A 540° posterior-anterior-posterior approach for 360° fused rigid severe cervical kyphosis: patient series

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BACKGROUND Treatment of severe rigid 360° fused cervical kyphosis (CK) is challenging and often requires a combined approach for ankylosis release, establishment of sagittal balance, and fixation with fusion.

OBSERVATIONS Four patients with iatrogenic 360° fused severe rigid CK (Cobb angle ≥40°) were enrolled for this retrospective analysis. All patients in the case series were female, with an average age of 27 years. All patients previously underwent posterior laminectomy/laminoplasty and cervical tumor resection when they were children (13–17 years). They underwent correction surgery with a 540° posterior-anterior-posterior approach. Preoperative and final follow-up radiography and computed tomography (CT) were used to evaluate kyphosis correction, internal fixation implants, and bone fusion. The preoperative and final follow-up average C2–7 Cobb angles were −32.4° ± 12.0° and 5.3° ± 7.1°, respectively. Preoperative and final follow-up CK angles averaged −47.2° ± 7.4° and −0.9° ± 16.1°, respectively. The mean correction angle was 46.3° ± 9.6°. At final follow-up, CT showed stable fixation and solid bone fusion.

LESSONS The rare iatrogenic severe kyphosis with 360° ankylosis requires a combined approach. The 540° posterior-anterior-posterior approach can completely release the bony fusion, and the CK can be corrected using an anterior plate. This technique can achieve good results and is an effective strategy.

https://thejns.org/doi/abs/10.3171/CASE21491

KEYWORDS fixed cervical kyphosis; circumferential ankylosis; posterior-anterior-posterior; 540°; procedure; cervical deformity correction; pedicle screw fixation

The etiological factors of cervical kyphosis (CK) deformity are wide ranging and include congenital, iatrogenic, neoplastic, and other factors.1,2 The most common cause is multilevel laminectomy, after which the incidence of CK is approximately 21%.3 After laminectomy, the posterior tension bands were destroyed, leading to CK.4 Laminoplasty has been suggested to help reduce the risk of CK by preserving the posterior column structures;5 however, the incidence of CK after laminoplasty remains high (up to 10%).6 The incidence, degree, and rate of progress of CK in adolescents after cervical surgery are higher than those in adults because of the incomplete ossification of the vertebral body, weakness of the neck extensors, and propensity for ligamentous stretching.7–9 Once CK has progressed to severe kyphosis (Cobb angle ≥40°), it leads to severe nerve compression; therefore, surgical correction remains the primary treatment option. The goal of surgery is to decompress the cervical cord, restore cervical and global sagittal balance, achieve spinal fusion,1,2,10 and improve the patient’s appearance and symptoms.

Currently, the classification and treatment protocols of CK remain controversial, and the surgical technique for severe fixed CK (Cobb angle ≥40°) with circumferential ankylosis (360° fusion) is yet to be established. In this retrospective study, we discuss the strategy of a 540° posterior-anterior-posterior approach for four young patients with rare cases of 360° fused severe CK.
after laminectomy/laminoplasty, and we review the 540° cervical correction surgery.

Study Description

Patient Population

From June 2018 to June 2020, four patients with 360° fused severe iatrogenic CK (after laminectomy/laminoplasty) were treated with a 540° posterior-anterior-posterior surgery at our institute. They were female and aged 16–34 years and had undergone cervical tumor resection in local hospitals when they were 13–17 years old. Cervical medullary hemangioblastoma recurrence in situ was observed in two patients.

Clinical Presentation

All four patients showed numbness and weakness in their upper limbs. Two patients developed lower limb numbness, and one patient developed neck pain. Physical examination revealed obvious pathological signs in four patients (Table 1).

Radiological Examination and Measurement

Radiological measurements included global cervical curvature, local CK angle, correction angle, chin–brow vertical angle (CBVA), T1 slope (T1S), C7 sagittal vertical axis (SVA), and C2–7 SVA. The global cervical curvature and local CK angle were measured using the Cobb method. The former ranged from the C2 to the C7 inferior endplate, and the latter from the most cranial to caudal ends of the vertebrae in kyphosis segments. A lordotic alignment was defined as a negative angle, whereas a kyphotic alignment was reported as a positive angle. The straight cervical spine was defined as −4° to +4°, kyphosis as greater than +4°, and lordosis as less than −4°.11 The correction angle was calculated as follows: postoperative local CK angle minus preoperative local CK angle. Intervertebral movement and deformity reduction were assessed using extension radiographs.

Preoperative intervertebral ankylosis (intervertebral space and facet joints), previous implants, and postoperative bone fusion status were evaluated using computed tomography (CT) and reconstructive methods. A solid fusion was determined when both criteria, including no continuous radiolucent lines/area across the fusion site and presence of bridging trabeculae across the fusion site, were met. CT angiography was used to exclude vertebral artery abnormalities. Magnetic resonance imaging (MRI) was used to assess the shape of the spinal cord and tumor residual or recurrence. Whole-spine plain radiographs were used to measure C7 SVA to assess the overall sagittal balance of the spine (Fig. 1).

Surgical Strategy

Because of the rigid kyphosis, preoperative cervical traction was not performed.2 The surgical strategy was a 540° posterior-anterior-posterior sequence. Somatosensory and motor evoked potentials were used intraoperatively for neurophysiological monitoring. The surgical strategy employed in case 2 is cited as an example (Fig. 2).

Posterior Facet Release and Pedicle Screw Implantation

With the patient in the prone position, a posterior approach was employed. Dissection exposed C2–6 from the medial stump of the lamina to the lateral margin of the facet on both sides and revealed incomplete absorption of the lamina with the fusion of C2–5 bilateral lateral masses into a column. We removed the previous implants and performed laminectomy. After removal of the ligamentum flavum, the spinal cord was decompressed. The position of the C2–6 pedicles was explored with a nerve dissector, and the fused bone between the lateral masses was removed by drilling between the adjacent pedicles. Under C-arm fluoroscopy, pedicle screws were inserted from C2 to C6. The wound was closed temporarily.

Anterior Cervical Discectomy and Fusion (ACDF), Bone Grafting, and Correction with an Anterior Plate

The patient was securely flipped to the supine position. We started with a left-sided anterior Smith-Robinson approach between C2 and C6. The surfaces of the C2–5 vertebral bodies were fused. Under C-arm fluoroscopy, the position of the intervertebral space was determined, and the bone on the disc surface was removed by drilling. Under the microscope, the intervertebral disc and cartilaginous endplate

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### TABLE 1. Clinical data obtained after admission in all patients undergoing 540° posterior-anterior-posterior approach for 360° fused rigid severe cervical kyphosis

| Case No. | Sex/Age (yrs) | Clinical Presentation | Pathology | Neoplasm Recurrence | Surgical History | Postoperative Duration (yrs) |
|----------|---------------|-----------------------|-----------|---------------------|-----------------|-----------------------------|
| 1        | F/34          | Left upper limb weakness, limitation of cervical movement, hyperreflexia, positive pathological signs | Schwannoma | No | Tumor resection by laminectomy (C1–5) | 20 |
| 2        | F/30          | Right limb pain, limitation of cervical movement, hyperreflexia, positive pathological signs | Cervical cord arteriovenous malformation | No | Tumor resection by replacement of vertebral lamina (laminoplasty) (C3–5) | 12 |
| 3        | F/16          | Right limb weakness, 4/5 muscle strength of upper limbs, gait disturbance, thenar muscle atrophy, limitation of cervical movement, hyperreflexia, positive pathological signs | Cervical cord hemangioblastoma | Yes | Tumor resection by replacement of vertebral lamina (laminoplasty) (C2–3) | 7 |
| 4        | F/28          | Left upper limb weakness, limitation of cervical movement, hyperreflexia, positive pathological signs | Cervical cord hemangioblastoma | Yes | Tumor resection twice by laminectomy (C2–5) | 11 |
were removed, and the fused posterior margin of the vertebral body to the posterior longitudinal ligament and fused uncinate joints were removed with a high-speed burr. After the posterior longitudinal ligament was resected, a suit-sized cage filled with an autogenous iliac cancellous bone was placed in the intervertebral space. Subsequently, a plate was implanted on the C2–C6 vertebral bodies. The cervical curvature was corrected to normal lordosis using the lifting force generated by gradually tightening the screws.

Posterior Rod Assembly

The patient was again placed in the prone position. Rods were shaped into a suitable curvature, which was secured into the C2–C6 screw heads on both sides. A negative pressure drainage tube was placed in the intervertebral space. Subsequently, a plate was implanted on the C2–6 vertebral bodies. The cervical curvature was corrected to normal lordosis using the lifting force generated by gradually tightening the screws.

Follow-Up

The patients were evaluated at 6 months and 1 year postoperatively. The Japanese Orthopaedic Association (JOA) scale improvement rate was calculated as (last follow-up JOA – preoperative JOA)/(17 – preoperative JOA) × 100% to assess neurological function.

Statistical Methods

Preoperative and latest follow-up JOA and radiological measurements were recorded, as well as the intraoperative fusion span in this operation and the resection span in the previous laminectomy/laminoplasty. The mean ± standard deviation for the normally distributed data and median (interquartile range) for the nonnormally distributed data were calculated.

Surgical Outcome

All patients underwent 540° correction (combined with intraspinal tumor resection in two patients) under a single episode of anesthesia in one stage. The mean operative time was 667 ± 268 min. The average amount of bleeding was 500 ± 258 ml. Patient 3 underwent subsequent intracranial tumor resection after recovery.

Clinical Outcome

Patient 2 developed postoperative dysphagia, which was relieved 3 days later. The follow-up period ranged from 12 to 24 months. All patients showed remission of symptoms at the last follow-up. The JOA improvement rate was 45.63% ± 37.00%.
Patient 1 had residual upper limb weakness. Patient 2 showed complete remission. Patient 3 had residual gait instability and limited upper limb movement at the last follow-up. Patient 4 had residual upper limb sensory and motor disorders.

Radiographic Outcome

Preoperative

The preoperative mean global cervical curvature was $-32.4^\circ \pm 12.0^\circ$. The preoperative local CK angle averaged $-47.2^\circ \pm 7.4^\circ$. Patient 1 had an obvious upward gaze. Patients 1 and 4 had C7 SVA $\geq 50$ mm. All had a normal C2–7 SVA (Table 2).

Follow-Up

The mean postoperative C2–7 Cobb angle was $-5.3^\circ \pm 7.1^\circ$. Two patients had a lordotic alignment, and the other two presented with a straight alignment. The postoperative local CK angle averaged $0.9^\circ \pm 16.1^\circ$. The mean correction angle was $-46.3^\circ \pm 9.6^\circ$.

Global spinal balance was improved in all patients with C7 SVA falling within 50 mm of the posterosuperior aspect of the sacrum (Fig. 3). However, case 3 (Supplemental Fig. 1) had anterior cervical translation (C2–7 SVA $>40$ mm) after surgery (Table 2).

Spinal fusion was achieved in all patients at the last follow-up.

Discussion

CK is divided into flexible and fixed deformities according to whether it can be reduced by extension movement or traction.\textsuperscript{2,12} Flexible CK is reducible with the help of hyperextension and traction; however, fixed CK is associated with anterior or posterior ankylosis, and no improvement is observed after extension and traction. Therefore, ankylosis should be released to restore the normal curvature.\textsuperscript{2,13}

In 2014, Hann et al.\textsuperscript{12} proposed the basic strategies for surgical correction of cervical deformity. They stated that correction of anterior fused and posterior fused rigid kyphosis should be performed by using the anterior-posterior and posterior-anterior-posterior approaches, respectively. However, guidelines for the rare 360° fused rigid kyphosis have not been established. Local release and correction by a single approach is mostly ineffective because of its extensive circumferential fusion area. Furthermore, the correction angle of a single approach is limited.\textsuperscript{1,12}

Thus, a combined approach is required for both circumferential lysis and ideal correction angle for iatrogenic, circumferentially fused, severe CK ($\geq 40^\circ$). We review the 540° correction procedure and present our strategy.

Observations

Characteristics of CK

There is no accepted range of parameters for cervical deformity; however, the available evidence suggests that T1S minus cervical lordosis (CL) $<15^\circ$, C2–7 SVA $<40$ mm, and CBVA between $-10^\circ$ and $+20^\circ$ are generally acceptable ranges.\textsuperscript{14} We summarize the characteristics of CK of the patients as follows: a 360° fused fixed CK with a severe kyphosis angle $\geq 40^\circ$; round CK with smooth curvature and retained vertebral body height, as well as the intervertebral space; severe anterior surface fusion of the vertebral bodies; deformed posterior structure; the cervical sagittal balance not translated, with C2–7 SVA $<40$ mm; most patients having the normal preoperative CBVA; most patients having the compensatory decreased T1S. This patient...
TABLE 2. Preoperative and postoperative assessment of all patients undergoing 540° posterior-anterior-posterior approach for 360° fused rigid severe cervical kyphosis

| Case No. | Fusion Level | During Operation | Preoperative/Postoperative Global Cervical Curvature (°)** | Preoperative/Postoperative Local Cervical Kyphosis Angle (°) | Preoperative/Postoperative CBVA (°)† | Preoperative/Postoperative C7 SVA (mm)‡ | Preoperative/Postoperative T1S (°) | Preoperative/Postoperative T1S Minus Cervical Lordosis (°)¶ | Preoperative/Postoperative C2–7 SVA (mm)** | Preoperative/Postoperative mJOA Score |
|----------|--------------|------------------|------------------------------------------------|-------------------------------------------------------------|----------------------------------|-----------------------------------|----------------------------------|------------------------------------------------|-----------------------------------|----------------------------------|
| 1        | C3–5         | C2–7             | 27.1°/–8.9                                      | 42.0°/–17.4                                                  | –21.6°/–4.0                      | –84.8°/–41.6                      | –1°/10.2                         | 26.1°/1.3                                                      | 6.3°/–10.8                        | 13/14                              |
| 2        | C3–5         | C2–6             | 28.6°/–12.4                                     | 50.4°/10.3‡                                                  | 2.2°/9.1                         | –25.2°/30.2                      | 6.2°/15.0                        | 34.8°/2.6                                                      | –24°/–1.5                        | 12/17                              |
| 3        | C2–5         | C2–6             | 23.8°/–3.9                                     | 40.3°/–7.4                                                  | –1.5°/2.4                        | 10.3°/8.4                        | 24.8°/2.14                      | 48.6°/17.5                                                     | 33.5°/42.3                       | 9/12                               |
| 4        | C3–6         | C2–7             | 50.1°/3.9                                      | 56.0°/17.9                                                  | –3.2°/6.6                        | –54.1°/36.6                      | 7.0°/11.4                        | 46.1°/15.3                                                     | 29.8°/18.1                       | 12/14                              |

mJOA = modified Japanese Orthopaedic Association scale.

* Lordosis is defined as negative and kyphosis as positive.
† When the head is tilted down, the CBVA is positive; when the head is tilted up, the CBVA is negative.
‡ When the T1 sagittal vertical axis is in front of the posterior-superior aspect of the sacrum, the T1 SVA is positive and vice versa.
§ When the T1 superior endplate is tilted down, the T1S is positive; when the T1 superior endplate is tilted up, the T1S is negative.
¶ When the spine was lordotic, T1S minus cervical lordosis (CL) was calculated as follows: T1S – C2–7 Cobb angle; when the spine was kyphotic, T1S minus cervical lordosis (CL) was calculated as follows: T1S + C2–7 Cobb angle.
** When C2 sagittal vertical axis is in front of C7 sagittal vertical axis, C2–7 SVA is positive and vice versa.
†† Wedged vertebra.
strategy was to release the circumferential bony fusion and subsequently to use an anterior plate to correct kyphosis. Thus, we chose the posterior-anterior-posterior sequence. The first step was to release the facet joints using the Ponte osteotomy technique during the posterior approach. The second step was to release all vertebral segments through the anterior intervertebral space. The CK was corrected using intervertebral distraction and the lifting effect of the posterior pedicle screw for posterior fixation. In order to avoid failure of the anterior plate, Stewart et al.22 reported the application of a Cobb periosteal elevator in the anterior approach. This technique was not considered feasible, because the facet joints were completely ground to achieve the release. Stewart et al.22 however, in our practice, we consider the anterior plate to be necessary because it provides not only more stability but also a strong corrective effect and higher corrective angles after intervertebral release, dilation, and cage implantation.

The second step of the operation was to release the anterior column through the intervertebral space. Most scholars have adopted anterior cervical corpectomy and fusion (ACCF) for anterior release.13,17–19,21 For patients with angular CK or complete intervertebral fusion, where intervertebral release is not possible, the ACCF technique is a reasonable choice to relieve spinal cord compression. However, in round CK cases where the intervertebral space is still retained, multilevel intervertebral release and distraction can provide better corrective results because ACFD can achieve better release of the fused uncinate joints on both sides of the intervertebral space than ACCF. Moreover, the risk of fusion cage collapse of ACFD is also significantly lower than that of ACCF.10 With five levels of ACFD, the cervical spine can be realigned with a cumulative correction of approximately 30°.14 However, the difficulty of performing ACFD in this group was indistinguishable intervertebral spaces due to the anterior complete surface fusion. Intraoperatively, C-arm fluoroscopy was performed to identify the intervertebral spaces to remove the fused bone and uncinate joints. Attention should be paid to avoid endplate injury and cage collapse caused by the deviation of the drill from the intervertebral space, as well as vertebral artery injury on both sides.

Fassett et al.4 suggested that the application of the anterior plate is optional because it increases stability. However, in our practice, we consider the anterior plate to be necessary because it provides not only more stability but also a strong corrective effect and higher corrective angles after intervertebral release, dilation, and cage implantation.

The final step was assembly of the posterior rods to strengthen stability. The biomechanical properties of pedicle screws were better than those of lateral mass screws, which fixed the three-column structure of the spine and had a pullout resistance four times higher than that of lateral mass screws.23

The combined approach has higher rates of complications and mortality.1 The patients in our series recovered well without any complications. It can be inferred that the 540° posterior-anterior-posterior sequence is an effective method for the treatment of 360° fused CK. At the latest follow-up, case 3 presented with T1S minus CL >15° accompanied by C2–7 SVA >40 mm, which was considered to be caused by the short segment and insufficient prebending of the anterior plate. We believe that the recovery of T1S minus CL <15° is the key to surgical correction for patients with normal CBVA. For patients without small T1S (case 3), the anterior corrective segment and curvature of the plate should be increased appropriately to correct the CL to a larger range in order to avoid postoperative sagittal cervical translation (C2–7 SVA >40 mm); for patients with compensatory decreased T1S (except case 3), the achievement of CL is not demanding, because preoperative sagittal cervical balance was not translated (C2–7 SVA <40 mm).

In summary, rare iatrogenic severe kyphosis with 360° ankylosis requires a combined approach. The 540° posterior-anterior-posterior approach can completely release the bony fusion, and the CK can be corrected using an anterior plate. This technique can achieve good results and is an effective strategy.

Acknowledgments
We thank Editage for English language editing.

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**Disclosures**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Author Contributions**

Conception and design: Chen, Qiang Jian. Acquisition of data: Chen, Liu, Duan, Fengzeng Jian. Analysis and interpretation of data: Chen, Liu. Drafting the article: Qiang Jian, Liu. Critically revising the article: Liu, Duan, Guan, Fengzeng Jian. Reviewed submitted version of manuscript: Duan. Statistical analysis: Qiang Jian. Administrative/technical/material support: Liu. Study supervision: Chen, Duan.

**Supplemental Information**

Online-Only Content

Supplemental material is available with the online version of the article. Supplemental Tables and Figure. https://thejns.org/doi/suppl/10.3171/CASE21491.

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