T-1 pedicle subtraction osteotomy for the treatment of rigid cervical kyphotic deformity: report of 4 cases

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Cervical kyphotic deformity represents a difficult to treat pathology often arising from multiple factors including, but not limited to, traumatic injuries, degenerative changes, and ankylosing spondylitis. Furthermore, treatment of these deformities becomes increasingly difficult with any preexisting instrumentation. Currently, several options exist to treat these severe deformities, with the Smith-Petersen osteotomy and C-7 pedicle subtraction osteotomy being the most frequently used approaches. However, these techniques come with significant risk to the patient including nerve root injury as well as compression of the vertebral arteries. The authors here report on a series of 4 patients with rigid cervical deformity who underwent T-1 pedicle subtraction osteotomy. The authors review the relevant literature and provide a novel, less risky, and potentially more corrective approach for treating cervical deformities.

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KEY WORDS pedicle subtraction osteotomy; cervical kyphotic deformity; spinal surgery; thoracic

RIGID cervical kyphotic deformity represents a very difficult to treat pathology. Its etiology is multifactorial and includes traumatic injuries, degenerative changes, ankylosing spondylitis, and, quite often, iatrogenic factors including postlaminectomy syndrome. The picture becomes more complicated with the presence of either anterior or posterior instrumentation.

Traditionally, rigid cervical kyphotic deformity, or “chin-on-chest deformity,” has been measured by the chin-brow vertical angle (CBVA).^{6,14,15,25,31} This angle is a measurement of horizontal gaze and can be used as an indicator of the effect of one’s deformity on activities of daily life, with 10° described as an optimal CBVA.³⁰ However, the CBVA is an older measurement tool, and it is not always possible to obtain such a measurement. To determine the CBVA, a physician needs a clinical photograph of the patient while standing, which is not always feasible or available. Furthermore, the CBVA is not always visible on standard cervical radiography. Consequently, other tools and measurements can be used to assess the extent of cervical deformity and sagittal imbalance.^{18,30}

Sagittal imbalance of the spine has been linked to

increasing disability proportional to the level of imbalance³² and often results in painful spine malalignment to maintain upright posture.^{2,9,32} Although many parameters exist to measure sagittal alignment, the sagittal vertical axis (SVA) measurement is frequently used. Most studies, though, have focused on the thoracolumbar or spinopelvic regions, with infrequent studies reporting on sagittal alignment of the cervical spine.^{10–13} Those that do exist have described several techniques to measure cervical sagittal balance, one of which is the C2–7 SVA measured as the deviation of a C-2 plumb line from the centroid of C-2 to the posterior superior endplate of C-7.³² The goal of these measurements is to provide a radiological marker for a patient’s cervical sagittal balance. The normal value for the C2–7 SVA measurement is 16.8 ± 11.2 mm;¹³ therefore, an ideal C2–7 SVA would fall somewhere around this number. Additional measurements that indicate the degree of deformity include the cervical Cobb angle and the C-2 slope, defined as the angle between the horizontal line and the inferior endplate of C-2.³⁰ For a comfortable horizontal gaze, a C-2 slope of 15° would result in a close to normal measurement.³⁰ While the decision to operate should be

ABBREVIATIONS CBVA = chin-brow vertical angle; MEP = motor evoked potential; PSO = pedicle subtraction osteotomy; SVA = sagittal vertical axis; VA = vertebral artery.

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based largely on the clinical picture and the extent of a patient's disability, these radiological markers can serve not only as a postoperative prognostic indicator for patients presenting with severe cervical kyphotic deformity, but also as good preoperative indicators of a patient's deformity.

Currently, several surgical options are available for the treatment of chin-on-chest deformity as well as other advanced rigid cervical deformities. Most of the time, surgery involves various combinations of anterior and posterior release osteotomies, followed by sagittal correction, instrumentation, and arthrodesis. Traditional osteotomies through the disc spaces and the facet joints have significant limitations in the cervical spine. A Smith-Petersen osteotomy could be performed; however, this procedure allows for only limited sagittal correction,³⁶ diminishes the quantity of bone mass available for screw fixation, carries the risk of nerve root injury, decreases the bone surface available for arthrodesis, and has a chance of kinking the vertebral artery (VA).²⁹

Advanced osteotomies such as pedicle subtraction osteotomy (PSO) at C-7 have been performed for cervical sagittal imbalance,³³ and successful corrections have been reported. This osteotomy allows 25°–35° of correction^{3,17} and can be performed even in situations in which instrumentation and rigid bone masses could be left intact above the osteotomy level. Limitations of the C-7 PSO include the potential for nerve root injury and compression in the C6–T1 “superforamen” with resultant triceps muscle and hand weakness, as well as injuries to the VAs, which could be present in the foramen transversarium of C-7 anywhere from 1.2% to 18.4% of the time.^{1,4,26,28}

There are numerous benefits to performing PSO at T-1, which we outline here. First, the T-1 PSO allows for a support construct from pedicle screw to pedicle screw, which allows for both easier closure and maintenance of the osteotomy closure. Furthermore, should nerve root injury occur, long-term consequences are less severe with injury to the T-1 nerve root compared with the C-8 nerve root, which can be damaged during a C-7 PSO. Additionally, because the T-1 vertebral body is substantially larger than the C-7 body, a larger degree of correction can be attained because of the larger pedicle size of the T-1 body. Lastly, dissection of the VA is unnecessary to perform a PSO at T-1. The current literature^{22,23} suggests bilateral removal of both the anterior and posterior aspects of the C-6 transverse foramina to mobilize the VA to prevent damage to or kinking of the artery during osteotomy closure. While removing the transverse foramina does allow the surgeon to freely operate around the VA, it introduces an operation-derived source of potential spine weakness that can be avoided entirely by performing PSO at T-1 rather than at C-7. By operating at T-1, the surgeon eliminates the need to operate around the VA, thereby eliminating the potential for injury to the VA during osteotomy closure.

Despite the frequency with which cervical PSO (most often at C-7) is performed, it is not without significant morbidity. Previously reported morbidities resulting from cervical PSO include quadriparesis, nerve root compression, radiculopathy, and vertebral subluxation.²¹ Furthermore, these complications are reported in a substantial

proportion of patients, in numbers anywhere from 23% to 26%.^{8,16,21,33} Some of these complications resolved with time; however, the majority of patients had postoperative complications that did not resolve. While any surgery carries the risk of complication, the numbers noted above warrant a second look at the surgical management of cervical kyphotic deformity. The patients described in the present report experienced no, or minimal (Case 2), postoperative complications, but it is important to note that complications such as dysphagia, dysphonia, and paresthesia are possible after surgery. However, these complications are not unique to the surgical technique that we propose and can occur with any major surgical realignment. Thus, regardless of the technique used, care must be taken to ensure that patients do not experience any lasting complications as a result of surgery. We here propose PSO at T-1 rather than at C-7 to decrease the prevalence of such complications and to minimize the severity if such complications do occur. This T-1 PSO technique should provide a safer alternative to cervical PSO and should help to prevent long-term complications.

Surgical Technique

Intraoperative motor evoked potentials (MEPs) were monitored throughout the procedure. Briefly, MEPs were determined using transcranial electrical stimulation with evoked potentials measured downstream at 4 bilateral muscle groups.

An overview of the procedure is demonstrated and narrated in Video 1.

VIDEO 1. Surgical technique demonstration and narration.

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Wide exposure of the cervicothoracic junction is performed, allowing visualization of the most proximal 6–9 cm of the T-1 rib. Laminectomy of C7–T2 is performed, and the bone is removed to be flush with the medial and inferior pedicles of C-7, the superior, medial, and inferior aspects of the pedicle of T-1, and the superior and medial aspects of the T-2 pedicle. The extent of the laminectomy should allow for the performance of the corrective maneuvers without kinking of the cord under the remaining edges of the laminae. For the same reason, we also recommend debulking any scar tissue in case of revision surgery.

Costotransversectomy is performed at T-1 with the removal of approximately 5 cm of the T-1 rib head, and the plane between the mediastinal tissues and the anterolateral surface of T-1 vertebral bodies is developed with Cobb elevators.

The vertebral bodies and pedicles of T-1 are decancelled (unilateral subtraction, Fig. 1; bilateral subtraction, Fig. 2) with a high-speed drill or a curette. Osteotomies are used to perform the osteotomy cuts while the medial cortical wall of the T-1 pedicles is maintained. Once the osteotomy cuts are completed, the remaining medial walls of the T-1 pedicles are removed using a small bone rongeur. We prefer to remove the posterior wall of the T-1 vertebral body with Kerrison rongeurs, but posterior wall impactors could also accomplish this task. It is important to maintain a unilateral temporary rod on alternating sides while the

FIG. 1. Unilateral pedicle subtraction and vertebral body decancellation.

osteotomy is performed to prevent accidental spine translation.

We use a 4-rod technique for the correction maneuvers (Fig. 3). Cervical and thoracic portions of the rods are connected via a lateral cross connector during closure of the osteotomy (Fig. 4) and could be exchanged later for a single rod, depending on screw alignment.

To ensure proper arthrodesis, posterior osteotomies are filled with either MagniFuse/bone morphogenetic protein (Case 1) or autologous local bone graft (Cases 2–4). The patient in Case 1 had to have a second surgery to close a remaining anterior defect in which autologous iliac crest-derived bone graft was used. Further clarification of our arthrodesis technique emphasizes direct placement of bone on dura mater at the osteotomy defect site. While not commonly performed, placement of bone directly on dura is not a novel concept but should be done with care. It has been reported by Chen et al.⁵ in thoracolumbar wedge osteotomy cases in which removed spinous processes have been replaced over the laminectomy sites at the end of the procedure, as well as by Lenke et al.¹⁹ in vertebral column resection cases in which rib segments have been placed over the laminectomy defect first to create a “rib bridge” to protect the dura. Additionally, we have had similar success in lumbar PSO cases with no long-term complications.

Case Reports

We conducted a retrospective chart review of patients who had undergone T-1 PSO. After obtaining institutional review board approval, we reviewed the charts of 4 patients (Table 1) from 2 institutions. The mean age was 59 years (range 45–77 years). Because CBVA measurements were not possible in our patients, the C2–7 SVA, cervical Cobb angle, and C-2 slope were used to assess both pre- and postoperative deformity. Traditionally, the cervical Cobb angle is determined using the inferior endplate of C-2 and the superior endplate of C-7. To better illustrate the surgi-

FIG. 2. Bilateral pedicle subtraction and vertebral body decancellation.

cal correction achieved by the T-1 PSO, we calculated the cervical Cobb angle using the inferior endplate of C-2 and the superior endplate of T-1. The mean preoperative C2–7 SVA was 58 mm (range 38–85 mm), and the mean postoperative C2–7 SVA was 33.5 mm (range 6–61 mm) for an average correction of 24.5 mm (range 20–32 mm). The mean preoperative cervical Cobb angle was -3.25° (range -66° to 47°), and the mean postoperative cervical Cobb angle was 6.25° (range -20° to 40°) for an average sagittal correction angle of 20° (range 7° – 46°). The mean preoperative C-2 slope angle was -58.5° (range -79° to -29°), and the mean postoperative C-2 slope angle was -19.5° (range -48° to 12°) for an average C-2 slope correction angle of 39° (range 25° – 64°). As per convention, positive angles represent cervical lordosis, while negative angles represent cervical kyphosis.

Case 1

History and Examination

A 65-year-old woman who had previously undergone multiple cervical surgeries for C1–2 instability and cer-

FIG. 3. Four-rod technique for osteotomy closure.

vical kyphotic deformity presented with a fixed chin-on-chest deformity (Fig. 5A), decreasing food intake, difficulty ambulating, and occiput to T-3 posterior cervical instrumentation with rigid fusion masses posterolaterally. She had a preoperative C2–7 SVA of 41 mm, cervical Cobb angle of -66° , and C-2 slope angle of -79° .

Operation

Preoperative planning was performed using the Spine-View software (Surgiview Corp.; Fig. 5B). The patient underwent revision surgery with a combined T1–2 PSO and correction of sagittal balance. After the PSO, there was a large wedge osteotomy defect that would not properly close. Consequently, the patient underwent a second, anterior surgery to fill the anterior osteotomy defect with autograft.

Postoperative Course

There were no postoperative complications and suc-

cessful sagittal correction was attained. At the 12-month follow-up, the patient had a C2–7 SVA of 19 mm (correction of 22 mm), a cervical Cobb angle of -20° (correction of 46°), and a C-2 slope of -15° (correction of 64°) with no neurological complications (Fig. 5C). Figure 6 features pre- and postoperative sagittal and frontal radiographs.

Case 2

History and Examination

A 49-year-old woman presented with posttraumatic cervical kyphosis. She had a preoperative C2–7 SVA of 68 mm, cervical Cobb angle of 34° , and C-2 slope angle of -52° .

Operation

The patient underwent T-1 PSO with correction of sagittal balance.

Postoperative Course

There were no immediate postoperative complications, and successful sagittal correction was performed. At the 42-month follow-up, the patient had a C2–7 SVA of 48 mm (correction of 20 mm), cervical Cobb angle of 20° (correction of 14°), and C-2 slope of -27° (correction of 25°) with occasional hand paresthesias.

Case 3

History and Examination

A 77-year-old woman presented with cervical kyphosis due to inflammatory spondyloarthropathy. She had a preoperative C2–7 SVA of 85 mm, cervical Cobb angle of -28° , and C-2 slope angle of -74° .

Operation

The patient underwent T-1 PSO with correction of sagittal balance.

Postoperative Course

There were no postoperative complications, and successful sagittal correction was performed. At the 12-month follow-up, the patient had a C2–7 SVA of 61 mm (correction of 24 mm), a cervical Cobb angle of -15° (correction of 13°), and a C-2 slope of -48° (correction of 26°) with no neurological complications.

FIG. 4. "Superforamen" after the osteotomy closure, containing the C-8 and T-1 roots.

TABLE 1. Cases of rigid cervical kyphotic deformity

Case No.	Sex	Age (yrs)	Level of Osteot	FU (mos)	Correction Angle		C2–7 SVA Correction (mm; preop → postop)	Diagnosis	Neurological Complication
					Cervical Cobb Angle (preop → postop)	C-2 Slope Angle (preop → postop)			
1	F	65	T1–2	12	46° (–66° → –20°)	64° (–79° → –15°)	22 (41 → 19)	Iatrogenic postlaminectomy kyphosis	None
2	F	49	T-1	42	14° (34° → 20°)	25° (–52° → –27°)	20 (68 → 48)	Posttraumatic kyphosis	Occasional hand paresthesias
3	F	77	T-1	12	13° (–28° → –15°)	26° (–74° → –48°)	24 (85 → 61)	Kyphosis on inflammatory spondyloarthropathy	None
4	F	45	T-1	37	7° (47° → 40°)	41° (–29° → 12°)	32 (38 → 6)	Posttraumatic kyphosis	None

FU = follow-up; osteot = osteotomy.

Case 4

History and Examination

A 45-year-old woman presented with posttraumatic cervical kyphosis. She had a preoperative C2–7 SVA of 38 mm, cervical Cobb angle of 47°, and C-2 slope angle of –29°.

Operation

The patient underwent T-1 PSO with correction of sagittal balance.

Postoperative Course

There were no postoperative complications and successful sagittal correction was performed. At the 35-month follow-up, the patient had a C2–7 SVA of 6 mm (correction of 32 mm), a cervical Cobb angle of 40° (correction of 7°), and a C-2 slope of 12° (correction of 41°) with no neurological complications.

Discussion

We performed T-1 PSO for the correction of cervical sagittal imbalance and rigid sagittal deformity. In our opinion, this osteotomy allows an increased amount of sagittal correction as the procedure is performed lower in the

spine and through a larger T-1 pedicle (average C-7 width × height = 6.4 mm × 7.25 mm;^{7,24,34,35} average T-1 width × height = 7.56 mm × 9.15 mm²⁰). Additionally, there is less risk of injury to the VA. We also believe that the potential neurological deficit associated with manipulation of the C-8 and T-1 roots is less significant than that when C-7 is involved. An additional advantage is the possibility of placing pedicle screws in both the C-7 and T-2 adjoining pedicles while palpating their medial walls through the T-1 laminectomy. In contrast, C-7 osteotomies imply using a lateral mass screw at C-6, which provides a lower quality anchoring point than pedicle fixation.²⁷ Furthermore, the use of intraoperative navigation would be necessary to optimally place instrumentation into the C-6 pedicle, whereas the direct C-7 pedicle instrumentation technique we propose obviates the need for navigation in cases in which the VA runs outside the foramen transversarium.

Conclusions

The T-1 PSO is a powerful correction technique for sagittal cervical imbalance in the presence of rigid deformities. In our opinion, it is superior to the C-7 PSO in terms of decreased risks of injury to the VA and clinically significant nerve root injury. We also believe that the T-1 PSO allows increased angles of correction, but a more

FIG. 5. Case 1. Preoperative sagittal CT scan demonstrating rigid chin-on-chest deformity (A). Preoperative plan with SpineView software (B). Postoperative correction (C).

FIG. 6. Case 1. Sagittal and frontal preoperative (upper) and postoperative (lower) radiographs. Measurements indicate the C2–7 SVA (A and E), cervical Cobb angle (B and F), and C–2 slope (C and G). Frontal radiographs (D and H).

comprehensive study needs to be done to prove this concept. We are very optimistic about these findings and the use of T-1 PSO as an alternative treatment for rigid cervical kyphotic deformity, but more cases must be analyzed before we can confirm our initial encouraging results.

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Disclosures

Dr. Neckrysh is a consultant to K2M, Medtronic, DePuy Spine, and Qualgenix, has stock options in Qualgenix, is on the speakers bureau for K2M and Globus Medical, is on the advisory board for K2M, receives royalties from K2M, and has a spine fellowship sponsored by Globus Medical. Dr. Schizas discloses the receipt of an unrestricted departmental research fund from DePuy Synthes unrelated to this study. Dr. Siemionow is a consultant to GMA, LifeSpine, DePuy Spine, Medtronic, and Amedica, is on the speakers bureau for DePuy Spine and Globus Medical, and has stock options in Teraphysics and Qualgenix.

Author Contributions

Conception and design: Neckrysh, Siemionow. Acquisition of data: Neckrysh, Tobin, Siemionow, Schizas. Analysis and interpretation of data: Neckrysh, Siemionow, Schizas. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Study supervision: Neckrysh.

Supplemental Information

Videos

Video 1. <https://vimeo.com/215838549>.

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