Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Asymmetric T1 Pedicle Subtraction Osteotomy for Rigid Cervicothoracic Kyphoscoliosis: Radiological Outcomes and Perioperative Safety Evaluation

Zhenhui Zhang
Medical School of Tianjin University
Qiangqiang Pan
Zhengzhou Orthopaedics Hospital
Tingkun Liu
Hami Central Hospital
Chunli Wang
Zhengzhou Orthopaedics Hospital
Zhe Shao
Zhengzhou Orthopaedics Hospital
Wentao Jiang
Zhengzhou Orthopaedics Hospital
Qingde Wang
Zhengzhou Orthopaedics Hospital
Wei Mei
Zhengzhou Orthopaedics Hospital
Xuyi Chen
chenxuyi1979@126.com

Characteristic Medical Center of Chinese People's Armed Police Force

Research Article

Keywords: Smith-Petersen osteotomy, Asymmetric T1 pedicle osteotomy, Rigid cervicothoracic kyphoscoliosis, Spinal deformity correction, Surgical efficacy

Posted Date: November 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11108314/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background Rigid cervicothoracic kyphoscoliosis is a complex spinal deformity involving both coronal and sagittal malalignment of the cervicothoracic junction. Safe and satisfactory deformity correction remains challenging owing to the complicated neurovascular anatomy in this region. The present study aims to investigate the clinical efficacy of asymmetric T1 pedicle subtraction osteotomy for rigid cervicothoracic kyphoscoliosis.

Methods Fifteen patients with rigid cervicothoracic kyphoscoliosis who underwent asymmetric T1 PSO from June 2012 to October 2022 were retrospectively enrolled, including 11 males and 4 females with a mean age of 53.1 ± 10.7 years (range, 43–69 years). Operative time, estimated blood loss, and peri-and post-operative complications were documented. Radiographic parameters including chin-brow vertical angle (CBVA), cervicothoracic kyphotic Cobb angle, cervicothoracic scoliotic Cobb angle, and C2-T1 sagittal vertical axis (SVA) were measured preoperatively, postoperatively, and at final follow-up. Deformity correction rates were calculated to evaluate surgical efficacy.

Results All patients achieved a mean follow-up of 33.2 ± 9.1 months (range, 22–50 months). Mean operative time was 292 min (range, 240–335 min), and mean blood loss was 1580 mL (range, 1250–2150 mL). According to radiographic measurements, mean CBVA improved from 98.6°±13.5° preoperatively to 26.2°±8.6°at final follow-up. Mean cervicothoracic kyphotic Cobb angle changed from 23.4°±9.8°pre-operatively to − 15.6°±9.4° at final follow-up. Mean cervicothoracic scoliotic Cobb angle decreased from 15.3°±1.3° to 2.3°±0.2°. Mean C2-T1 SVA decreased from 11.2 ± 4.5 cm to 6.4 ± 2.6 cm. Repeated-measures ANOVA revealed statistically significant differences for all parameters across time-points ($P < 0.001$). Two patients presented transient numbness and weakness of the left hand, which resolved within three months with conservative management. Two other patients had delayed wound healing that improved after symptomatic treatment. No permanent neurological deficits or implant-related failures (screw loosening, rod breakage, screw fracture) occurred. Coronal and sagittal spinal balance was preserved in all patients at the final follow-up.

Conclusion Asymmetric T1 PSO is a safe and effective surgical technique for rigid cervicothoracic kyphoscoliosis, offering satisfactory deformity correction with a low risk of complications.

Introduction

Cervicothoracic kyphoscoliosis is a spinal deformity characterized by abnormal coronal and sagittal alignment of the cervicothoracic junction, arising from diverse etiologies including trauma, degenerative changes, and ankylosing spondylitis [1]. Depending on the deformity characteristics, it can be classified into flexible and rigid types. Rigid cervicothoracic kyphoscoliosis is defined as kyphotic flexibility of less than 30% on hyperextension radiographs or the presence of local bony ankylosis on cervical computed tomography [2]. This deformity is commonly observed in patients with advanced ankylosing spondylitis, manifesting as a chin-on-chest deformity that severely restricts horizontal gaze, impairs the ability to lie flat, and compromises mastication, swallowing, and respiration. In severe cases, it may also lead to

spinal cord compression and neurological deficits. Osteotomy and corrective surgery currently represents the only effective treatment, aiming to restore horizontal gaze, relieve neural compression, reestablish local and global spinal alignment, and achieve rigid fixation and fusion to maintain satisfactory correction [3].

However, the complex neurovascular anatomy and unique biomechanical properties of the cervicothoracic junction render osteotomy in this region extremely challenging and high-risk [4]. The surgical techniques most commonly employed in clinical practice include posterior C7-T1 extension osteotomy (C7-T1 SPO), C7 pedicle subtraction osteotomy (C7 PSO), and T1 pedicle subtraction osteotomy (T1 PSO), all of which have demonstrated favorable outcomes in correcting cervicothoracic kyphosis [5]. Compared with C7-T1 SPO and C7 PSO, T1 PSO not only substantially reduces the risk of vertebral artery and nerve root injury but also enables a greater degree of sagittal correction [6]. Nevertheless, clinical studies on the use of asymmetric T1 PSO for the treatment of rigid cervicothoracic kyphoscoliosis remain scarce both domestically and internationally. In this context, we retrospectively analyzed fifteen patients with rigid cervicothoracic kyphoscoliosis who underwent asymmetric T1 PSO, all of whom achieved satisfactory clinical results.

Materials and Methods

Inclusion and exclusion criteria

Patients were included if they met the following criteria: (1) cervicothoracic kyphoscoliosis causing restricted horizontal gaze that substantially impaired quality of life, where satisfactory correction could not be achieved through thoracic or lumbar osteotomy alone; (2) treatment with asymmetric T1 pedicle subtraction osteotomy (PSO); (3) a minimum follow-up of 24 months with complete follow-up data. Patients were excluded if they had concurrent spinal disorders such as infection or tumor, or severe medical comorbidities precluding tolerance of anesthesia and surgery, including cardiopulmonary insufficiency and cerebrovascular disease.

Patient characteristics

This was a retrospective case series. Clinical data of fifteen patients with rigid cervicothoracic kyphoscoliosis admitted to our spinal surgery department between June 2012 and October 2022 who met the inclusion criteria were collected. The cohort included eleven males and four females, with a mean age of 53.1 ± 10.7 years (range, 43–69 years). Among these patients, seven had a history of ankylosing spondylitis, three presented with typical chin-on-chest deformity, and one had undergone prior left hip arthroplasty. Preoperative assessments included plain radiographs of the cervicothoracic junction and full-length spine, three-dimensional computed tomography (CT) reconstruction of the cervicothoracic junction, magnetic resonance imaging (MRI) of the cervicothoracic junction, and computed tomography angiography (CTA) of the vertebral arteries. This study was approved by the

institutional ethics committee of our hospital. Written informed consent was obtained from all patients prior to surgery.

Preoperative preparation

CT angiography is an important imaging modality for diagnosing vascular pathology and characterizing vascular anatomy. Preoperative CTA allowed assessment of the course and anatomic variations of the vertebral arteries, thereby enabling evaluation of the risk of vascular injury during screw placement and osteotomy.

Preoperative imaging planning was performed using digital orthopedic technology to simulate the osteotomy. Morphologic changes under different osteotomy parameters were compared to predict the osteotomy angle, providing a quantitative basis for intraoperative execution of the osteotomy.

Surgical technique

General anesthesia was induced with fiberoptic bronchoscope-assisted nasotracheal intubation while the patient remained awake, and neurophysiologic monitoring was maintained throughout the procedure. The patient was positioned on a Jackson full-carbon fiber table and turned from the supine to the prone position. The Mayfield head holder was adjusted, and the table was placed in a reverse Trendelenburg position. A posterior midline incision was made to expose the cervicothoracic junction. After confirmation of the correct level by C-arm fluoroscopy, lateral mass screws were inserted at C4 to C6, and pedicle screws were placed at C7 and T2 to T4. The spinous processes and laminae from C7 to T2 were removed to expose the T1 pedicles and the C8 and T1 nerve roots. A temporary rod was placed on one side for stabilization. Osteotomy of the T1 pedicle and vertebral body was performed on one side using an ultrasonic bone scalpel and curettes of various angles, with preservation of the medial cortical wall of the T1 pedicle. After completion of the osteotomy, the remaining medial wall of the T1 pedicle was removed with a rongeur. The same procedure was then performed on the contralateral side, with asymmetric resection of the vertebral body according to the preoperative plan. The posterior wall of the T1 vertebral body was finally resected using a Kerrison rongeur. After confirming that the C8 and T1 nerve roots were free of bony compression, the Mayfield head holder was gradually adjusted to extend and translate the head and neck posteriorly, allowing gradual closure of the T1 osteotomy site (Fig. 1). When satisfactory correction of the cervicothoracic deformity was achieved, pre-bent rods were sequentially placed and compressed on both sides to further close the osteotomy and complete the correction. Fluoroscopy confirmed satisfactory correction and appropriate implant position, and exploration confirmed that the spinal cord and bilateral C8 and T1 nerve roots were free of compression. After ensuring hemostasis, the wound was irrigated, a drain was placed, and the incision was closed in layers.

Postoperative management

Prophylactic antibiotics, anti-inflammatory medication, and analgesic therapy were administered routinely. Early in-bed mobilization was encouraged, particularly lower extremity flexion and extension exercises, to prevent deep vein thrombosis. Depending on the patient's overall condition, ambulation with a cervicothoracic orthosis was initiated at 1 week postoperatively.

Clinical assessment

Operative time, intraoperative blood loss, and complications were recorded. The chin-brow vertical angle (CBVA), cervicothoracic kyphotic Cobb angle, cervicothoracic scoliotic Cobb angle, and C2-T1 sagittal vertical axis (SVA) were measured preoperatively, postoperatively, and at the final follow-up. The deformity correction rate was calculated, and clinical outcomes were evaluated. Anteroposterior and lateral radiographs of the cervical spine, whole-spine anteroposterior and lateral radiographs, and CT with reconstruction of the cervicothoracic junction were obtained at 3 months, 6 months, 1 year, and at the final follow-up to assess bony fusion and maintenance of correction.

Statistical analysis

Statistical analysis was performed by SPSS 25.0 software. Continuous data were expressed as mean ± standard deviation. Repeated-measures analysis of variance (ANOVA) was adopted to compare differences in radiographic parameters among preoperative, postoperative and final follow-up time-points. The significance level was set at $\alpha = 0.05$. Descriptive statistics were used to summarize operative data, follow-up information and perioperative complications.

Results

All 15 patients completed follow-up ranging from 22 to 50 months, with a mean follow-up duration of 33.2 ± 9.1 months. All surgeries were successfully completed without intra-operative neurophysiologic monitoring alerts. The mean operative time was 292 min (range, 240–335 min), and the mean estimated intra-operative blood loss was 1580 mL (range, 1250–2150 mL).

Radiographic outcomes are summarized in Table 1. The mean preoperative CBVA was 98.6°±13.5°, which decreased to 25.4°±8.3° postoperatively and remained 26.2°±8.6° at final follow-up. The mean cervicothoracic kyphotic Cobb angle was 23.4°±9.8° preoperatively, changed to − 14.2°±9.3° postoperatively, and was − 15.6°±9.4° at final follow-up. The mean cervicothoracic scoliotic Cobb angle decreased from preoperative 15.3° ± 1.3° to postoperative 2.6°±0.3°, and was 2.3°±0.2° at final follow-up. The C2-T1 SVA reduced from 11.2 ± 4.5 cm preoperatively to 6.8 ± 2.3 cm postoperatively and 6.4 ± 2.6 cm at final follow-up. Repeated-measures ANOVA demonstrated significant improvements in all radiographic parameters across preoperative, postoperative and final follow-up assessments ($P < 0.001$). Both coronal and sagittal spinal balance were well-maintained in all patients at the last follow-up. Representative radiographs and clinical photographs of one typical case are shown in Fig. 2.

Two patients developed transient numbness and weakness involving the left hand after surgery, and symptoms fully resolved within three-month conservative treatment. Two patients experienced delayed wound healing, which recovered after local wound care and symptomatic therapy. No additional permanent neurological complications or implant-related adverse events including screw loosening, rod breakage or screw breakage were observed during follow-up.

Table 1
Radiographic parameters before surgery, after surgery and at final follow-up among 15 patients receiving asymmetric T1 pedicle subtraction osteotomy (mean ± SD)

Time point	Kyphotic Cobb angle (°)	C2-T1 SVA (cm)	Chin-brow vertical angle (°)	Scoliotic Cobb angle (°)
Preoperative	23.4 ± 9.8	11.2 ± 4.5	98.6 ± 13.5	15.3 ± 1.3
Postoperative	−14.2 ± 9.3	6.8 ± 2.3	25.4 ± 8.3	2.6 ± 0.3
Final follow-up	−15.6 ± 9.4	6.4 ± 2.6	26.2 ± 8.6	2.3 ± 0.2
F-value	81.30	9.88	244.56	1361.46
P-value	< 0.001	< 0.001	< 0.001	< 0.001

Discussion

According to the literature, C7/T1 extension osteotomy and C7 pedicle subtraction osteotomy (PSO) are the two most commonly applied procedures [7]. In 1958, Urist et al. [8] first reported the use of C7/T1 extension osteotomy for the treatment of kyphotic deformity secondary to ankylosing spondylitis, achieving correction by disrupting the C7/T1 disc space and the anterior longitudinal ligament. However, this technique lacks anatomical constraints, which may lead to overcorrection and consequently result in serious complications such as dislocation at the osteotomy site and injury to anterior vital vascular structures.In 2007, Tokala et al. [9] performed C7 PSO in eight patients with cervicothoracic kyphosis, reporting a mean correction of 52.5° in the cervicothoracic kyphotic angle and 41.9° in the cervical-thoracic kyphosis. Despite the favorable surgical outcomes, three patients developed mild postoperative sensory disturbances. The authors suggested that C8 nerve root injury is the most common neurological complication associated with C7 PSO, potentially leading to weakness of the triceps, wrist extensors, and intrinsic hand muscles. It has been reported [10] applied C7/T1 extension osteotomy and C7 PSO in eight patients with cervicothoracic deformity secondary to ankylosing spondylitis, achieving satisfactory correction with a low risk of complications. Tobin et al. [6] reported four cases of rigid cervical kyphosis treated with T1 PSO and proposed that, compared with C7 PSO, T1 PSO offers several advantages, including greater postoperative spinal stability, a larger permissible correction angle, and a lower risk of nerve root and vertebral artery injury, making it a powerful surgical correction technique.

In 1972, Simmons et al. [11] reported eight cases of cervical kyphosis treated with T1 PSO, five of whom underwent osteotomy at T1. All patients achieved horizontal gaze postoperatively, with a mean

correction of 36°. Two patients developed radiating pain, numbness, and weakness in the right upper extremity, which resolved within a short period after surgery. Tobin et al. reported that 25% of patients experienced occasional hand paresthesia following T1 PSO; however, they considered the long-term consequences of T1 nerve root injury to be relatively milder than those of C8 nerve root injury [6]. In the present study, the magnitudes of correction from preoperative status to the final follow-up were 72.4° for CBVA, 39.0° for cervicothoracic kyphotic Cobb angle, 13.0° for cervicothoracic scoliotic Cobb angle, and 4.8 cm for C2-T1 SVA, respectively, which is generally consistent with previous reports[12]. Two patients in our series developed postoperative numbness and weakness of the left hand, which resolved after conservative treatment. This complication was likely attributable to traction irritation of the T1 nerve root during correction, underscoring the importance of closely monitoring neural structures throughout the corrective maneuver to minimize the risk of neurological complications.

Asymmetric T1 PSO offers several technical advantages in the management of rigid cervicothoracic kyphoscoliosis. First, the large pedicle of T1 permits a substantial degree of deformity correction, and the relatively wide spinal canal at this level facilitates posterior osteotomy. Second, osteotomy at T1 does not require dissection of the vertebral artery, thereby reducing the potential interference with cerebral blood flow during closure of the osteotomy. Third, in the event of nerve root injury, the long-term consequences of T1 nerve root damage are less severe than those of C8 nerve root injury associated with C7 osteotomy, with a smaller impact on patients' quality of life. Fourth, this technique achieves a pedicle screw-to-pedicle screw fixation construct, which facilitates osteotomy closure and enhances the stability of the cervicothoracic spine. Nevertheless, T1 PSO is not without limitations. The procedure requires resection of the first rib, which may predispose patients to complications such as pleural rupture [13].

Given the complex anatomy of the cervicothoracic junction, patients may face complications including vertebral displacement at the osteotomy site, vascular injury, and damage to the spinal cord or nerve roots, all of which can seriously threaten patient safety and quality of life [14]. In our experience, the following key steps warrant special emphasis. First, anesthesia induction and patient positioning: patients with cervicothoracic kyphosis often present difficulties in tracheal intubation and positioning. We employed awake fiberoptic bronchoscope-assisted anesthesia and utilized a Jackson all-carbon radiolucent turning table to facilitate the prone positioning from the supine position. The head frame was carefully adjusted to prevent postoperative facial and orbital edema as well as optic neuropathy [15]. Second, adequate laminectomy: sufficient bony decompression is a prerequisite for deformity correction, as it prevents neural kinking and compression during the corrective maneuver [16]. We resected the laminae from C7 to T2 to create adequate space for correction. Third, asymmetric osteotomy: for patients with concomitant scoliotic deformity, asymmetric osteotomy is a critical technical element. Preoperative imaging analysis is essential for planning osteotomy parameters and predicting postoperative correction, and intraoperative execution should strictly follow these plans to restore coronal balance [17]. Fourth, closure of the osteotomy: careful handling of osteotomy closure is required to ensure sufficient approximation for maintaining correction while avoiding overclosure, which may cause spinal cord compression due to epidural hemorrhage or cord swelling [18]. Fifth, correction

maneuver: vertebral displacement at the osteotomy site is a serious complication during correction. To minimize this risk, we employed a sliding rod technique, in which the cervical screws are locked first while the rod is allowed to slide freely on the thoracic side, and the Mayfield head holder is locked once an acceptable correction angle is achieved [19, 20]. We also emphasize avoiding overcorrection, maintaining an ideal CBVA between 0° and 10° to maximize functional improvement [21]. Sixth, rod placement: the connecting rod should be precisely contoured preoperatively and seated without tension to prevent screw pullout [22, 23]. Satellite rods may be used when necessary to enhance the strength of internal fixation.

Limitations

However, as a retrospective study, this work has limitations including a moderate sample size and the absence of a control group. Therefore, large-sample prospective studies with follow-up surveys on overall patient surgical satisfaction are required in the future to further verify its safety and efficacy.

Conclusions

This study adopted asymmetric T1 pedicle subtraction osteotomy for the correction of rigid cervicothoracic kyphoscoliosis. Satisfactory deformity correction and reliable clinical efficacy were achieved with a low risk of complications, suggesting that this is a safe and effective surgical corrective technique.

Declarations

Ethics approval and consent to participate

Ethics approval and consent to participate The Institutional Review Board of Zhengzhou Orthopaedic Hospital approved the study (approval number: 2014KY12056). All patients gave written informed consent regarding study participation .Patient data were kept private for every phase of this study, and occurred out according to with the Helsinki Declaration .

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

Funding

This work was not supported by any funding.

Author Contribution

All authors contributed to the study conception and design. All operations were performed by Qingde Wang and Wei Mei . Material preparation, data collection and analysis were performed by Zhenhui Zhang, Qiangqiang Pan, Tingkun Liu Chunli Wang, Zhe Shao, Wentao Jiang, and Xuyi Chen. The first draft of the manuscript was written by Zhenhui Zhang and Qiangqiang Pan, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Kaidi AC. Kim HJ.Classification(s) of cervical deformity[J].Neurospine,2022,19(4): 862–7.10.14245/ns.2245864.392
2. Koller H, Ames C, Mehdian H et al. Characteristics of deformity surgery in patients with severe and rigid cervical kyphosis (CK): results of the CSRS-Europe multi-centre study project[J]. Eur Spine J 2019,28(2):324–44.10.1007/s00586-018-5835-2
3. Liu H, Yang C, Zheng Z, et al. Comparison of Smith-Petersen osteotomy and pedicle subtraction osteotomy for the correction of thoracolumbar kyphotic deformity in ankylosing spondylitis: a systematic review and meta-analysis. Spine (Phila Pa 1976). 2015;40(8):570–9.
4. Williamson TK, Lebovic J, Schoenfeld AJ et al. A Hierarchical approach to realignment strategies in adult cervical deformity surgery[J].Clin Spine Surg,2023,36(3): 106–11.10.1097/BSD.0000000000001442
5. Qian BP, Huang JC, Qiu Y, et al. Complications of spinal osteotomy for thoracolumbar kyphosis secondary to ankylosing spondylitis in 342 patients: incidence and risk factors. J Neurosurg Spine. 2018;30(1):91–8.
6. Tobin MK, Birk DM, Rangwala SD et al. T-1 pedicle subtraction osteotomy for the treatment of rigid cervical kyphotic deformity: report of 4 cases[J]. J Neurosurg Spine 2017,27(5):487–93.10.3171/2016.8.SPINE121065
7. Safaee MM. Tan LA,Ames CP.Posterior osteotomy techniques for rigid cervical deformity correction[J].J Spine Surg,2020,6(1): 274–9.10.21037/jss.2020.01.07
8. URIST MR. Osteotomy of the cervical spine; report of a case of ankylosing rheumatoid spondylitis[J].J Bone Joint Surg Am,1958,40-A(4): 833–43.
9. Tokala DP. Lam KS,Freeman BJ,C7 decancellisation closing wedge osteotomy for the correction of fixed cervico-thoracic kyphosis[J]. Eur Spine J 2007,16(9): 1471–8.10.1007/s00586-006-0290-x

10. Luan H, Peng C, Liu K, Song X. Comparison of pedicle subtraction osteotomy and vertebral column decancellation for the correction of thoracolumbar kyphotic deformity in ankylosing spondylitis: a systematic review and meta-analysis. J Neurosurg Spine. 2023;39(3):370–9.
11. Caruso L, Barone G, Farneti A et al. Pedicle subtraction osteotomy for the treatment of chin-on-chest deformity in a post-radiotherapy dropped head syndrome: a case report and review of literature[J]. Eur Spine J 2014 23 Suppl 6:634–43.10.1007/s00586-014-3544-z
12. Kim KT, Park DH, Lee SH, Lee JH. Results of Corrective Osteotomy and Treatment Strategy for Ankylosing Spondylitis with Kyphotic Deformity.
13. Jiang D, Zhao D, Zhong R, Zhang Z, Hu Z. Radiologic and clinical outcomes of combining pedicle subtraction osteotomy and Smith-Peterson osteotomy in correcting severe ankylosing spondylitis kyphosis.
14. Zhou L, Yang H, Wang J, Zhang Y, Wang Y, Hai Y. Comparison of posterior trans-intervertebral osteotomy and pedicle Subtraction osteotomy for the correction of thoracolumbar kyphotic deformity secondary to ankylosing spondylitis. J Orthop Surg Res. 2025;20(1):679. Published 2025 Jul 19.
15. Deviren V, Scheer JK, Ames CP. Technique of cervicothoracic junction pedicle subtraction osteotomy for cervical sagittal imbalance: report of 11 cases. J Neurosurg Spine. 2011;15(2):174–81.
16. Sivaganesan A. Kim HJ.A review of indications,surgical technique,and outcomes for the cervical pedicle subtraction osteotomy[J].J Am Acad Orthop Surg,2022,30(3): e295–300.10.5435/JAAOS-D-21-00177
17. Khoueir P. Hoh DJ,Wang MY.Use of hinged rods for controlled osteoclastic correction of a fixed cervical kyphotic deformity in ankylosing spondylitis[J]. J Neurosurg Spine 2008,8(6): 579–83.10.3171/SPI/2008/8/6/579
18. Mehdian S. Arun R.A safe controlled instrumented reduction technique for cervical osteotomy in ankylosing spondylitis[J].Spine (Phila Pa 1976),2011,36(9): 715–20.10.1097/BRS.0b013e3181fc1a5e
19. Simmons ED, DiStefano RJ,Zheng Y et al. Thirty-six years experience of cervical extension osteotomy in ankylosing spondylitis: techniques and outcomes[J].Spine (Phila Pa 1976),2006,31(26):3006–12.10.1097/01.brs.0000250663.12224.d9
20. Passias PG, Williamson TK. Commentary: incidence and risk factors of mechanical complications after posterior-based osteotomies for correction of moderate to severe adult cervical deformity:1-year and 2-year follow-up[J].Neurosurgery,2022,90(4):e88–9.10.1227/NEU.0000000000001829
21. Mummaneni PV, Mummaneni VP,Haid RWJ et al. Cervical osteotomy for the correction of chin-on-chest deformity in ankylosing spondylitis.Technical note[J].Neurosurg Focus,2003,14(1): e9.10.3171/foc.2003.14.1.10
22. Samudrala S, Vaynman S, Thiayananthan T et al. Cervicothoracic junction kyphosis: surgical reconstruction with pedicle subtraction osteotomy and Smith-Petersen osteotomy.Presented at the

2009 Joint Spine Section Meeting.Clinical article[J].J Neurosurg Spine,2010,13(6):695–706.10.3171/2010.5.SPINE08608

23. Deviren V. Scheer JK,Ames CP.Technique of cervicothoracic junction pedicle subtraction osteotomy for cervical sagittal imbalance: report of 11 cases[J]. J Neurosurg Spine 2011,15(2):174–81.10.3171/2011.3.SPINE10536

Figures

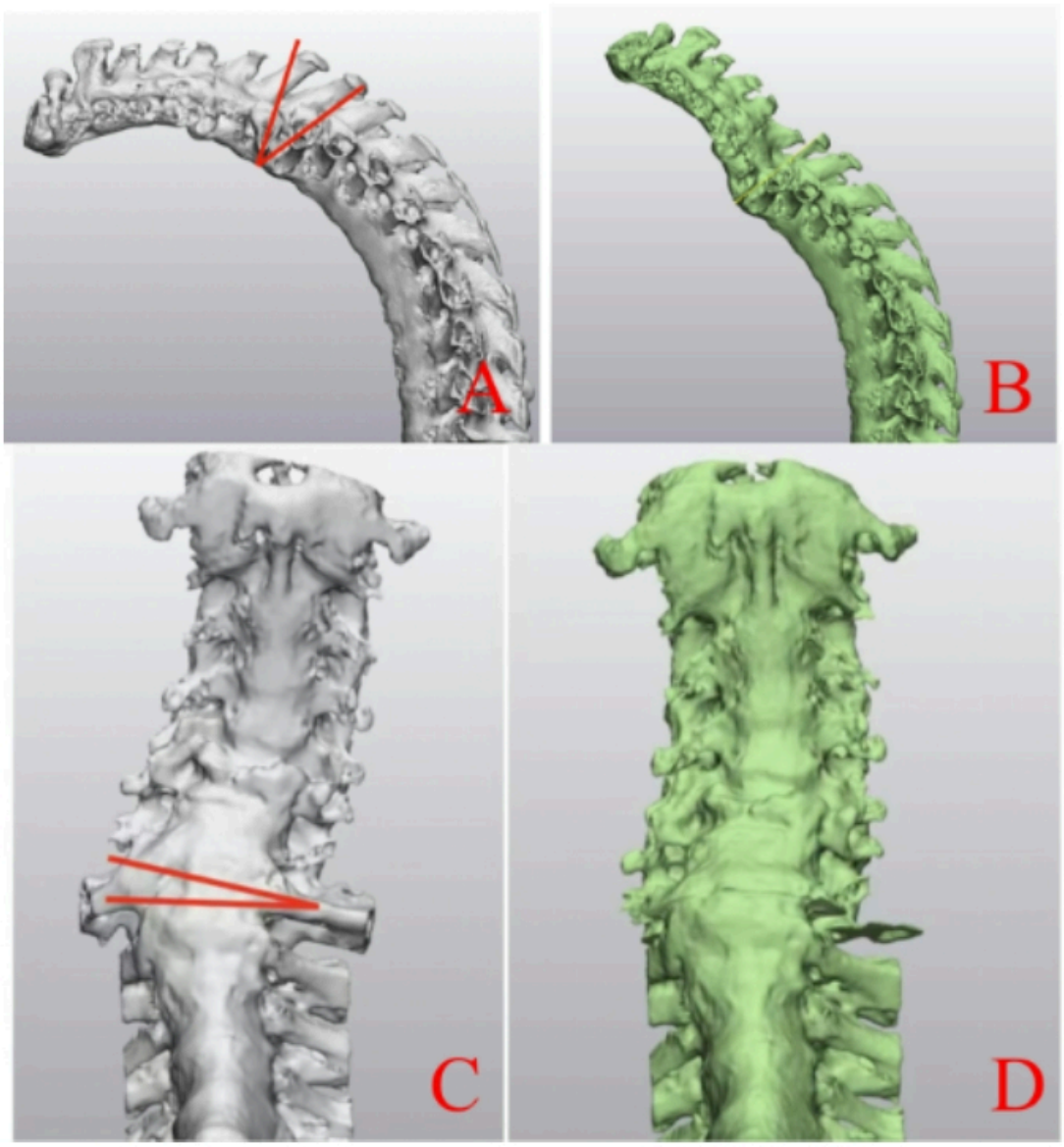


Figure 1

illustrates the surgical procedure of asymmetric T1 pedicle subtraction osteotomy (PSO) for the treatment of rigid cervicothoracic kyphoscoliosis: (A) Resection of the C7 and T1 laminae and wedge-shaped osteotomy via the T1 pedicle; (B) Gradual backward extension of the head-neck segment by adjusting the head frame to progressively close the posterior osteotomy site of T1 and correct sagittal deformity; (C) Asymmetric osteotomy through the T1 pedicle; (D) Backward extension combined with translation of the head-neck segment via head-frame adjustment to correct coronal deformity.

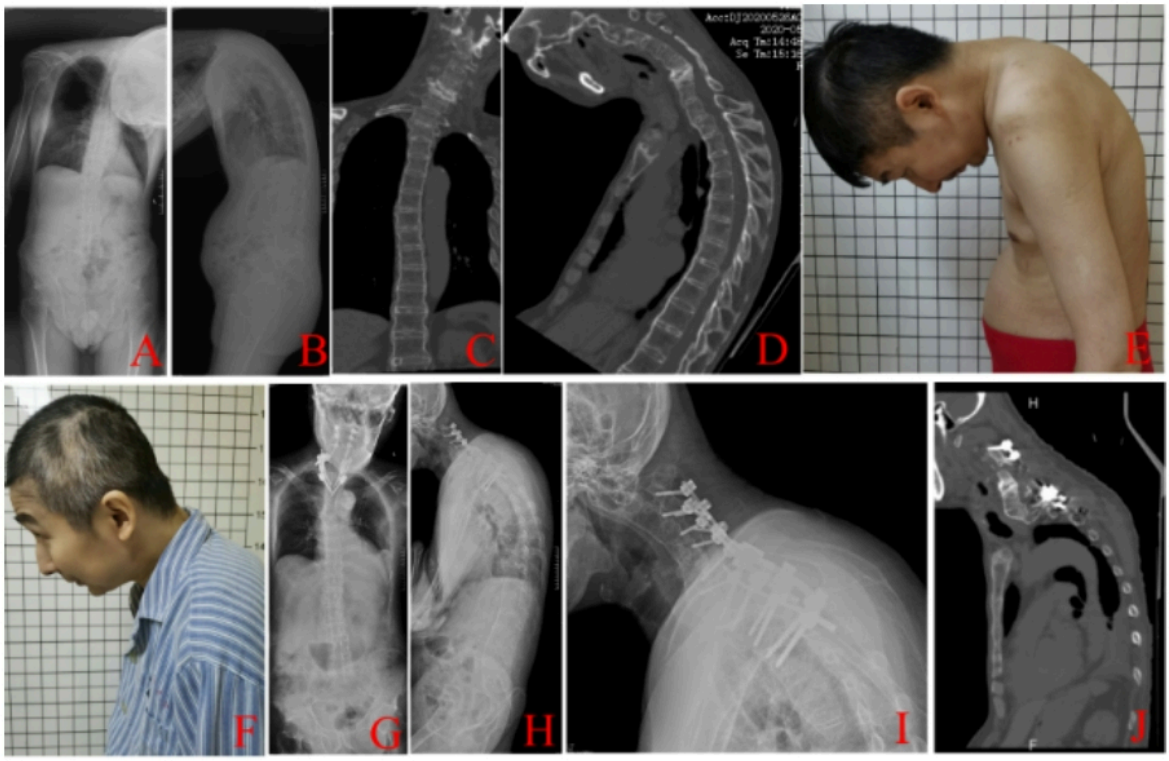


Figure 2

Presents pre- and postoperative imaging of a patient with rigid cervicothoracic kyphoscoliosis treated with asymmetric T1 pedicle subtraction osteotomy: (A,B) Preoperative full-spine anteroposterior and lateral radiographs, respectively; (C,D) Preoperative coronal and sagittal CT reconstructions of the cervicothoracic segment, showing old fractures of C5-C6 vertebrae, obvious ankylosing ossification and local rigidity of the cervicothoracic spine; (E) Preoperative clinical photograph demonstrating “chin-on-chest”deformity at the cervicothoracic junction; (F) Postoperative lateral clinical photograph with satisfactory correction; (G,H) Full-spine anteroposterior and lateral radiographs obtained at 1-week

post-operation, showing restored cervicothoracic alignment; (I) Postoperative lateral radiograph of the cervicothoracic segment with nearly normalized cervicothoracic alignment; (J) Sagittal CT reconstruction of the cervicothoracic segment at 2-year follow-up, revealing solid bony union at the T1 osteotomy site and well-maintained correction.