incidence of symptomatic adjacent segmental disease (sASD) and reoperations due to sASD in patient group who had post-operational kyphosis, whereas only 12% incidence in patient group with restored lordosis. In a retrospective study of 672 patients[9], sASD was accountable for 47.5% of all ACDF revision surgeries, mainly due to suboptimal lordosis correction.

Despite this compelling data, there are still considerable difficulties in restoring cervical sagittal balance due to the limitations of current ACDF implants. Structural allograft and static cervical implants have discrete heights that cannot be customized to optimal patient-specific lordotic angles. Patient positioning, trialing, distraction, and bony resection required to accommodate static cages for appropriate segmental lordosis are time consuming steps and their effectiveness is highly dependent on bone quality. In addition, impaction and bony resection can violate the vertebral endplates, resulting in subsidence, which is the most common failure mode of ACDF surgery (Figure 1). Subsidence was also found in some studies to be statistically correlated with segmental kyphosis and lower fusion rates [10-12]. Worse yet, given the complexity in severe cases of fixed kyphosis, a 360˚ surgical approach is often needed to achieve greater sagittal correction, which causes 3 times more operational tissue morbidity than anterior only approach[13].

In contrast, novel expandable cages have been introduced to provide the ability to dial-up each intervertebral disc space to its desired (and required) lordotic angle for an optimal global sagittal correction. It also allows for endplate coverage and bony ingrowth to prevent subsidence. This case study presents an evaluation of HiJAK™ cervical expandable cages (Atlas Spine, Inc.) - implants designed to address the aforementioned challenges in restoring cervical sagittal balance from an anterior-only approach.

Fig. 1. Common ACDF kyphosis due to subsidence

Patient History – A 74-year-old male smoker (8 cigarettes per day) presented with symptoms of shooting neck pain that radiated down his spine and down both arms. Patient had persisted numbness and tingling sensations on both forearms and fingers, which had significantly affected fine motor function. Progressive balance difficulties were present for three months and typical ataxic gait was noticed by the nursing staff as patient entered the clinic. He experienced increasing fatigue and weakness during leisure activities that required moderate physical work in his shop as well as progressive difficulty holding up his head. Radiographs (Figure 2a) and representative MRI images (Figure 2b) indicated that patient had a fixed cervical kyphosis from C3-7 with disc herniation at multiple levels as well as cord and root compression, which are responsible for his progressive severe myelo-radiculopathy. In addition to heightened reflexes throughout, patient had positive Hoffman's and Lhermitte's signs with three bouts of clonus in the left ankle.

Prior to our encounter, patient had undergone non-surgical treatments including an aggressive physical therapy program, non-steroidal anti-inflammatory drugs (NSAIDs), and non-narcotic pain medications; however, patient reported persistence of debilitating pain and progression of myelopathic symptoms was clearly noted.

Fig. 2a – 2b. Left: Pre-operative radiograph; Right: Pre-operative MRI image

Surgical Intervention – In consideration of patient's progressive spondylotic myelopathy and fixed cervical kyphosis, he was offered a four-level ACDF with the understanding that posterior osteotomies and fixation to restore optimal sagittal balance would possibly be required.

After standard anterior cervical Smith-Peterson approach was created to the C3-7 levels, opening wedge osteotomies were required at C3-4 and C4-5 to enter into the fused disc spaces and perform proper cord and root decompressions. The Posterior Longitudinal ligament (PLL) was resected at all levels after discectomies at C5-6 and C6-7 for thorough neural decompression, and at each level, cervical expandable cages were placed (HiJAK^{TM} AC, Atlas Spine Inc.).

Individual distraction and lordosing procedures were safely performed through the expansion of each individual implant. Eventually, a 4-level anterior cervical Ozark plate from K2M was used for fixation to maintain the optimized alignment. Based on patient's global alignment correction, good-to-excellent bone quality, and screw purchase, the decision was made to spare him from a posterior reconstruction. Total estimated blood loss was 60mL and surgical time was 1.65h. Fluoroscopic beam 'on' time was 24 seconds, which was higher than usual due to the osteotomies, cage expansion/bone distraction of the cages, and verification of the patient's alignment correction. Neuromonitoring signals improved dramatically after the first and second levels were surgically corrected and representative images for the motor evoked potential (mEP) changes are shown below in Figure 3a-b.

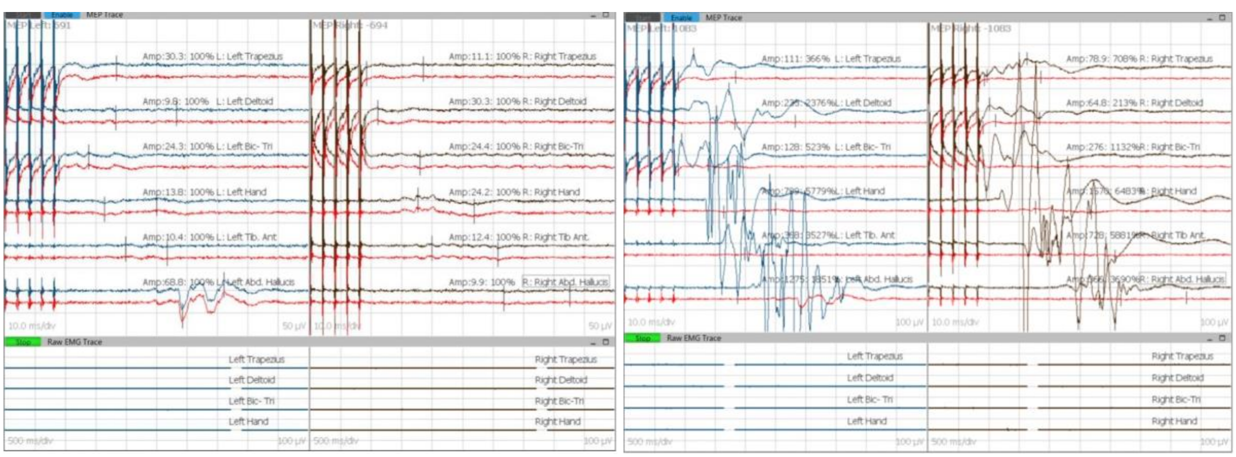

Fig. 3a – b. Intraoperative mEP improvement before (left) and after (right) C3-5 reconstruction with HiJAK^{TM} realignment and spinal cord decompression

Three cervical cages (Footprint 13x15mm, Height 7mm/0-7°, 8mm/5-12°, 8mm/5-12° at C3-4, C5-6, and C6-7) were expanded about 2.5mm anteriorly and 1.25mm posteriorly, while a hyper-lordotic version of the 8mm cage at C4-5 allowed for expansion from 12˚ to 20˚ . All except one implant at the C3-4 level were taken to the full torque limit provided in the system (9 in-lbs.). Local shavings, bones from osteotomies, and synthetic allograft (MagnetOs^{TM}, Kuros BioSciences corp.) was manually placed in all four cages prior to insertion of the implants. After implantation, a bone funnel was used to post-fill the additional graft space created during expansion of the cages. A total of approximately 0.3cc allograft material for each level was implanted pre- and post- expansion.

Results – A quantitative analysis was performed on the patient's cervical sagittal alignment. Lateral standing radiographs taken immediately before and after surgery (Figure 4a-b) showed a corrected global cervical lordosis (C2-7 Cobb's Angle) of 23.6˚

from the previous -15.8˚. Post-operative cervical Sagittal Vertical Axis (SVA) decreased from 63.4mm to 15.0mm and cranial offset decreased from 43.3mm to 6.3mm (Figure 4a-b).

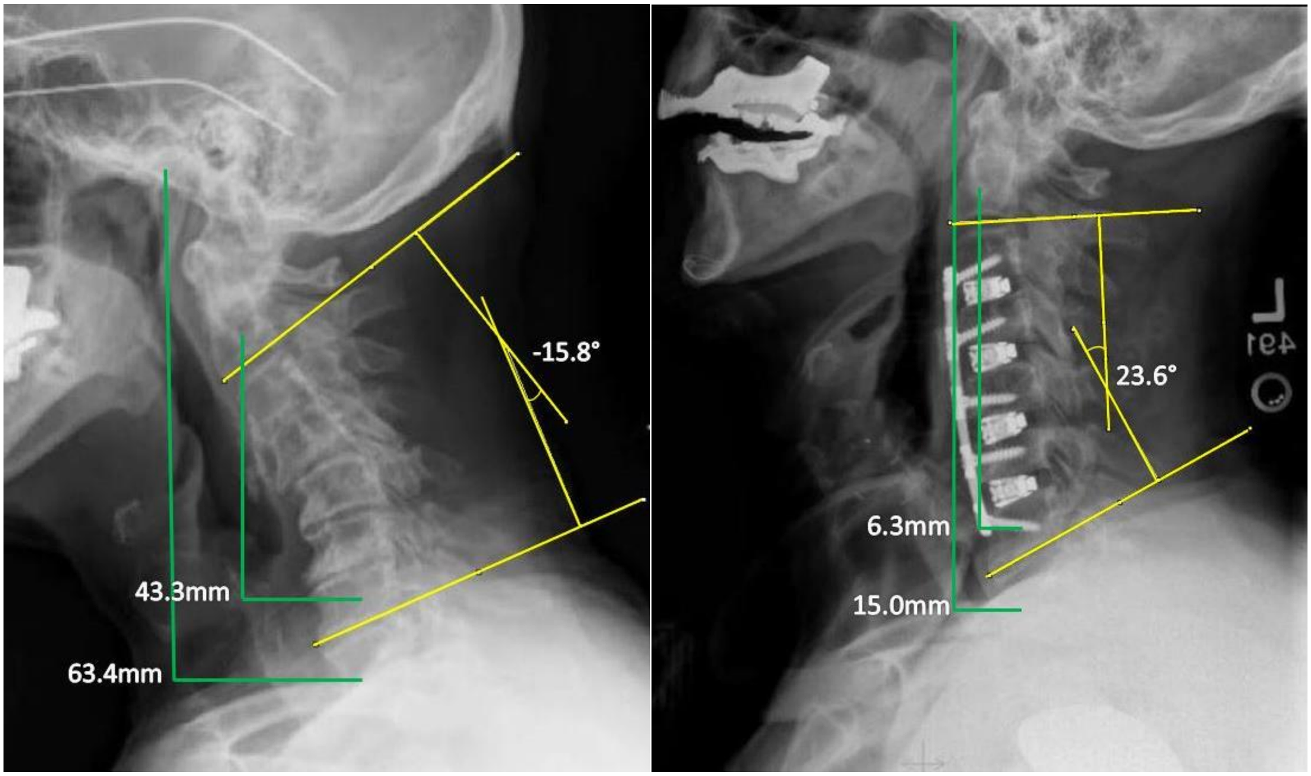

Fig. 4a-b. Pre- and post-operative standing radio- graphs showing global cervical lordotic improvement

Segmental Lordotic angle (SA) was measured (ImageJ 1x, NIH) at each operative level subsequent to implant insertion but prior to expansion (Table 1; Figure 5a). There was lordotic improvement at each level consistent with expectations based on the expansion mechanism (ranging from 5.5˚ to 8.4˚ of angle increase for the three fully expanded implants). In addition, posterior disc height was measured along the posterior border of the superior and inferior vertebral bodies (Table 2; Figure 5a). Posterior disc height increased at each level, with measurements (0.8 to 1.5mm) consistent with the nominal implant expansion capability. Radiographic measurements were not taken at C6-7 due to image quality.

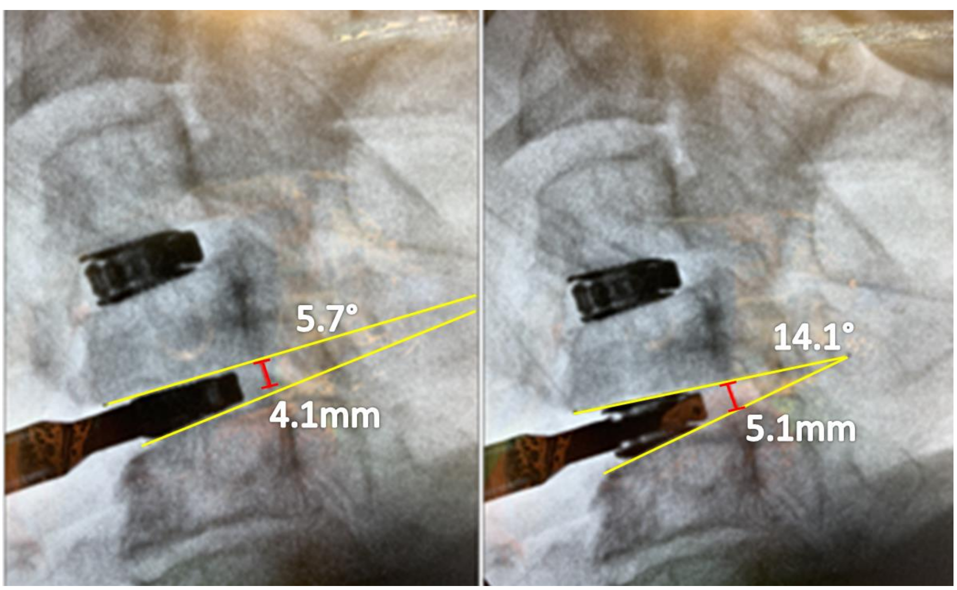

Fig. 5a. Segmental Lordotic Angle (SA) and posterior disc height measurement example shown at level C4-5

TABLE I. SEGMENTAL LORDOTIC ANGLE (SA)

Segmental Lordotic Angle (SA)	C3-4	C4-5	C5-6	C6-7
Pre-expansion (˚)	5.5	5.7	7.1	6.5
Post-expansion (˚)	8.9	14.1	12.6	12.5
Δ from expansion **(˚)**	**+3.4***	**+8.4**	**+5.5**	**+6.0**

*Implant intentionally not fully expanded based on tactile feel and adjacent level assessment

TABLE II. POSTERIOR DISC HEIGHT

Posterior Disc Height	C3-4	C4-5	C5-6	C6-7
Pre-expansion (mm)	3.5	4.1	3.1	N/A
Post-expansion (mm)	4.3	5.1	4.6	N/A
Δ (mm)	**+0.8***	**+1.0**	**+1.5**	**N/A***

*Implant intentionally not fully expanded at C3-4; radiographic measurement was not taken at C6-7 level due to image quality.

Discussion - The quantifiable results described above show a clear improvement of the overall sagittal balance of the patient. While non-expandable technology could have been used to achieve this correction, the value of an expandable cervical interbody was evident on multiple fronts discussed below.

Surgical Approach - According to a recent study [16], combined anterior and posterior (360˚) operations typically have a mean operative time of 7.41h and mean estimated blood loss of 396.0 mL, which is more than four times of the operative time (1.65h) and more than three times of the blood loss (60mL) reported in this surgery. Avoiding posterior cervical dissection is typically tied to lower perioperative wound healing and infections risks, as well as a significantly shorter postoperative hospital stay. The favorable economic impact of an anterior only approach is similarly significant.

While posterior reconstruction will certainly be required for some complex cases, the ability to shift even a few cases to an anterior only approach shows the value of an expandable cervical interbody.

Lordotic Restoration - Multi-level reconstruction as defined in this surgery would often require a 360˚ approach to achieve appropriate sagittal balance. The ability to dial in from 0-20 degrees of lordosis allowed complete sagittal correction from an anterior approach.

Posterior Neural Decompression - The severity of bilateral spinal stenosis in this patient would typically require additional neural decompression from the posterior approach, but was achieved in this clinical case with the 1-2mm posterior expansion capability of the cage.

Adjustable Height - One of the four cages was not taken to full height but instead left partially expanded. The exact expansion was a result of tactile feel and visual comparison to adjacent levels. With 1mm increments in traditional static cages this adjustment would not have been possible. This optimal height could minimize the risk of non-unions associated with under-sizing a cage while avoiding any over-distraction morbidities associated with over-sizing a cage.

Disc space distraction - This procedure was completed without Caspar pins for distraction. An intradiscal spreader was used for disc prep purposes. Pins would normally be necessary to open up the disc space for cage insertion but were not necessary for this case. It's expected that this step can save up to 10 minutes over four levels. Caspar distractor pins compromise the mechanical integrity of vertebral body, and the use of which is a possible cause of adjacent level ossification [14].

Implant positioning - The ability to slide the implant in and expand the cage allowed for optimal positioning within the disc space. On the C5/C6 level the cage was provisionally expanded, collapsed to reduce the load, and then repositioned further anteriorly to maximize lordosis prior to its final position. This type of intraoperative adjustment would have been difficult with a static cage.

Trialing - The continuous expansion capability of 2.5mm of this cervical implant eliminates the need for trialing. Over a four-level procedure, this saves approximately 5-10 additional minutes and further decreases the risk of inadvertent endplate damage as well as risk of implant subsidence.

Cage insertion - The expandable capability eliminates the need for any impaction to insert the graft into the space. For collapsed discs with severe kyphosis (especially the C3-4 and C4-5 levels where osteotomies were required), this minimizes the risk of endplate damage during graft insertion. Such endplate damage can increase the risk of subsidence which has been shown to decrease lordotic restoration during the first 1-4 week postoperative time period [10-12] [15].

Conclusion- This clinical case study demonstrated that the advantages of an expandable cervical cage could reduce a 360° surgical case to an anterior only operation. The expandable cervical cage used in this surgical reconstruction provided optimal lordosis restoration with a much greater operational expediency and less invasive procedure by eliminating the need for disc space distraction, trialing, and impaction. Its posterior expansion feature also overcame the key limitation of a static approach by providing measurable additional neural decompression. Further investigation of the intraoperative, postoperative, and financial implications of expandable cervical interbody cages is warranted.

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