

A controlled anterior sequential interbody dilation technique for correction of cervical kyphosis

Darryl Lau, MD, John E. Ziewacz, MD, MPH, Hai Le, BS, Rishi Wadhwa, MD, and Praveen V. Mummaneni, MD

Department of Neurological Surgery, University of California, San Francisco, California

OBJECT Cervical kyphosis can lead to spinal instability, spinal cord injury, and disability. The correction of cervical kyphosis is technically challenging, especially in severe cases. The authors describe the anterior sequential interbody dilation technique for the treatment of cervical kyphosis and evaluate perioperative outcomes, degree of correction, and long-term follow-up outcomes associated with the technique.

METHODS In the period from 2006 to 2011, a consecutive cohort of adults with cervical kyphosis (Cobb angles $\geq 0^\circ$) underwent sequential interbody dilation, a technique entailing incrementally increased interbody distraction with the sequential placement of larger spacers (at least 1 mm) in the discectomy and/or corpectomy spaces. The authors retrospectively reviewed these patients, and primary outcomes of interest included kyphosis correction, blood loss, hospital stay, complications, Nurick grade, pain, reoperation, and pseudarthrosis. A subgroup analysis among patients with preoperative kyphosis of 0° – 9° (mild), 10° – 19° (moderate), and $\geq 20^\circ$ (severe) was performed.

RESULTS One hundred patients were included in the study: 74 with mild preoperative cervical kyphosis, 19 with moderate, and 7 with severe. The mean patient age was 53.1 years, and 54.0% of the patients were male. Mean estimated blood loss was 305.6 ml, and the mean length of hospital stay was 5.2 days. The overall complication rate was 9.0%, and there were no deaths. Sixteen percent of patients underwent supplemental posterior fusion. There was significant correction in cervical alignment ($p < 0.001$), and the mean overall kyphosis correction was 12.4° . Patients with severe preoperative kyphosis gained a correction of 24.7° , those with moderate kyphosis gained 17.8° , and those with mild kyphosis gained 10.1° . A mean correction of 32.0° was obtained if 5 levels were addressed. The mean follow-up was 26.8 months. The reoperation rate was 4.7%. At follow-up, there was significant improvement in visual analog scale neck pain ($p = 0.020$) and Nurick grade ($p = 0.037$). The pseudarthrosis rate was 6.3%.

CONCLUSIONS Sequential interbody dilation is a feasible and effective method of correcting cervical kyphosis. Complications and reoperation rates are low. Similar benefits are seen among all severities of kyphosis, and greater correction can be achieved in more severe cases.

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KEY WORDS cervical; corpectomy; deformity; discectomy; kyphosis; fusion

NORMAL cervical lordosis is becoming well recognized as a critical component in maintaining normal sagittal alignment and sagittal balance.²⁸ When the normal cervical curvature is reversed and cervical kyphosis is present, patients may have pain symptomatology.² Cervical kyphosis has been shown to contribute to the pathogenesis of spinal cord injury and myelopathy through direct ventral pressure and flattening of the spinal

cord.^{17,37,40} Therefore, addressing cervical kyphosis is critical in improving functional status and mitigating potential neurological injury.

Patients with cervical kyphosis can present with signs and symptoms of radiculopathy, myelopathy, instability, pain, and, in severe cases, with dysphagia, dyspnea, and difficulty maintaining horizontal gaze. In patients with such symptoms, surgical intervention is often warranted.

ABBREVIATIONS BMP = bone morphogenetic protein; PEEK = polyetheretherketone; VAS = visual analog scale.

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Recent clinical studies have directly correlated cervical kyphosis following surgery with worse neurological disability and pain,^{2,14,18,21} and patients who obtain lordosis after surgery have better functional outcomes.^{7,14} The correction of cervical kyphosis can be challenging, especially in severe cases, and osteotomies are often used to attain maximal correction.¹³ While posterior osteotomies have been effective for achieving correction, there are limitations to the technique. Mainly, anterior decompression and spinal column reconstruction are not easily achieved via a posterior-only approach in the cervical spine, and a combined anteroposterior procedure is commonly needed when treating cervical deformity caused by an anterior element pathology.³ A technique that allows direct access to anterior pathology, adequate decompression, and various extents of cervical kyphosis correction is ideal.

In this paper, we present a technique we call “anterior sequential interbody dilation” to correct cervical kyphosis of any severity. This method does not rely on posterior osteotomies and can be readily used when performing anterior decompressive procedures (corpectomy and/or discectomy). We also review the perioperative (that is, intraoperative and immediately postoperative) and long-term outcomes in a surgically managed cohort and perform a subgroup analysis comparing outcomes among patients who were treated for mild, moderate, and severe cervical kyphosis.

Methods

Anterior Sequential Interbody Dilation Technique

Patients are positioned supine. Standard anterior cervical corpectomy and/or discectomy are performed using previously described techniques.¹⁹ After completing the corpectomy and/or discectomy, sequential interbody dilation is initiated. Dilation of the space is initiated utilizing customized surgical instruments (Fig. 1). The size of the individual interbody spacer ranges between 5 and 65 mm. Each end of the spacer can be further enlarged by 1- or 2-mm increments for a controlled approach to dilation. Initial dilation of the interbody space is performed using a spacer sized to firmly fit into the interbody space. Then, sequentially larger interbody spacers are placed to correct the kyphosis. This technique entails incrementally increased interbody dilation and distraction with the sequential placement of larger spacers by at least 1 mm in the interbody space until a larger spacer can no longer be placed. If multiple levels are being dilated, the process is typically done in a rostral to caudal fashion. Fluoroscopy is used at each incremental enlargement to ensure kyphotic correction is safely achieved. The largest spacers and/or cages capable of maintaining the kyphotic correction obtained through dilation are implanted. Polyetheretherketone (PEEK) cages are used for this technique. Anterior fusion is performed mainly with local autograft, uncommonly with allograft, or rarely with bone morphogenetic protein (BMP; in 4% of cases). In each case in this study, the utilization of local autograft within a structural PEEK cage was the surgeon's first choice for anterior fusion; however, in certain cases in which a sufficient amount of local autograft could not be obtained (as in tumor or os-



FIG. 1. Surgical instruments customized for the sequential interbody dilation technique. **A:** The size of the individual interbody spacer ranges between 5 and 65 mm. **B:** Each end of the spacer can be further enlarged by 1- or 2-mm increments for a controlled approach to dilation. Figure is available in color online only.

teomyelitis cases), allograft or BMP was used. A semi-rigid anterior plating system is then applied at the appropriate levels as previously described.¹⁹ Fixed angle screws are inserted at the bottom of the plate, and variable angle screws are used at all other levels. Neuromonitoring is performed in all cases. In cases in which posterior instrumentation and fusion are indicated, the patient undergoes a second staged procedure. In such cases, posterior fusion is a method of stabilization, and posterior osteotomies are not performed. In general, the indications for posterior spinal fusion are consecutive corpectomies of 3 or more levels, anterior fusions involving more than 3 disc levels, and/or clinical evidence of osteopenia (poor purchase of anterior screws). The presence of any of these 3 conditions warrants a second-stage posterior spinal fusion.

Figures 2 and 3 illustrate an example of how the anterior sequential interbody dilation technique is systematically performed and corrects cervical kyphosis. Figure 2A shows a cervical spine with vertebral body disease at C-4 and C-5 causing both focal and global cervical kyphotic deformity. Corpectomies of the diseased levels are performed. In addition, discectomy of the C6–7 disc is performed to aid in greater kyphosis correction (Fig. 2B). Figure 3A shows initial dilation of the corpectomy space, and slight correction of the kyphosis can be appreciated. Next, dilation with sequentially larger spacers in the corpectomy site is performed, and greater correction is obtained each time (Fig. 3B and C). Dilation of the C6–7 disc space begins, and sequential dilation is eventually performed as well (Fig. 3D). A lordotic cage is then placed into the corpectomy site to maintain cervical correction. An interbody spacer is eventually placed in the C6–7 discectomy space as well. After placement of the largest permanent spacers possible, an anterior fixation plate is implanted to hold the construct in place (Fig. 2C). As seen in Fig. 4, significant correction of cervical kyphosis can be obtained utilizing the anterior sequential interbody dilation technique.

Patient Cohort

We retrospectively identified all patients who, dur-

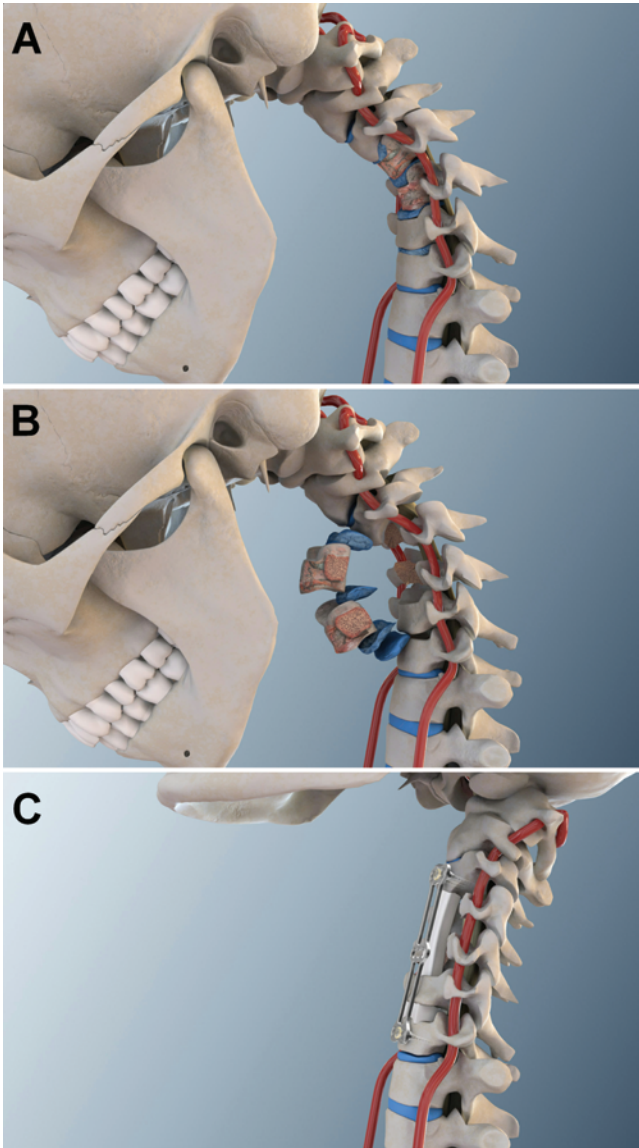


FIG. 2. Depiction of cervical kyphosis correction using the sequential interbody dilation technique. **A:** Vertebral body disease at C-4 and C-5 causing both focal and global cervical kyphotic deformity. **B:** Corpectomies of the diseased levels (C-4 and C-5) are performed. In addition, discectomy of the C6–7 disc is performed. **C:** Lordotic permanent spacers implanted in the corpectomy and discectomy spaces and secured with an anterior fixation plate. Significant kyphosis correction is obtained.

ing the period from 2006 to 2011, had undergone anterior corpectomy and/or discectomy of the cervical spine performed by the senior author (P.V.M.). Patients who had undergone anterior sequential interbody dilation were further identified for this study based on a priori inclusion and exclusion criteria. The inclusion criteria were age ≥ 18 years, anterior sequential interbody dilation, and a diagnosis of cervical kyphosis (defined as a global cervical Cobb angle $\geq 0^\circ$). Patients who had undergone posterior fusion prior to anterior decompression were excluded from the study as they had not undergone sequential interbody dilation. Indications for surgery were neurological vulnerabil-

ity due to spinal column instability, myelopathy, radiculopathy, and/or intractable pain.

Data

Demographic and baseline clinical variables were retrospectively collected through electronic medical records. These variables included age (years), sex, body mass index (kg/m^2), and comorbidities: heart disease, chronic obstructive pulmonary disease, liver disease, kidney disease, stroke, hypertension, and diabetes mellitus. Diagnoses were recorded and stratified into 4 groups: degenerative disease, trauma, metastasis/tumors, and infection/osteomyelitis. Patients treated for postsurgical kyphosis and pseudarthrosis were categorized into the degenerative groups for statistical purposes.

Primary outcomes of interest consisted of both perioperative and long-term follow-up outcomes. Perioperative data included the type of surgery used (discectomy alone, corpectomy alone, or combined corpectomy and discectomy), number of levels treated, need for posterior fusion, estimated blood loss, length of stay, 30-day complication, and mortality. Length of stay was defined as the number of days from the surgery date to the discharge date. Complication was defined as any unforeseen additional medical or surgical intervention, both intraoperatively and postoperatively. Dysphagia was specifically recorded as an outcome of interest given its importance in approaches to the anterior cervical spine. Dysphagia evaluation was performed by an inpatient speech and swallow consult team when patients reported difficulty or changes in their ability to swallow. A formal evaluation was not done for patients who did not complain of dysphagia.

Clinical follow-up outcomes of interest included cervical alignment, visual analog scale (VAS) neck pain scores,¹⁶ and Nurick grades.³¹ For each outcome entity, preoperative and follow-up outcomes were obtained. Preoperative and postoperative imaging of the cervical spine was reviewed to evaluate for alignment and curvature of the cervical spine. For measurements of cervical alignment, global Cobb angles were measured with neutral position lateral radiographs. Two lines were drawn: one parallel to the inferior endplate of the C-2 vertebra and the other parallel to the superior endplate of the C-7 vertebra. Lines perpendicular to the first 2 lines were then drawn, and the angle from the intersecting perpendicular lines provided the angle of cervical alignment as previously described.³³ The alignment angle was recorded in degrees. Alignments $\geq 0^\circ$ were defined as kyphotic. Pain was measured using a VAS (0 as no pain, and 10 as the worst pain experienced).

The secondary outcome of interest was radiographic fusion status and subsidence at a minimum 1-year follow-up. All patients were routinely evaluated with dedicated 4-view radiographs of the cervical spine: lateral neutral, lateral flexion, lateral extension, and anterior-posterior neutral. Pseudarthrosis was defined as the following features: 1) radiolucent lines/area across the fusion site or around any of the screw sites; 2) absence of bridging trabeculae across the fusion site; 3) motion between the spinous processes on flexion-extension radiographs; and 4) motion between vertebral bodies on flexion-extension.²⁰ Subsidence,

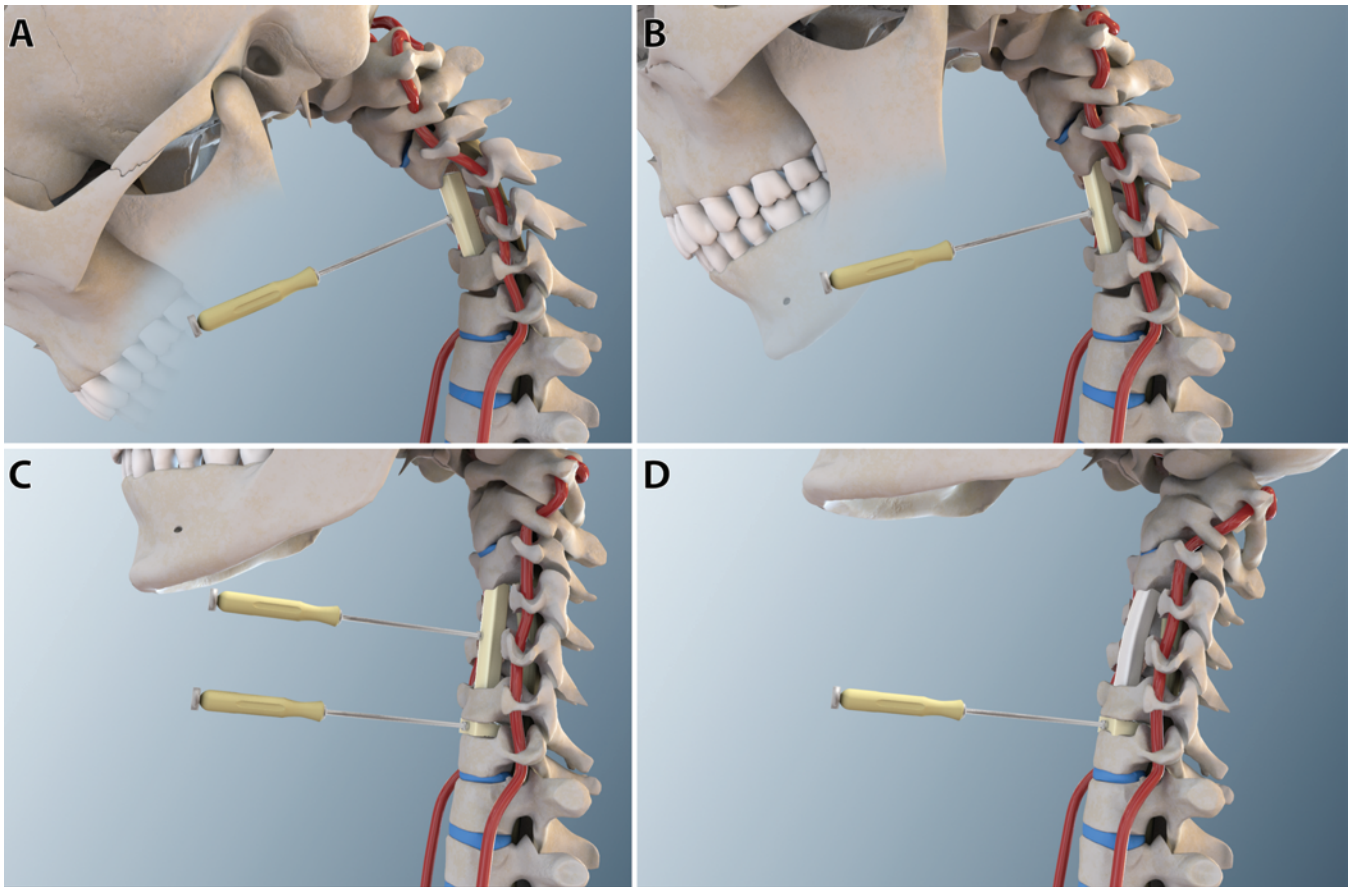


FIG. 3. Depiction of the dilation process when performing the sequential interbody dilation technique. **A:** Initial dilation of the corpectomy space and slight correction of kyphosis can be appreciated. **B and C:** Dilation with sequentially larger spacers in the corpectomy site is performed, and greater correction is obtained each time. **D:** Dilation of the C6–7 disc space begins, and sequential dilation is performed as well. A lordotic cage is placed into the corpectomy site to maintain cervical correction.

defined in this study as at least 2 mm, was measured with neutral position lateral cervical radiographs.

Statistical Analysis

Descriptive statistics were used to describe the patient cohort as a whole. The cohort was then stratified into 3 groups: mild cervical kyphosis (0° – 9°), moderate cervical kyphosis (10° – 19°), and severe kyphosis ($\geq 20^{\circ}$). Comparative analyses of preoperative and follow-up outcomes were performed for the cohort as a whole and by kyphosis severity (mild vs moderate vs severe). For continuous outcomes, a 2-tailed Student t-test was employed. For categorical outcomes, the chi-square test was used. Subgroup analyses of outcomes were performed among the different severities of kyphosis: mild, moderate, and severe. Descriptive and comparative statistics of demographics, baseline clinical variables, perioperative outcomes, and long-term follow-up outcomes among the 3 severity groups were used. For continuous outcomes, ANOVA was used, and for categorical outcomes, the chi-square test was used. A p value < 0.05 was used as the significant threshold. All statistical analysis was performed through SAS version 9.3 (SAS Institute Inc.).

Results

Demographics and Baseline Clinical Characteristics

Table 1 lists the overall demographics and baseline clinical characteristics for the cohort. One hundred patients were included in the study: 74 with mild cervical kyphosis (0° – 10°), 19 with moderate (10° – 19°), and 7 with severe ($\geq 20^{\circ}$). The mean patient age was 53.1 years, and 54.0% of the patients were male. The mean preoperative kyphosis Cobb angle was 5.7° (range 0° – 29°). Among the 100 patients, the mean VAS score in those with pain was 6.6 of 10, the mean preoperative Nurick grade was 1.4, and 58.0% had myelopathy. Most patients underwent sequential interbody dilation for degenerative disease (70.0%), whereas 11.0%, 7.0%, and 12.0% underwent surgery for trauma, tumor/metastasis, and infection/osteomyelitis, respectively. Three patients underwent surgery for postlaminectomy kyphosis. Among the 100 patients, 80.0% underwent fusion with local autograft, 16.0% with allograft, and 4.0% with BMP.

Table 1 also lists the demographics and baseline clinical variables for each group with mild, moderate, and severe cervical kyphosis who underwent anterior sequential

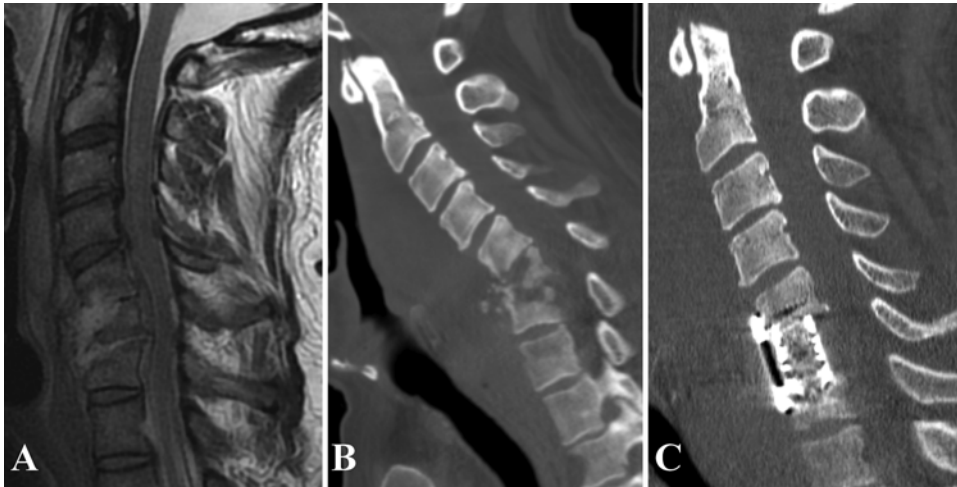


FIG. 4. Case illustration of a patient with cervical kyphosis due to osteomyelitis. **A:** Sagittal T2-weighted MR image reveals severe cervical stenosis and destruction of the vertebral bodies of C5–7 secondary to osteomyelitis. **B:** Preoperative midsagittal CT image of the cervical spine showing a C2–7 Cobb angle of 32° of kyphosis. **C:** Postoperative midsagittal CT of the cervical spine showing kyphosis correction following C-6 corpectomy and sequential interbody dilation. An interbody cage was placed between C-5 and C-7. The C2–7 Cobb angle was corrected to neutral (0°).

interbody dilation. Notably, worse kyphosis (mild vs moderate vs severe) tended to be associated with worse Nurick grades (1.3 vs 1.5 vs 1.9) and higher rates of preoperative myelopathy (54.1% vs 63.2% vs 85.7%). In addition, the distribution of treated pathology was different among the severities of kyphosis; patients with severe kyphosis had higher rates of infectious processes/osteomyelitis diagnosis. However, other than the expected variables such as preoperative Cobb angle, there were no significant differences in all other demographic and baseline clinical variables among the 3 severity groups.

Perioperative Outcomes

Table 2 summarizes and describes the perioperative (intraoperative and immediately postoperative) outcomes in patients who underwent anterior sequential interbody dilation. Among the 100 patients, 40% underwent discectomy alone, 41.0% corpectomy alone, and 19.0% combined corpectomy and discectomy. Sixteen percent underwent a second stage posterior spinal fusion. Mean estimated blood loss was 305.6 ml, and mean hospital stay was 5.2 days. Overall complication rate was 9.0%. Intraoperative and postoperative complication rates according to the number of events were 4.0% and 6.0%, respectively. There were no deaths. The mean kyphotic correction was 12.4°, and the mean postoperative global Cobb angle was 6.7° of lordosis.

When comparing perioperative outcomes among patients with mild, moderate, and severe cervical kyphosis, the only significant differences were surgery type ($p = 0.049$), postoperative alignment ($p = 0.001$), and degree of cervical kyphosis correction ($p < 0.001$; Table 2). A greater percentage of patients with moderate or severe kyphosis underwent combined corpectomy and discectomy (36.8% and 42.9%, respectively), compared to patients with mild kyphosis (9.5%). Not unexpectedly, there was a significant difference in the postoperative cervical Cobb angle among

the 3 groups. Patients with greater preoperative kyphosis had less lordotic postoperative curvatures: mild, 8.2° of lordosis; moderate, 3.6° of lordosis; and severe, 1.9° of lordosis. However, with greater preoperative kyphosis, significantly greater postoperative correction was obtained. Patients who underwent surgery for mild kyphosis had a mean kyphotic correction of 10.1°, while patients with moderate and severe kyphosis gained 17.8° and 24.7° of correction after surgery, respectively. A case example can be seen in Fig. 4.

There were no significant differences in the overall, intraoperative, and postoperative complication rates among the 3 groups ($p = 0.833$; Table 2). Specific complications and dysphagia incidence, stratified by preoperative kyphosis severity, are summarized in Table 3. Self-resolving dysphagia occurred in 12 patients (12.0%) and was relatively equally distributed in all 3 groups. One patient required a feeding tube for less than 24 hours; this patient had undergone a reoperation for an anterior 3-level surgery. Otherwise, none of the other patients required any intervention and their dysphagia resolved during their stay in the hospital.

Benefits of Anterior Sequential Interbody Dilation by Kyphosis Severity

Table 4 compares preoperative and postoperative outcomes of patients who underwent correction of cervical kyphosis using the anterior sequential interbody dilation technique, as a single cohort and stratified by kyphosis severity. There were radiographic and clinical improvements in all outcome end points (cervical alignment, neck VAS score, and Nurick grade), regardless of whether patients were considered a single cohort or stratified by preoperative kyphosis severity. As a single cohort, preoperative versus postoperative/follow-up outcomes were significantly different in regard to alignment (5.7° of kyphosis vs 6.7° of lordosis, $p < 0.001$), neck VAS score (6.2 vs 4.4, $p =$

TABLE 1. Demographic and baseline clinical characteristics overall and according to kyphotic severity

Parameter	Overall	0°–9° Kyphosis	10°–19° Kyphosis	≥20° Kyphosis	p Value
No. of patients	100	74	19	7	
Mean age (yrs)	53.1 ± 11.4	52.4 ± 12.0	54.6 ± 8.6	56.0 ± 11.1	0.607
Male (%)	54.0	54.1	52.6	57.1	0.979
Preop mean Cobb angle (degrees of kyphosis)	5.7 ± 7.3	1.9 ± 2.6	14.2 ± 2.7	22.9 ± 3.7	<0.001
Range of Cobb angles (degrees)	0–29	0–9	11–19	20–29	<0.001
Preop mean neck VAS score (1–10)	6.6 ± 2.3	6.5 ± 2.3	6.4 ± 2.9	7.7 ± 1.6	0.449
Preop mean Nurick grade (0–5)	1.4 ± 1.5	1.3 ± 1.5	1.5 ± 1.5	1.9 ± 1.6	0.584
Preop myelopathy (%)	58.0	54.1	63.2	85.7	0.236
Comorbidity (%)					
Heart disease	10.0	8.1	10.5	14.3	0.251
COPD	9.0	4.1	10.5	14.3	0.361
Liver disease	5.0	6.8	15.8	14.3	0.414
Renal disease	2.0	4.1	10.5	0.0	0.421
Stroke	2.0	2.7	0.0	0.0	0.699
Hypertension	39.0	37.8	42.1	42.9	0.922
Diabetes mellitus	14.0	13.5	15.8	14.3	0.968
Mean BMI (kg/m ²)	27.6 ± 5.7	27.2 ± 5.5	29.8 ± 6.4	25.4 ± 4.0	0.209
Diagnosis (%)					0.095
Degenerative/pseudarthrosis	70.0	77.0	78.9	57.1	
Trauma	11.0	9.5	5.3	0.0	
Tumor/metastasis	7.0	5.4	0.0	0.0	
Infection/osteomyelitis	12.0	8.1	15.8	42.9	

BMI = body mass index; COPD = chronic obstructive pulmonary disease.

0.020), and Nurick grade (1.4 vs 0.9, $p = 0.037$). In patients treated for mild cervical kyphosis, significant differences in preoperative versus postoperative/follow-up outcomes were present in regard to cervical alignment (1.9° of kyphosis vs 8.2° of lordosis, $p < 0.001$), neck VAS score (6.5 vs 4.2, $p = 0.027$), and Nurick grade (1.3 vs 0.8, $p = 0.029$). In patients treated for moderate cervical kyphosis, signifi-

cant differences in preoperative versus postoperative/follow-up outcomes were present in regard to cervical alignment (14.2° of kyphosis vs 3.6° of lordosis, $p < 0.001$) but were not statistically significant for neck VAS score (6.4 vs 4.7, $p = 0.073$) and Nurick grade (1.5 vs 1.3, $p = 0.351$). In patients treated for severe cervical kyphosis, significant differences in preoperative versus postoperative/follow-

TABLE 2. Perioperative and radiographic outcomes of anterior sequential interbody dilation among patients with different severities of cervical kyphosis

Parameter	Overall	0°–9° Kyphosis	10°–19° Kyphosis	≥20° Kyphosis	p Value
Surgery type (%)					0.049
Discectomy alone	40.0	44.6	31.6	14.3	
Corpectomy alone	41.0	39.2	31.6	42.9	
Corpectomy w/ discectomy	19.0	9.5	36.8	42.9	
Posterior fusion (%)	16.0	17.6	10.5	14.3	0.751
Mean estimated blood loss (ml)	305.6 ± 366.8	290.1 ± 392.1	312.6 ± 285.7	450.0 ± 278.4	0.547
Length of stay (days)	5.2 ± 5.2	4.8 ± 5.4	5.9 ± 4.3	7.9 ± 5.4	0.279
Complication (%)					0.833
Overall	9.0	8.1	10.5	14.3	
Intraop	4.0	1.4	10.5	14.3	
Postop	6.0	6.8	5.3	0.0	
Mortality (%)	0.0	0.0	0.0	0.0	NA
Postop Cobb angle (degrees of lordosis)	6.7 ± 7.3	8.2 ± 7.2	3.6 ± 6.6	1.9 ± 3.9	0.001
Kyphotic correction (degrees)	12.4 ± 8.0	10.1 ± 7.2	17.8 ± 6.8	24.7 ± 2.7	<0.001

NA = not applicable.

TABLE 3. Complication and dysphagia according to severity of kyphosis

Parameter	0°–9° Kyphosis	10°–20° Kyphosis	≥20° Kyphosis
Complication (no. of patients)	Hardware failure, infection (1)	Durotomy (1)	Durotomy (1)
	Durotomy (1)	Redone corpectomy, DVT (1)	
	Rt wrist & hand drop w/ some proximal weakness (1)		
	Rt side vocal cord paralysis (1)		
	C-5 palsy (1)		
	Renal failure (1)		
Dysphagia (no. of patients)	Self-resolving dysphagia (8)	Self-resolving dysphagia (3)	Dysphagia requiring feeding tube (1)*

DVT = deep vein thrombosis.

* One patient had a feeding tube placed for less than 24 hours. A multilevel anterior approach was redone in this patient.

up outcomes were present in regard to cervical alignment (22.9° of kyphosis vs 1.9° lordosis, $p < 0.001$) but were not statistically significant for neck VAS score (7.7 vs 5.0, $p = 0.090$) and Nurick grade (1.9 vs 0.8, $p = 0.129$).

Long-Term Outcomes

Table 5 summarizes and describes the long-term follow-up outcomes of all patients who underwent anterior sequential interbody dilation and compares patients by preoperative kyphotic severity. Among the 100 patients, 86 (86.0%); 65 patients with mild preoperative cervical kyphosis, 16 with moderate, and 5 with severe) had a mean clinical follow-up of 26.8 months. The long-term mean neck VAS score was 3.4 and mean Nurick grade was 0.9. The overall reoperation rate was 4.7%. One patient underwent reoperation at the same site for tumor recurrence. The other 3 patients had hardware failure and/or pseudarthrosis requiring reoperation. Eighty patients (59 with mild preoperative cervical kyphosis, 16 with moderate, and 5

with severe) had adequate cervical spine radiographs for at least 1 year after surgery to assess for fusion; the pseudarthrosis rate in these patients was 6.3%. When patients were stratified by kyphosis severity, there were no significant differences in all follow-up outcomes (neck VAS score, Nurick grade, reoperation rate, and pseudarthrosis rate). Among the 80 patients with at least 1 year of radiographic follow-up, 13.8% showed evidence of subsidence greater than 2 mm. The extent of subsidence ranged from 2.0 to 5.2 mm, with a mean of 3.7 mm of subsidence. There was no significant difference in subsidence rates among the 3 severity groups (mild 15.3% vs moderate 12.5% vs severe 0.0%, $p = 0.628$).

Factors Affecting the Degree of Correction

Table 6 shows the relation between potential factors associated with the extent of cervical kyphosis correction when using the anterior sequential interbody dilation technique. Posterior fusion was not associated with greater corrective ability using this technique, as we used supplemental posterior fusion as an additional method of stabilizing the spine and did not perform posterior osteotomies ($p = 0.762$). Rather, it seems that using corpectomy with discectomy ($p < 0.001$) and addressing more levels ($p < 0.001$) allows greater cervical kyphosis correction. A mean of 32.0° of correction was obtained when 5 levels were surgically treated.

Discussion

The extent of and the ability to surgically correct cervical kyphosis have varied widely, according to reports in the literature.⁹ This variability is explained by the fact that the extent of cervical kyphosis correction depends on a multitude of factors, including the surgeon's plan to correct the kyphosis, the surgical techniques used, and patient characteristics (for example, diagnosis, severity of kyphosis, and comorbidities). In past studies evaluating the surgical correction of cervical kyphosis, the extent of cervical kyphosis correction seems to vary based on different techniques and approaches: 11°–32° with an anterior approach,^{10,15,41,42,45} 23°–54° with a posterior approach,^{1,5,12,22,24,27,38,43} and 24°–61° with a combined ap-

TABLE 4. Benefits of cervical kyphosis correction with anterior sequential interbody dilation

Parameter	Preop	Postop/FU	p Value
Cobb angle (degrees)			
All patients	5.7 ± 7.3	6.7 ± 7.3	<0.001
0°–9° kyphosis	1.9 ± 2.6	8.2 ± 7.2	<0.001
10°–19° kyphosis	14.2 ± 2.7	3.6 ± 6.6	<0.001
≥20° kyphosis	22.9 ± 3.7	1.9 ± 3.9	<0.001
VAS neck score (1–10)			
All patients	6.2 ± 2.6	4.4 ± 2.0	0.020
0°–9° kyphosis	6.5 ± 2.3	4.2 ± 2.1	0.027
10°–19° kyphosis	6.4 ± 2.9	4.7 ± 1.5	0.073
≥20° kyphosis	7.7 ± 1.6	5.0 ± 2.8	0.090
Nurick grade (0–5)			
All patients	1.4 ± 1.5	0.9 ± 1.5	0.037
0°–9° kyphosis	1.3 ± 1.5	0.8 ± 1.4	0.029
10°–19° kyphosis	1.5 ± 1.5	1.3 ± 1.8	0.351
≥20° kyphosis	1.9 ± 1.6	0.8 ± 1.6	0.129

FU = follow-up.

TABLE 5. Outcomes following anterior sequential interbody dilation among patients with different severities of cervical kyphosis

Parameter	Overall	0°–9° Kyphosis	10°–19° Kyphosis	≥20° Kyphosis	p Value
Mean length of FU (mos)*	26.8	25.5 ± 17.0	30.3 ± 20.1	31.8 ± 22.9	0.518
FU mean VAS neck score (1–10)*	3.4 ± 2.0	4.2 ± 2.1	4.7 ± 1.5	5.0 ± 2.8	0.618
FU mean Nurick grade (0–5)*	0.9 ± 1.5	0.8 ± 1.4	1.3 ± 1.8	0.8 ± 1.6	0.466
Reoperation (%)*	4.7	4.6	6.3	0.0	0.336
Subsidence (%)†	13.8	15.3	12.5	0.0	0.628
Pseudarthrosis (%)†	6.3	6.8	6.3	0.0	0.362

* 86.0% of patients had clinical follow-up: 65 with mild kyphosis, 16 with moderate, and 5 with severe.

† 80.0% of patients had minimum 1-year radiographic follow-up: 59 with mild kyphosis, 16 with moderate, and 5 with severe.

proach.^{29,30,34} There is a trend for greater correction when a posterior or combined anteroposterior approach is taken. A majority of patients in the posterior-only and combined approach studies had severe preoperative kyphosis and were treated for pathological processes (such as ankylosing spondylitis) that required radical methods of kyphosis correction. With a posterior approach, particularly a combined anteroposterior approach, variations of posteriorly based osteotomies were used.³ While osteotomies are extremely powerful techniques, they are not ideal in patients with mainly anterior thecal sac compression who do not require posterior fusion or in patients who cannot tolerate a prone position. Therefore, utilizing an anterior approach to cervical kyphosis correction may be beneficial.

Standard cervical corpectomy and discectomy can intrinsically offer increased axial height and curvature correction with the placement of large spacers, but without purposeful dilation and distraction of the interbody space, the extent of curvature correction can be variable.^{7,25,32} The reported extent of global cervical curvature correction from a standard single-level corpectomy ranges from –1.0° to 5.0°, and from a 2-level discectomy it ranges from 1.6° to 8.0°.^{7,25,32} With the sequential interbody dilation technique, 1-level dilation resulted in a mean of almost 9° of global kyphosis correction (this is greater than a standard 2-level discectomy). More specifically, a 1-level corpectomy with sequential interbody dilation resulted in a mean correction of 10.0°, and a 2-level discectomy with sequential interbody dilation resulted in a mean correction of 11.3°. Mean cervical kyphosis correction continued to increase, with up to 5 levels obtaining 30° of correction. Given the magnitude of correction that the sequential interbody dilation techniques offers, patients with mild kyphosis who undergo even a 1- or 2-level anterior decompression can obtain adequate kyphosis correction via a single-stage approach if needed.

Most studies dedicated to reviewing anterior approaches to cervical kyphosis correction are small, and the extent of correction varies in those studies. The earliest case series of a primarily anterior approach to cervical kyphosis correction was published by Zdeblick and Bohlman in 1989.⁴⁵ They treated 14 patients with severe cervical kyphosis and myelopathy by using multilevel anterior corpectomy and strut grafting. A reduction from a mean of 45° of kyphosis to a mean of 13° of kyphosis was obtained (mean of 32° corrected).⁴⁵ About a decade later, Herman and Sonntag retrospectively reviewed their experience surgically managing

20 patients with postlaminectomy kyphosis.¹⁵ All patients underwent external axial traction as well as corpectomy of at least 2 levels (mean of 3.8 levels) for kyphosis correction. In their cohort, the authors were able to obtain a mean correction of 25° (mean preoperative kyphosis of 38° and mean postoperative kyphosis of 13°). More recently, Steinmetz et al. performed a retrospective study of 12 patients who had undergone a distraction technique during anterior cervical decompression to correct for cervical kyphosis.⁴² In their surgical technique, patients were positioned supine with the head in a neutral position or slight extension. They used corpectomy, discectomy, or corpectomy with discectomy for anterior decompression. To correct kyphosis, they placed distraction posts in a convergent manner, and with straightening of the posts (to the point where the posts are parallel to one another) cervical kyphosis was corrected. Eleven of the 12 patients attained lordosis following surgery, and the mean kyphosis correction was 19° (mean preoperative kyphosis of 13° and mean postoperative lordosis of 6°). In a retrospective study of 28 patients with kyphosis and myelopathy, Ferch et al. performed an anterior decompressive approach.¹⁰ Mean correction was 11°. The preoperative mean regional kyphotic angle was

TABLE 6. Factors associated with the degree of cervical kyphosis correction using the anterior sequential interbody dilation technique

Parameter	Correction (°)	p Value
Surgery type		<0.001
Discectomy alone	9.5 ± 6.5	
Corpectomy alone	12.1 ± 7.4	
Corpectomy & discectomy	19.3 ± 8.3	
Posterior fusion		0.762
Yes	13.0 ± 8.5	
No	12.3 ± 5.2	
No. of levels*		<0.001
1	8.8 ± 6.2	
2	12.3 ± 6.4	
3	19.5 ± 9.3	
4	20.8 ± 4.9	
5	32.0 ± 1.4	

* The number of levels treated depends on how many levels were treated with either corpectomy or discectomy and subsequent sequential interbody dilation.

10°, and the postoperative mean regional kyphotic angle was -1° (lordosis). Similarly, in a study of 15 patients who underwent anterior reconstruction for cervical kyphosis, Song et al. obtained a mean of 13° of correction.⁴¹

In the present study, the mean correction for all patients was 12.4°. In patients with moderate and severe kyphosis preoperatively, the mean postoperative correction was 17.8° and 24.7°, respectively.^{15,45} The latter 2 categories of patients had similar severities of preoperative kyphosis compared to patients included in prior studies and underwent similar extents of kyphosis correction. Patients with more severe kyphosis needed a greater extent of correction and therefore underwent multilevel sequential dilation to maximize correction. We found that the anterior sequential interbody dilation technique is an effective approach to obtain a variety of degrees of cervical kyphosis correction.

These findings demonstrate not only that adequate kyphosis correction can be achieved using the sequential interbody dilation technique, but also that the technique is associated with low morbidity. Overall, the 30-day complication rate when utilizing the technique was low (9.0%), and there was no difference in complication rates among patients with different severities of preoperative kyphosis. Our complication rate is low compared with those reported in the literature; reported complication rates following surgical correction of cervical kyphosis with the anterior approach range from 8% to 30%,^{10,13,15,42,45} with the posterior approach, from 13% to 67%,^{1,5,12,13,27,38,43} and with the combined anteroposterior approach, from 22% to 44%.^{13,29,30,34} In fact, compared with the published complication rates of standard corpectomy and discectomy, our complication rates remain within the lower end of those ranges (10%–21%).^{6,7,11,26} These findings suggest that the anterior sequential interbody dilation technique has a risk profile similar to those in previously published anterior surgical series.

Dysphagia is a common complication following anterior approaches to the cervical spine.³⁶ The reported incidence of dysphagia ranges widely throughout the literature, but rates as high as 50% at 1 month have been reported.^{4,39,46} Our dysphagia rate of 12.0% is comparable to those in other reports. Except in 1 patient, all of our patients' dysphagia began to resolve during the hospital stay without intervention.

As in prior studies of kyphosis correction through an anterior approach, our cohort benefited in all long-term clinical outcome end points: pain, neurological status, and function.^{10,15,42,45} And this continued to be true for all long-term outcomes in a subgroup analysis of patients with mild preoperative kyphosis. While there were fewer patients in the moderate and severe cohorts, it appeared that patients with moderate kyphosis benefited more in regard to pain and that patients with severe kyphosis benefited more from a neurological standpoint. In the patients with moderate kyphosis, pain was present in almost 95% of them; at follow-up, about half of those patients were pain free. In patients with severe kyphosis, 6 of the 7 patients presented with myelopathy, but only 1 remained myelopathic at follow-up. This result may suggest that patients benefit differently, depending on the severity of preoperative kyphosis and their associated presenting signs and symptoms.

There are advantages and disadvantages to the anterior sequential interbody dilation technique. Some of the most prominent advantages are low morbidity, the ability to decompress the ventral thecal sac, the efficacy for all severities of kyphosis, lack of reliance on posterior fusion, high fusion rates, and low reoperation rates (indicating exceptional durability). The 16 patients who underwent posterior instrumentation and fusion did not undergo posterior osteotomies for correction. In general, those who underwent supplemental posterior fusion underwent more than 2 consecutive level corpectomies, more than 3 level anterior fusions, or had osteoporosis.

The limitations of this technique are the need for custom surgical equipment that may not be accessible to all surgeons and the experience required to perform the technique. Experience is important when deciding when sufficient dilation has been performed because it is based on surgeon perception and feel. Additional conceptual limitations to the technique exist as well. First, there may be a theoretical concern about the risk of axial cord tension with overcorrection. However, among our cohort we did not have any patients who experienced a neurological deficit due to the effects of ventral cervical distraction. This type of injury is rare even in the literature.⁴² To further mitigate the risk of neurological injury, we used intraoperative neuromonitoring; more specifically, we used transcranial motor evoked potentials.^{8,22,35} The second concern with sequential interbody dilation and distraction is a theoretical increased risk for subsidence due to larger forces between the interface of the bony endplates and cage footplates as dilation is performed. The observed subsidence rates in this study fall within the lower range of previously reported rates following anterior cervical corpectomy and discectomy, even when utilizing a sensitive threshold of 2 mm of total subsidence. In addition, mean subsidence was only 3.7 mm. Over the past years, our experience with PEEK cages has been satisfactory, and clinically significant subsidence is a rare event given the similar modulus of elasticity between PEEK and bone. Metal cages such as expandable ones are more likely associated with a greater risk for and extent of subsidence.²³ The risk for subsidence is multifactorial: degree of osteopenia and/or osteoporosis, cage type (higher risk of subsidence with expandable cages compared with static cages such as PEEK ones), and footplate/vertebral body ratio.^{23,44} Expandable cages can be theoretically used to distract interbody spaces, but there are significant limitations with their design. With expandable cages, the ability to control distraction is not as fine-tuned as with 1-mm interbody dilation trials in the anterior sequential interbody dilation technique. Finally, expandable cages have limited space to place intracompartmental bone grafts.

One of the limitations associated with the retrospective nature of our study is the lack of the routine use of CT scanning to evaluate for pseudarthrosis. Patients who have an unremarkable postoperative course and do well from surgery do not routinely undergo CT scanning at our institution. All patients who returned for follow-up did have standardized cervical spine 4-view radiography studies, including dynamic radiographs, to assess for pseudarthrosis as suggested in the cervical guidelines.²⁰

Conclusions

The surgical treatment of cervical kyphosis can be technically difficult, especially in severe cases when osteotomies are used. Nonetheless, there is an accumulation of evidence that kyphosis correction is important in obtaining normal sagittal balance and offers improved neurological and pain outcomes. Data in this study suggest that the anterior sequential interbody dilation technique can offer effective kyphosis correction and can be safely performed. The technique offers a single operative procedure that combines anterior decompression, reduction, fusion, and immediate internal fixation, with the use of anterior plating techniques. With this technique, the degree of cervical correction is well controlled and can be tailored to the amount of correction a patient requires. In addition, overall complication rates and reoperation rates are low (9.0% and 4.7%, respectively), and patients benefit significantly in regard to long-term outcomes (pain and neurological function). Therefore, the anterior sequential interbody dilation technique should be considered as an alternative procedure for cervical kyphosis correction in patients who undergo anterior decompression.

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Author Contributions

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Supplemental Information

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Correspondence

Praveen V. Mummaneni, Department of Neurological Surgery, University of California, San Francisco, 505 Parnassus Ave., Rm. M779, San Francisco, CA 94143-0112. email: vmum@aol.com.