JNS SPINE

CLINICAL ARTICLE

Necessity of posterior osteotomies for mild flexible cervical deformity correction

Robert K. Eastlack, MD,[1,2] Nikita Lakomkin, MD,[3] Stacie Tran, MPH,[2] Michael Jelousi, BA,[1] Alex Soroceanu, MD,[4] Peter Passias, MD,[5] Themistocles Protopsaltis, MD,[5] Justin S. Smith, MD, PhD,[6] Eric Klineberg, MD,[7] Shay Bess, MD,[8] Virginie Lafage, PhD,[9] D. Kojo Hamilton, MD,[10] Han Jo Kim, MD,[11] Douglas Burton, MD,[12] Christopher I. Shaffrey, MD,[13] Christopher P. Ames, MD,[14] and Gregory Mundis Jr., MD,[1,2] on behalf of the International Spine Study Group

[1]Department of Orthopaedic Surgery, Scripps Health, San Diego, California; [2]San Diego Spine Foundation, San Diego, California; [3]Department of Neurologic Surgery, Mayo Clinic, Rochester, Minnesota; [4]Department of Orthopaedic Surgery, University of Calgary, Alberta, Canada; [5]Department of Orthopaedic Surgery, New York University, New York, New York; [6]Department of Neurosurgery, University of Virginia, Charlottesville, Virginia; [7]Department of Orthopaedic Surgery, University of Texas, Houston, Texas; [8]Department of Orthopaedic Surgery, Denver International Spine Center, Denver, Colorado; [9]Department of Orthopaedic Surgery, Lenox Hill Hospital, New York, New York; [10]Department of Neurological Surgery, University of Pittsburgh, Pennsylvania; [11]Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, New York; [12]Department of Orthopaedic Surgery, University of Kansas, Kansas City, Kansas; [13]Department of Neurological Surgery, Duke University, Durham, North Carolina; and [14]Department of Neurological Surgery, University of California, San Francisco, California

OBJECTIVE Correction of mild flexible cervical deformity (CD) via the posterior approach has been described with and without the use of posterior osteotomies (POs), despite a lack of clarity regarding their necessity or risks. The purpose of this study was to determine whether the use of POs when correcting mild flexible CD leads to improved clinical or radiographic outcomes, as well as defining the relative risks in utilizing them.

METHODS A prospective multicenter registry of operative CD patients was analyzed. Inclusion criteria were cervical kyphosis > 10°, cervical scoliosis > 10°, cervical sagittal vertical axis (cSVA) > 4 cm, or chin-brow vertical angle > 25°. Mild deformity was defined by a cSVA of 3–5 cm and/or kyphosis < 15°. Flexibility was defined by a C2–7 angular change > 5° on preoperative flexion/extension radiographs. Patients who received a posterior column osteotomy (PCO) (Ames grades 1 and 2) were compared with patients who did not undergo a PCO (noPCO) as well as those who underwent a three-column osteotomy (3CO) (Ames grades 3–6).

RESULTS Ninety-five patients (33 PCO, 49 noPCO, 13 3CO) met the inclusion criteria. Both the number of levels fused (9.2 vs 7.7, p = 0.001) and the estimated blood loss (EBL) (1027 vs 486 mL, p = 0.012) were higher in the PCO cohort. Patients in the noPCO group were more likely to have a cervical apex of kyphosis (71.1%, p = 0.046), while those undergoing 3COs were more likely to have a thoracic apex (58.3%, p = 0.005). Preoperative cSVA (PCO vs noPCO: 45.4 vs 37.9 cm, p = 0.084), T1 slope (32.5° vs 29.6°, p = 0.376), C2–7 lordosis (−8.9° vs −9.2°, p = 0.942), and modified Japanese Orthopaedic Association (mJOA) score (13.4 vs 13.5, p = 0.854) were similar; however, both Neck Disability Index (NDI) (55.6 vs 42, p = 0.002) and numeric rating scale (NRS) neck (7.2 vs 5.8, p = 0.028) scores were higher in the PCO group before surgery. When adjusting for the use of an anterior approach, there was no significant difference in 1-year postoperative cSVA (35.7 and 35.6 cm, respectively; p = 0.969), C2–7 lordosis (13.7° and 10.1°, respectively; p = 0.393), and patient-reported outcome measures (NRS, NDI, and mJOA) between the PCO and noPCO groups. Two-year radiographic outcomes were largely similar, except for C2 slope, which was higher in the PCO group (29.1° vs 18°, p = 0.026).

ABBREVIATIONS CD = cervical deformity; cSVA = cervical SVA; EBL = estimated blood loss; mJOA = modified Japanese Orthopaedic Association; NDI = Neck Disability Index; NRS = numeric rating scale; PCO = posterior column osteotomy; PO = posterior osteotomy; PROM = patient-reported outcome measure; PT = pelvic tilt; SVA = sagittal vertical axis; TPA = T1 pelvic angle; TS-CL = T1S minus cervical lordosis mismatch; T1S = T1 slope; 3CO = three-column osteotomy.

SUBMITTED November 8, 2023. **ACCEPTED** May 24, 2024.
INCLUDE WHEN CITING Published online September 13, 2024; DOI: 10.3171/2024.5.SPINE231223.

The overall complication rates progressively increased with more complex osteotomy use (noPCO 68.8% vs PCO 71.9% vs 3CO 75%) but did not reach significance (p = 0.063).

CONCLUSIONS The use of POs for mild flexible adult CD may not be necessary to achieve desirable radiographic correction. They are associated with greater EBL and fusion burden. Further studies are needed to fully delineate the risks of adverse events for various types of osteotomies.

https://thejns.org/doi/abs/10.3171/2024.5.SPINE231223

KEYWORDS kyphosis; fusion; spinal alignment; osteotomy; scoliosis; cervical; deformity

Cervical deformity (CD) can result in neck pain, contribute to neurological dysfunction, and present significant challenges for surgical intervention. Various corrective techniques have been described, including anterior cervical discectomy and fusion/corpectomy, posterior arthrodesis, and combined anteroposterior approaches.[1–7] When using posterior approaches, solely or in part, posterior-based osteotomies are frequently utilized to improve the corrective capacity of the operation.[8] While more severe and/or fixed deformities may require three-column closing-wedge osteotomies, milder deformities may be addressed with less aggressive techniques.[8,9]

When addressing milder flexible CDs via a posterior approach, the indications for utilizing posterior osteotomies (POs) have not been clearly defined. A recent study showed that an anterior approach alone can be sufficient in many cases of mild flexible CDs; however, there are circumstances in which a posterior approach is more appropriate.[10] When presented with such a situation, there is no available evidence-based guidance on when it is appropriate to use posterior releases/osteotomies for correction. Because of the additional morbidity incurred when performing osteotomies, it is important to define their relative benefit in this clinical scenario. As such, the purpose of this study was to evaluate whether the use of POs was associated with significantly improved radiographic correction and patient-reported outcome measures (PROMs), as well as assessing any differences in postoperative adverse events in patients presenting with mild CD.

Methods

Data Source

This study represents a retrospective review of a prospective multicenter database of patients undergoing surgery for CD. Following approval from each institutional review board, patients were enrolled from 13 high-volume spine centers across the United States. Inclusion criteria for the database were patients 18 years of age or older with radiographic evidence of CD, as defined by the presence of any one of the following criteria at baseline: cervical kyphosis (C2–7 Cobb angle) > 10°, cervical scoliosis (C2–7 coronal Cobb angle) > 10°, C2–7 cervical sagittal vertical axis (cSVA) > 4 cm, or chin-brow vertical angle > 25°. Patients were excluded from the database if they had any active tumors or infections.

Mild Flexible CD

Mild CD was defined by the presence of a cSVA of 3–5 cm and/or kyphosis < 15°, and flexibility was determined by identifying a C2–7 angular change > 5° on preoperative flexion/extension radiographs.

All patients underwent cervical spine deformity correction and fusion surgery (preoperative and postoperative example radiographs obtained in the same patient are presented in Figs. 1 and 2, respectively). They were categorized into groups of patients who underwent a PO and those who did not undergo a posterior column osteotomy (noPCO). We included patients who had undergone concomitant anterior approaches as part of their index surgi-

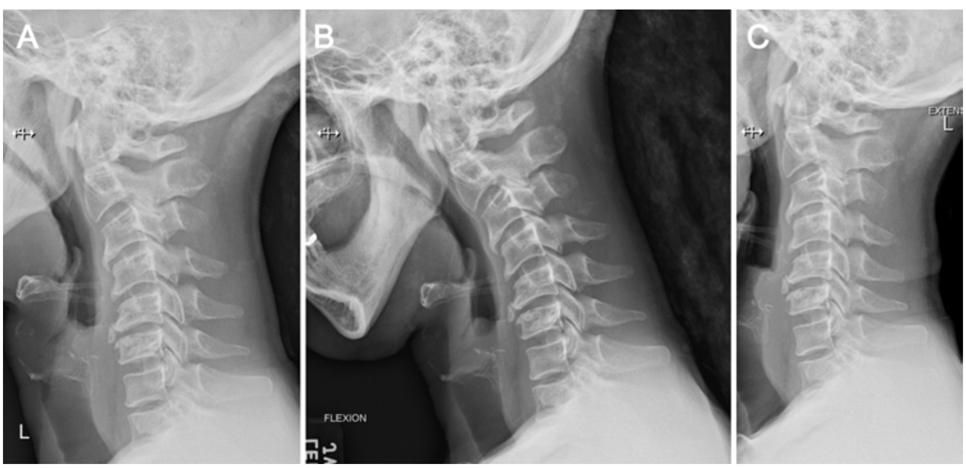

FIG. 1. Preoperative lateral (**A**), flexion (**B**), and extension (**C**) radiographs obtained in a patient with an apex of kyphosis in the cervical region undergoing anterior and posterior reconstruction.

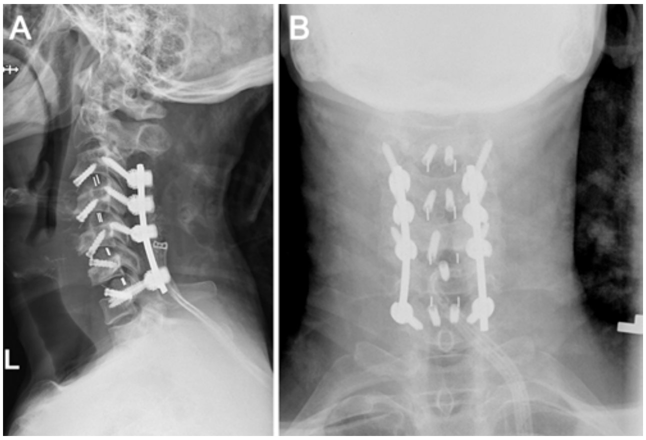

FIG. 2. Postoperative lateral (**A**) and anteroposterior (**B**) radiographs obtained in the patient with mild flexible CD from Fig. 1, after having undergone a combined approach without osteotomies.

TABLE 1. Demographics, approach, and deformity apex for each cohort

	noPCO	PCO	3CO	p Value*
No. of patients	49	33	13	
Age, yrs	62.3 (10)	60.1 (10)	64.1 (6)	0.323
Female sex	30 (61.2)	23 (70.0)	8 (61.5)	0.333
Op time, mins	293 (170)	377 (189)	353 (148)	0.071
EBL, mL	486 (520)	1027 (1015)	1265 (1044)	**0.012**
No. of levels fused	7.7	9.2	10.6	**0.001**
Approach				**0.041**
Posterior	14 (28.6)	17 (51.5)	13 (100)	
Anteroposterior	35 (71.4)	16 (48.5)	0 (0)	
Apex of kyphosis				
Cervical	32 (71.1)	17 (54.8)	4 (33.3)	**0.046**
Cervicothoracic	7 (15.6)	6 (19.4)	1 (8.3)	0.672
Thoracic	6 (13.3)	8 (25.8)	7 (58.3)	**0.005**

Values are presented as number of patients (%) or mean (SD) unless otherwise indicated. Boldface type indicates statistical significance.
* Between the PCO and noPCO groups.

cal correction. Osteotomy types were determined based on the Ames classification.[21] PO cohorts were further subdivided into those undergoing lower-grade PCOs (Ames grades 1 and 2) and those undergoing higher-grade three-column osteotomies (3COs) (Ames grades 3–6).

Data Collection and Radiographic Analysis

Data were collected at baseline and 6 months, 1 year, and 2 years postoperatively. Demographic and clinical data collected in the database included patient age and sex. Perioperative data consisted of operative time, estimated blood loss (EBL), and complications, which were classified as major and minor based on prior study group reports.[10] In addition, PROMs such as the numeric rating scale (NRS), modified Japanese Orthopaedic Association (mJOA) score for myelopathy, Neck Disability Index (NDI), and EQ-5D (a quality of life instrument) were collected for patients at various time points. Cervical radiographic parameters included the following: C2–7 cervical lordosis (angle between the lower endplates of C2 and C7), cervical scoliosis coronal Cobb angle (C2–7 Cobb angle), cSVA (C2 plumb line offset from the posterosuperior corner of C7), C2 slope, T1 slope (T1S), and T1S minus cervical lordosis mismatch (TS-CL). Spinopelvic radiographic parameters included the following: sagittal vertical axis (SVA) (C7 plumb line relative to the posterosuperior corner of S1), T1 pelvic angle (TPA) (angle between a line from the center of T1 to the femoral head and a line from the femoral head to the center of the S1 endplate), and pelvic tilt (PT) (angle between the vertical and the line through the sacral midpoint to the center of the two femoral heads). All radiographic measurements of deformity were obtained on upright weight-bearing radiographs.

Statistical Analysis

Descriptive statistics, including mean and standard deviation as well counts and percentages, are used to describe each variable of interest. Comparative statistical tests were performed between the noPCO group and the PCO group (Ames grades 1 and 2). Categorical variables were compared using chi-square goodness-of-fit tests or Fisher's exact tests, as appropriate. Continuous variables were evaluated using Student t-tests. Any cases of missing data were excluded via listwise deletion. A priori statistical significance was defined as $p < 0.05$. The use of an anterior approach was controlled for when comparing 1-year radiographic, operative, and patient-reported outcome measures between the PCO and noPCO groups.

Results

Ninety-five patients (46 PO, 49 noPCO) met the inclusion criteria with similar mean ages (PCO 60.1 vs noPCO 62.3 years, p = 0.323). Combined anterior and posterior approaches were more frequent in the noPCO group (71.4% vs 48.5%, p = 0.041).

In the PO group, grade 1 and 2 POs were used in 33 (71.7%) patients and grade 3–6 POs in 13 (28.3%) patients. The preoperative apex of kyphosis was more likely to be cervical in location for the noPCO and PCO groups (71.1% and 54.8%, respectively; p = 0.046), while patients undergoing more complex 3COs were more likely to have a thoracic apex (58.3%, p = 0.005) (Table 1). A cervicothoracic apex of kyphosis was of similar prevalence between groups (PCO 19.4%, noPCO 15.6%).

Operative time was greater for PCO patients when compared with their noPCO counterparts but did not reach statistical significance (377 vs 293 minutes, p = 0.071). EBL was greatest in the 3CO group, with a mean of 1265 mL, compared with 1027 mL for the PCO group and 486 mL for the noPCO group (p = 0.012). The mean number of fused levels was highest for the 3CO group (10.6) and significantly greater in the PCO cohort when compared with the noPCO group (9.2 vs 7.7, p = 0.001).

TABLE 2. Preoperative radiographic and patient-reported outcome measures

	noPCO	PCO	3CO	p Value*
Preop radiographic parameters				
cSVA, cm	37.9 (19.7)	45.4 (17.8)	47.8 (9.5)	0.084
TS-CL, °	38.8 (22.0)	41.4 (23.2)	32.2 (13.3)	0.606
T1S, °	29.6 (15.1)	32.5 (14.1)	40.7 (19.5)	0.376
C2S, °	37.2 (23.5)	41.2 (24.2)	35.1 (14.6)	0.463
CBVA, °	6.5 (7.0)	5.37 (10.4)	7.41 (5.1)	0.846
C2–7 lordosis, °	–9.2 (16.5)	–8.9 (23.0)	8.5 (26.5)	0.942
C2–7 Cobb angle, °	–3.93 (30.0)	–16.6 (43.0)	–3.1 (33.6)	0.151
SVA, cm	15.6 (58.8)	–17.2 (81.4)	–2.7 (70.5)	0.057
PT, °	21.3 (9.8)	20.0 (13.1)	23.7 (12.2)	0.632
TPA, °	16.1 (10.6)	12.7 (15.8)	15.9 (11.8)	0.257
Preop PROMs				
NRS neck score	5.8 (2.79)	7.2 (2.6)	7.2 (1.9)	**0.028**
NDI score	42.0 (19.0)	55.6 (17.4)	45.4 (14.9)	**0.002**
mJOA score	13.5 (3.0)	13.4 (2.8)	15.0 (2.5)	0.854

CBVA = chin-brow vertical angle; C2S = C2 slope.
Values are presented as mean (SD) unless otherwise indicated. Boldface type indicates statistical significance.
* Between the PCO and noPCO groups.

TABLE 3. Two-year results in radiographic and patient-reported outcome measures

	noPCO	PCO	3CO	p Value*
2-yr radiographic parameters				
cSVA, cm	32.1 (17.5)	41.1 (14.1)	33.8 (5.1)	0.12
TS-CL, °	21.7 (9.1)	31.9 (15.8)	29.1 (9.5)	0.062
T1S, °	32.5 (11.5)	41.5 (14.5)	48.1 (18.5)	0.062
C2S, °	18.0 (8.5)	29.1 (15.7)	27.7 (10.3)	**0.026**
C2–7 lordosis, °	10.8 (9.8)	10.6 (14.1)	19.0 (14.4)	0.053
C2–7 Cobb angle, °	–14.9 (25.7)	–20.9 (54.2)	14.7 (23.0)	0.157
SVA, cm	26.0 (39.5)	27.2 (83.3)	36.2 (77.2)	0.967
PT, °	22.9 (8.9)	21.9 (13.1)	21.6 (18)	0.822
TPA, °	18.6 (9.1)	15.8 (15.2)	18.1 (21.4)	0.621
2-yr PROMs				
NRS neck score	3.0 (2.4)	4.93 (3.2)	4.3 (3.1)	0.074
NDI score	25.6 (17.3)	42.9 (22.7)	36.5 (15.4)	**0.023**
mJOA score	15.3 (3.2)	13.5 (3.1)	15.7 (2.5)	0.103

Values are presented as mean (SD) unless otherwise indicated. Boldface type indicates statistical significance.
* Between the PCO and noPCO groups.

Preoperative radiographic parameters were largely similar between the PCO and noPCO groups (Table 2). These included preoperative cSVA (PCO vs noPCO: 45.4 vs 37.9 cm, p = 0.084), T1S (32.5° vs 29.6°, p = 0.376), and C2–7 lordosis (–8.9° vs –9.2°, p = 0.942), among others. Additionally, there were no statistically significant differences in global spinopelvic parameters, including SVA (PCO vs noPCO: –17.2 vs 15.6 cm, p = 0.057), TPA (12.7° vs 16.1°, p = 0.257), and PT (20.0° vs 21.3°, p = 0.632).

With respect to PROMs, the preoperative NRS score for neck pain and NDI score were lower in the noPCO group than in the PCO group (Table 2). However, there were no preoperative differences between the groups for mJOA scores (noPCO 13.5 vs PCO 13.4, p = 0.854).

At 2 years postoperatively, there were no differences between groups in radiographic outcomes or PROMs (Table 3), with the exception of persistently greater NDI scores in the PCO group compared with the noPCO cohort (42.9 vs 25.6, p = 0.023). Although the PCO group did have significantly greater preoperative NRS scores, both groups experienced similar decreases at the 2-year follow-up (PCO 2.3 points and noPCO 2.8 points, p = 0.18).

When adjusting for the use of a concomitant anterior approach, radiographic parameters at the 1-year follow-up were not significantly different between the PCO and noPCO groups (Table 4). These included cSVA (PCO vs noPCO: 35.7 vs 35.6 cm, p = 0.969), C2–7 lordosis (13.7° vs 10.1°, p = 0.393), and an array of PROMs (NRS, NDI, and mJOA scores). Interestingly, the T1S was slightly higher for both groups postoperatively than before surgery (PCO: 41.1° vs 32.5°; noPCO: 32.3° vs 29.6°), but there were no statistically significant differences between groups after surgery (p = 0.061). At 1 year after surgery, the mean NRS neck score was greater in the PCO group compared with the noPCO group (5.2 vs 2.9) but did not reach statistical significance (p = 0.068). Two-year NRS outcomes similarly did not reach statistical significance, with a mean score of 3.0 for noPCO patients and 4.9 for the PCO group (p = 0.074).

The overall complication rates progressively increased with more complex osteotomy use (noPCO 68.8% vs PCO 71.9% vs 3CO 75%) but did not reach significance (p = 0.063) (Table 5).

Discussion

Mild flexible CDs may allow for a variety of surgical approaches in achieving adequate realignment. Anterior, posterior, and anteroposterior approaches have been described in treating cervical kyphosis, but no studies have previously evaluated the specific role and benefit of osteotomies in the context of treating milder CDs.[1–3,10] In this study, we specifically aimed to evaluate the radiographic and clinical benefits of utilizing osteotomies, as well as ascertaining the additive risk associated with their use.

Based on the analysis of our cohorts, the additional use of POs does not appear to substantially improve the postoperative radiographic alignment when compared with not utilizing them. Certainly, this conclusion could be influenced by the concomitant application of an anterior cervical approach, as a greater proportion of patients without osteotomies underwent anterior approaches. However,

TABLE 4. One-year radiographic and patient-reported outcome measures when adjusted for use of an anterior approach

	noPCO	PCO	p Value*
1-yr radiographic parameters			
cSVA, cm	35.6 (16.5)	35.7 (11.9)	0.969
TS-CL, °	22.2 (10.3)	27.5 (12.4)	0.203
T1S, °	32.3 (10.8)	41.1 (14.1)	0.061
C2S, °	21.1 (8.5)	23.5 (12.6)	0.538
CBVA, °	5.1 (4.5)	2.6 (8.8)	0.595
C2–7 lordosis, °	10.1 (10.0)	13.7 (13.1)	0.393
C2–7 Cobb angle, °	–14.7 (22.3)	–7.50 (60.9)	0.753
SVA, cm	24.3 (45.9)	32.0 (75.5)	0.804
PT, °	19.3 (9.6)	24.2 (10.1)	0.188
TPA, °	15.6 (9.1)	20.1 (15.2)	0.477
1-yr PROMs			
NRS neck score	2.9 (2.6)	5.2 (3.5)	0.068
NDI score	27.3 (17.3)	36.5 (25.2)	0.289
mJOA score	14.8 (3.1)	14.0 (2.6)	0.471

Values are presented as mean (SD) unless otherwise indicated.
* Between the PCO and noPCO groups.

TABLE 5. Complication and reoperation rates for each subcohort of deformity patients

	noPCO	PCO	3CO	p Value*
Complications	33 (68.8)	23 (71.9)	9 (75)	0.063
Major complications	13 (27.1)	12 (37.5)	4 (33.3)	0.59
Minor complications	19 (39.6)	7 (21.9)	2 (16.7)	0.076
Dysphagia	6 (12.5)	0	0	**0.02**
Cardiopulmonary	2 (4.2)	1 (3.1)	0	0.22
Electrolyte	1 (2.1)	0	0	0.42
Gastrointestinal	0	1 (3.1)	0	0.77
Infection	2 (4.2)	0	0	0.85
Instrumentation	0	0	0	0.47
Neurological	7 (14.6)	1 (3.1)	0	0.42
Operative	2 (4.2)	2 (6.3)	0	0.40
Vascular	0	0	0	0.153
Radiographic	3 (6.3)	2 (6.3)	0	0.55
Reop	5 (10.4)	5 (15.6)	3 (25)	0.95

Values are presented as number of patients (%) unless otherwise indicated. Boldface type indicates statistical significance. In each group, data were missing for 1 patient.
* Between the PCO and noPCO groups.

even when correcting for an anterior approach, patients had similar radiographic and patient-reported outcome measures at the 1-year follow-up.

Importantly, the decision to use POs may also be influenced by the degree of the deformity or location of the apex of kyphosis.[8,9,11–14] We were specifically evaluating milder CDs, and thus more severe or higher-degree deformities were not relevant to our assessment. However, an apex of the deformity in the upper thoracic spine could certainly influence the desire to use a posterior approach and extend more caudally. In addition, these cases may undergo more aggressive correction through the use of 3COs. In support of this assertion, we did find that more than 70% of patients who had an apex of their kyphosis in the thoracic spine underwent osteotomies (with 46.7% undergoing 3COs), and those undergoing 3CO had a greater number of levels fused. In our experience, these techniques can be particularly valuable in cases of prior cervical fusion for degenerative disease, or in the setting of a previous, long thoracolumbar construct followed by the development of a cervical spinal deformity. Figure 3A and B depicts preoperative lateral and anteroposterior radiographs obtained in a 55-year-old female with a past surgical history of C4–6 anterior cervical discectomy and fusion, followed by a posterior cervical decompression and fusion from C4 to C7 for adjacent-segment cervical stenosis. She presented with symptoms of CD and a cervicothoracic apex of kyphosis on upright radiographs. She subsequently underwent removal of the instrumentation at C7, an Ames grade 6 osteotomy at C7, and extension of her posterior construct from C2 to T4. She did well after surgery. The 3-month lateral and anteroposterior radiographs for this patient are presented in Fig. 3C and D.

A higher T1S relative to cervical lordosis could also influence the need for more levels of caudal fixation, as well as inspire a more aggressive correction. Tang et al. demonstrated the importance of T1S and TS-CL given their correlation with PROMs.[15] More importantly, a higher T1S or more significant TS-CL may portend a greater likelihood of distal junctional kyphosis.[16–18] Extending fixation more caudally into the thoracic spine may therefore be advocated and commensurately result in greater levels of fixation (as was evident in the PO cohort). Despite this potential concern over selection bias within the study, the preoperative T1S and TS-CL values in both of our groups were similar. Thus, it is unlikely that this factor played a significant role in decision-making regarding the use of osteotomies. Rather, the greater mean number of fused levels for the PO group is more likely the result of lower apices of kyphosis, as a significantly greater proportion of patients undergoing PCOs had junctional or thoracic apices of kyphosis.

Operative time was greatest in the PCO cohort but did not reach significance. However, it remains unclear whether this time is secondary to the increased use of concomitant anterior approaches or the POs themselves. While we did not specifically analyze the benefit of the anterior approach in this study, we have previously shown that the additive clinical and radiographic benefits may not warrant additional operative time (unpublished data). Further studies would be valuable in specifically identifying those who would benefit from anterior reconstruction.

EBL progressively increased with the complexity of the osteotomies, with 3CO patients having the greatest mean EBL at nearly 1.3 L. Pedicle subtraction osteotomies and vertebral column resections are well known to substantially elevate blood loss during adult spinal deformity surgery.[11,19,20] With the advent of less invasive techniques,

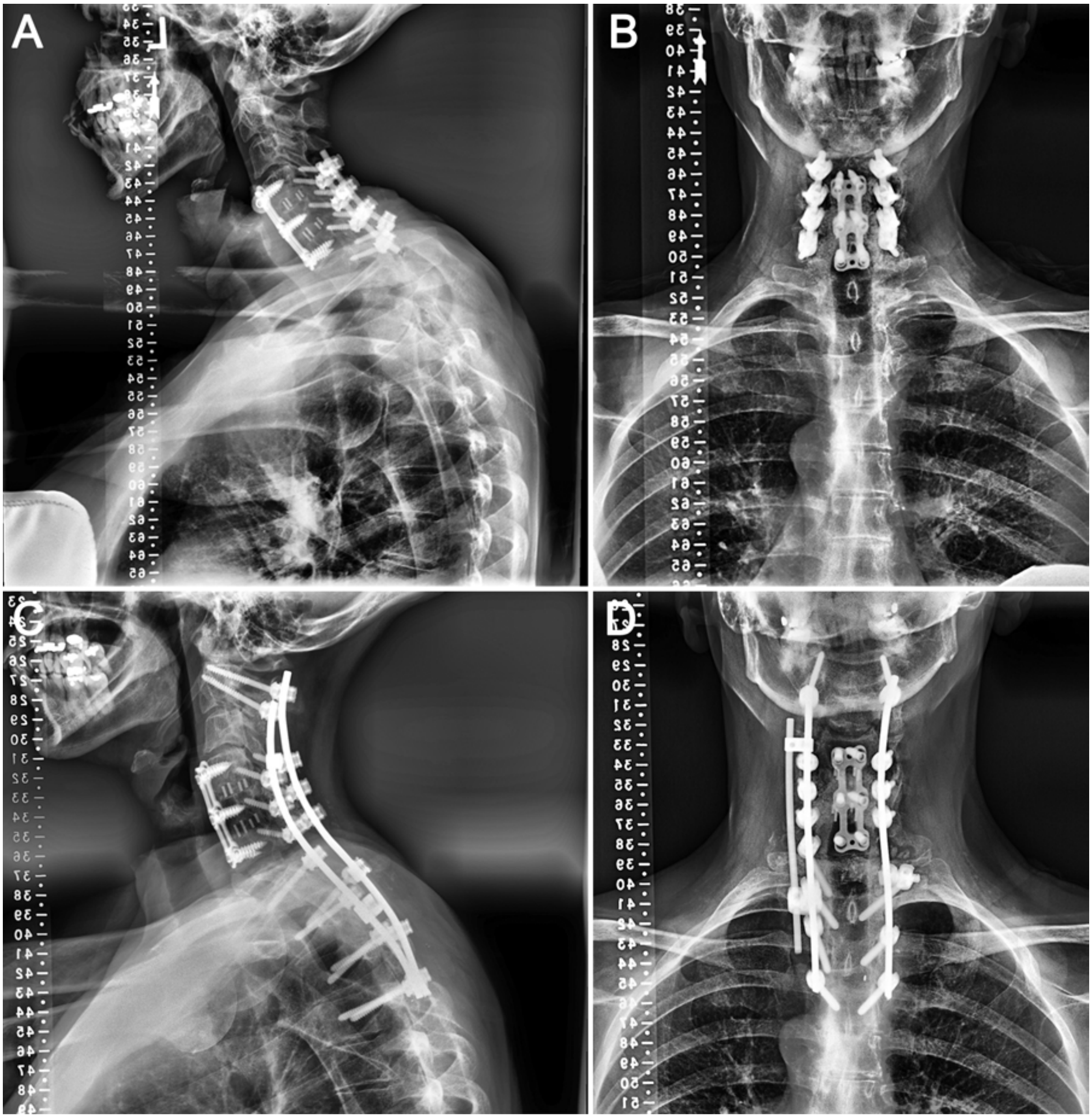

FIG. 3. Preoperative lateral (**A**) and anteroposterior (**B**) standing radiographs obtained in a patient with a prior cervical fusion and a cervicothoracic apex of kyphosis. Postoperative lateral (**C**) and anteroposterior (**D**) radiographs obtained in the same patient after having undergone a 3CO at C7 and extension of her posterior construct.

these factors should be carefully considered when deciding on the optimal correction for each case.

Finally, overall complication rates were greatest among those undergoing 3COs, and patients undergoing PCOs had a slightly increased rate of overall complications when compared with the noPCO group. However, significance was not reached. It is possible that certain complications, such as dysphagia, were underestimated in the groups with lower numbers of patients. Other adverse events such as neurological and operative complications were similar, regardless of the use of osteotomies. Not surprisingly, patients in the 3CO group experienced greater rates of reoperation compared with their counterparts. It is known that instrumentation-related events as well as pseudarthrosis are among the most common complications following pedicle subtraction osteotomies and other invasive techniques. Additional studies will be valuable in delineating these outcomes for complex CDs.

Limitations

One of the limitations of our study was the heterogeneity in patient inclusion with respect to the apex of kyphosis. This variable likely contributes substantially to surgical decision-making, for both levels of fixation and the use of more aggressive corrective maneuvers, such as osteotomies. Controlling for this factor in our analysis would have substantially reduced our patient numbers and thus statistical power. Furthermore, the subdivision of the PO cohort into PCO and 3CO groups reduced the statistical power for subanalyses, such as long-term complication rates, and may have contributed to certain tests being underpowered. In addition, other variables affecting outcomes after these operations, such as surgeon experience or variation in technique, were not incorporated. Finally, this study represents a retrospective analysis of a prospectively collected registry, thus creating an inherent risk of selection bias.

Conclusions

The use of POs in correcting mild flexible CD in adults may not be necessary to achieve desirable radiographic alignment, regardless of the concomitant use of an anterior approach. Their utilization may be associated with a higher operative blood loss and greater fusion burden. The apex of kyphosis may further influence the decision and potential need for POs. Further studies are needed to fully delineate the risks of adverse events for various types of osteotomies.

References

1. Steinmetz MP, Kager CD, Benzel EC. Ventral correction of postsurgical cervical kyphosis. *J Neurosurg*. 2003;98(1 Suppl):1-7.
2. Grosso MJ, Hwang R, Krishnaney AA, Mroz TE, Benzel EC, Steinmetz MP. Complications and outcomes for surgical approaches to cervical kyphosis. *J Spinal Disord Tech*. 2015; 28(7):E385-E393.
3. Song KJ, Johnson JS, Choi BR, Wang JC, Lee KB. Anterior fusion alone compared with combined anterior and posterior fusion for the treatment of degenerative cervical kyphosis. *J Bone Joint Surg Br*. 2010;92(11):1548-1552.
4. Smith JS, Klineberg E, Shaffrey CI, et al. Assessment of surgical treatment strategies for moderate to severe cervical spinal deformity reveals marked variation in approaches, osteotomies, and fusion levels. *World Neurosurg*. 2016;91: 228-237.
5. Ferch RD, Shad A, Cadoux-Hudson TAD, Teddy PJ. Anterior correction of cervical kyphotic deformity: effects on myelopathy, neck pain, and sagittal alignment. *J Neurosurg*. 2004; 100(1 Suppl Spine):13-19.
6. O'Shaughnessy BA, Liu JC, Hsieh PC, Koski TR, Ganju A, Ondra SL. Surgical treatment of fixed cervical kyphosis with myelopathy. *Spine (Phila Pa 1976)*. 2008;33(7):771-778.
7. Abumi K, Shono Y, Taneichi H, Ito M, Kaneda K. Correction of cervical kyphosis using pedicle screw fixation systems. *Spine (Phila Pa 1976)*. 1999;24(22):2389-2396.
8. Kim HJ, Piyaskulkaew C, Riew KD. Comparison of Smith-Petersen osteotomy versus pedicle subtraction osteotomy versus anterior-posterior osteotomy types for the correction of cervical spine deformities. *Spine (Phila Pa 1976)*. 2015;40(3):143-146.
9. 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. *J Neurosurg Spine*. 2010;13(6):695-706.
10. Eastlack RK, Mundis GM Jr, Nguyen S, et al. Friday, September 28, 2018 9:00 AM–10:00 AM best papers Friday: 152. Anterior reconstruction provides better outcomes when correcting mild flexible cervical deformity. *Spine J*. 2018;18(8 Suppl):S76.
11. Mummaneni PV, Dhall SS, Rodts GE, Haid RW. Circumferential fusion for cervical kyphotic deformity. *J Neurosurg Spine*. 2008;9(6):515-521.
12. Ailon T, Smith JS, Shaffrey CI, et al. Outcomes of operative treatment for adult cervical deformity: a prospective multicenter assessment with 1-year follow-up. *Neurosurgery*. 2018; 83(5):1031-1039.
13. Tan LA, Riew KD, Traynelis VC. Cervical spine deformity—part 3: posterior techniques, clinical outcome, and complications. *Neurosurgery*. 2017;81(6):893-898.
14. Bronson WH, Moses MJ, Protopsaltis TS. Correction of dropped head deformity through combined anterior and posterior osteotomies to restore horizontal gaze and improve sagittal alignment. *Eur Spine J*. 2018;27(8):1992-1999.
15. Tang JA, Scheer JK, Smith JS, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. *Neurosurgery*. 2012;71(3):662-669.
16. Scheer JK, Tang JA, Smith JS, et al. Cervical spine alignment, sagittal deformity, and clinical implications: a review. *J Neurosurg Spine*. 2013;19(2):141-159.
17. Ames CP, Blondel B, Scheer JK, et al. Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. *Spine (Phila Pa 1976)*. 2013;38(22 Suppl 1):S149-S160.
18. Passias PG, Vasquez-Montes D, Poorman GW, et al. Predictive model for distal junctional kyphosis after cervical deformity surgery. *Spine J*. 2018;18(12):2187-2194.
19. Daubs MD, Brodke DS, Annis P, Lawrence BD. Perioperative complications of pedicle subtraction osteotomy. *Global Spine J*. 2016;6(7):630-635.
20. Etame AB, Wang AC, Than KD, La Marca F, Park P. Outcomes after surgery for cervical spine deformity: review of the literature. *Neurosurg Focus*. 2010;28(3):E14.
21. Ames CP, Smith JS, Scheer JK, et al. A standardized nomenclature for cervical spine soft-tissue release and osteotomy for deformity correction. *J Neurosurg Spine*. 2013;19(3):269-278.

Disclosures

Dr. Eastlack reported personal fees from Aesculap, Globus, Medtronic, DePuy, Spinal Elements, SeaSpine, Neo, Silony, Biedermann Motech, and SI-Bone; shareholder in Alphatec; and royalties from Globus, SeaSpine, and SI-Bone outside the submitted work. Ms. Tran reported current employment at NuVasive, but not during the conduct of the study. Dr. Passias reported grants from Medtronic and Cerapedics outside the submitted work. Dr. Protopsaltis reported consulting fees from Globus, NuVasive, Medtronic, and Stryker K2M; royalties from Altus; and stock in OnPoint Surgical outside the submitted work. Dr. Smith reported grants from DePuy Synthes/ISSGF, SeaSpine, AO Spine, and NREF; and personal fees from ZimVie, NuVasive, Cerapedics, SeaSpine, Medtronic, and Carlsmed outside the submitted work. Dr. Klineberg reported royalties from Stryker Spine; stock ownership in MMI and Relatable; nonfinancial support (consultant) from DePuy Synthes, Stryker Spine, Medtronic, SeaSpine, SI-Bone, and Agnovos; speaker fees from AONA Spine; and board of directors of IMAST, AONA Spine, and SRS outside the submitted work. Dr. Bess reported grants from DePuy Synthes and ISSGF during the conduct of the study; grants from DePuy Synthes, Medtronic, Stryker, NuVasive, Globus, Carlsmed, and ISSGF; and personal fees from ATEC outside the submitted work. Dr. Lafage reported consulting fees from Alphatec and Globus Medical; royalties from NuVasive; lecture fees from Johnson & Johnson, Stryker, and Implanet; EC member of ISSG; and committee member of SRS outside the submitted work. Dr. Kim reported grants from ISSGF; royalties/licenses from Zimmer Biomet, K2M/Stryker, and Acuity Surgical; consulting fees from NuVasive; leadership fees from Vivex Biologics and Aspen Medical; and fellowship support from AO Spine paid to institution during the conduct of the study. Dr. Burton reported personal fees from DePuy Synthes Spine,

Globus, and Blue Ocean Spine; stock options in Progenerative Medical; and board of directors of Scoliosis Research Society and International Spine Study Group outside the submitted work. Dr. Shaffrey reported grants from ISSG Foundation to Duke University during the conduct of the study; and personal fees from NuVasive, Medtronic, SI-Bone, and Proprio outside the submitted work. Dr. Ames reported royalties from Biomet Zimmer Spine, DePuy Synthes, K2M, Medicrea, Next Orthosurgical, NuVasive, and Stryker; consulting fees from DePuy Synthes, Medtronic, Medicrea, K2M, Agada Medical, and Carlsmed; personal research fees from Titan Spine, DePuy Synthes, and ISSG; grants from SRS; and nonfinancial support from Global Spinal Analytics (director), ISSG (executive committee), and SRS Safety and Value Committee (chair) outside the submitted work. Dr. Mundis reported royalties from NuVasive, SeaSpine, and Stryker; paid consultant of NuVasive, SeaSpine, SI-Bone, and Viseon; stock/stock options in NuVasive, Alphatec Spine, and Orthofix; and scientific advisory board of NuVasive, SeaSpine, and Carlsmed during the conduct of the study; and nonprofit leadership in Global Spine Outreach (CEO), San Diego Spine Foundation (president), and San Diego Orthopaedic Society (board member).

Author Contributions

Conception and design: Eastlack, Lakomkin, Jelousi, Soroceanu, Passias, Protopsaltis, Smith, Bess, Hamilton, Burton, Shaffrey, Mundis. Acquisition of data: Eastlack, Lakomkin, Jelousi, Soroceanu, Passias, Protopsaltis, Smith, Bess, Lafage, Burton, Shaffrey. Analysis and interpretation of data: Eastlack, Lakomkin, Tran, Jelousi, Passias, Protopsaltis, Smith, Klineberg, Bess, Hamilton, Ames, Mundis. Drafting the article: Eastlack, Lakomkin, Jelousi, Passias, Hamilton. Critically revising the article: Eastlack, Lakomkin, Tran, Soroceanu, Passias, Protopsaltis, Smith, Klineberg, Lafage, Hamilton, Kim, Burton. Reviewed submitted version of manuscript: Eastlack, Lakomkin, Tran, Jelousi, Soroceanu, Passias, Protopsaltis, Klineberg, Bess, Lafage, Hamilton, Burton, Shaffrey, Mundis. Approved the final version of the manuscript on behalf of all authors: Eastlack. Statistical analysis: Eastlack, Lakomkin, Tran, Passias, Ames. Administrative/technical/material support: Eastlack, Passias, Bess, Lafage, Kim. Study supervision: Eastlack, Soroceanu, Passias, Klineberg, Bess, Kim, Shaffrey, Ames.

Correspondence

Robert K. Eastlack: Scripps Clinic, La Jolla, CA. eastlack.robert@scrippshealth.org.