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The Influence of Lordotic cages on creating Sagittal Balance in the CMIS treatment of Adult Spinal Deformity

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Abstract

Background

CMIS techniques are heavily dependent on placement of lateral interbody cages. Cages with an increased lordotic angle are being advocated to improve segmental lordosis and SVA. We assessed the segmental lordosis achieved with the individual cages. We further studied three variables and the effect each had on segmental lordosis: the lordosis angle of the cage, the position of the cage in the intervertebral space, and the level that it has been placed.

Methods

This is a retrospective study of 66 consecutive patients who underwent lateral interbody fusion using lordotic cages as part of CMIS correction of scoliosis from June 2012 to January 2016. Standing radiographs at pre op and 6-week follow-up were reviewed to identify the position of the cage in the intervertebral space and the amount of segmental lordosis achieved.

Results

A total of 224 cages were placed. The 6°, 10°, 12°, and 20° cages achieved a mean segmental lordosis of 9.00°, 13.09°, 13.23°, and 18.32°, respectively ($P < .05$). Additionally, cages placed in the anterior, middle, and posterior 3rd of the disk space produced 13.02°, 11.47°, and 8.23° of lordosis, respectively ($P < .05$). Stratifying by level, cages placed at T12-L1, L1-2, L2-3, L3-4, and L4-5 translated to mean segmental lordotic values of 8.43°, 10.02°, 11.38°, 12.91°, and 14.58°, respectively ($P < .05$).

Conclusions

The angle of the cage had an impact on segmental lordosis. Achieved segmental lordosis was notably more when the cage was placed in lower lumbar levels. Additionally, cages placed in the posterior 3rd of the intervertebral space had significantly worse segmental lordosis compared to those placed in the anterior or middle 3rd. Our study shows that an average delta change of 8.03° can be achieved with 12° cages and this when done at each subsequent level results in a progressive harmonious creation of lordosis.

IRB approval was obtained for this study.

MINIMALLY INVASIVE SURGERY
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Introduction

Circumferential Minimally Invasive Spinal (CMIS) correction of adult spinal deformity (ASD) has emerged as a novel, less-invasive alternative to traditional open surgery. There are many advantages to a minimally invasive surgical (MIS) approach including less blood loss, lower complication rates, and improved cosmesis.[1-10] Nonetheless, widespread adoption of CMIS correction has been limited by a steep learning curve[11,12] and the relative inability to achieve a robust sagittal alignment.[13-17]

The standard open approach for correction of ASD relies on posterior osteotomies to accomplish adequate lordosis.[18-23] This relatively invasive solution requires broad exposure of the posterior anatomy and widespread tissue destruction.[24-27] Despite its invasiveness, open correction can achieve superior sagittal balance as compared to early reports of CMIS.[13-17]

As a result, there has been a bias amongst surgeons to reserve CMIS correction for cases with minimal sagittal deformity.[16,28] Considering the importance of sagittal balance on functional outcome, CMIS correction needs ways to attain greater correction in the sagittal plane.[29-33]

Novel innovations have been introduced to tackle the problem of sagittal alignment. These include anterior column realignment (ACR),[34-41] rod contouring,[42,43] and the utilization of hyperlordotic cages.[34,38] These are designed to maximize the sagittal correction achievable with CMIS techniques while maintaining the many benefits that MIS operations offer. Although they show promise, the efficacy of these new approaches has not been well studied.

Our analysis focused specifically on the use of hyperlordotic cages. It is known that angled cages improve lordosis and subsequent spino-pelvic harmony. However, the influence of specific cage factors has not been well studied. We focused on 3 parameters of these cages: (1) angle of the cage, (2) relative position in the disc space, and (3) the spinal level of cage placement. We quantified the gains in sagittal alignment using hyperlordotic cages and looked at the influence of these three parameters.

Materials and methods

This is a single center study from a prospective database of patients who underwent CMIS correction for ASD (Cobb angle > 20 degrees or SVA > 50 mm or PI/LL mismatch > 10) by the senior author from June 2012 to January 2016. Internal Review Board approval was obtained.

Only patients with 2 or more levels fused were included. Indications for surgery included symptomatic back and/or leg pain attributed to ASD that was unresponsive to conservative measures. All patients were treated with MIS strategies using MIS Lateral Lumbar Interbody Fusion (LLIF) with percutaneous pedicle screw and rod instrumentation. Details of our techniques have been extensively published before.[2,5,6,44-52] Patients were instrumented at each level with either a 6°, 10°, 12°, or 20° hyperlordotic cages. At L4-5 and L3-4, all patients had a 12° cage placed. At L2-3, patients had either a 6°, 10° or 12° degree cage based on the amount of sagittal correction needed. At L1-2 and T12-L1, usually a 6° or 10° cage was used. A few patients had ALL release and a 20° cage was used. At L5-S1 an ALIF was done. Patients who underwent posterior osteotomies were excluded from the study. 66 patients were identified who met the inclusion criteria.

Radiographic measures were assessed using full-length 36-inch radiographs at the time of enrollment and 6-week follow-up. Few patients had inadequate or unavailable 6-week follow-up, so earliest follow-up imaging was used. Segmental lordosis at each level was defined as the angle created by the upper end plate of the lower vertebrae and the lower end plate of the upper vertebrae. Regional lumbar lordosis was measured as the Cobb angle between the upper end plate of L1 and the upper end plate of S1.

The position of the implant was decided by dividing the inferior vertebral body into three parts and the position was determined as to what third of the body the prosthesis predominantly occupied.

Statistical Methods

Lumbar lordosis and segmental lordosis at pre op and post op for the entire patient pool was compared using T-testing. In 3 separate analyses, the data was stratified based on (1) lordotic angle of the cage, (2) relative position in the disc space, and (3) the spinal level of cage placement. For each of these parameters, mean pre op, post op, and delta segmental lordosis was calculated. Pre op values were compared to post op values using T-testing. Mean post op segmental lordosis was compared between groups in each parameter using ANOVA analysis. Statistical analyses were 2-sided and $p < 0.05$ was considered statistically significant. All statistical analysis was conducted using SPSS (Version 22).

Results

Table 1 shows demographic information. For the 66 patients who met inclusion criteria, the mean age was 66.08 (SD 8.22, Range 48-84). The mean number of levels fused with LLIF was 3.39 (SD 0.99, Range 2-5). A total of 224 cages were placed. Table 2 stratifies the total number of cages based on lordotic angle, relative position in the disc space, and spinal level of placement.

For the total patient pool, mean lumbar lordosis at pre op and at immediate post op was 39.43° and 49.32°, respectively. Table 3 shows mean segmental lordosis and lumbar lordosis figures for all cages placed in the study.

Placement of 6°, 10°, 12°, and 20° cages yielded post op segmental lordotic angles of 9.00°, 13.09°, 13.23°, and 18.32°, respectively. Anteriorly, middle, and posteriorly placed cages produced 13.02°, 11.47°, and 8.23° of post op lordosis, respectively. Instrumentation at T12-L1, L1-L2, L2-L3, L3-L4, and L4-L5 translated to mean post op segmental lordotic values of 8.43°, 10.02°, 11.38°, 12.91°, and 14.58°, respectively. The mean post op values were statistically significant between all groups using ANOVA analysis. Moreover, all mean post op values were statistically significant compared to pre op figures. Tables 4-6 stratify pre op and post op segmental lordosis based on lordotic angle (Table 4), relative position in the disc space (Table 5), and spinal level of placement (Table 6). Figures reflect preoperative (Figure 1), intraoperative (Figure 2), and postoperative (Figure 3) radiographs of a patient who underwent CMIS correction with 2-level cage placement.

Table 1. Demographic information.

Number of Patients	66
Mean Age	66.08 (48-84)
Total LLIF Levels	224
Mean Levels	3.39

Table 2. Total number of cages stratified by lordosis, position, and spinal level.

Lordosis	Cages	Position	Cages	Spinal Level	Cages
6°	58	Anterior	111	T12-L1	14
10°	31	Middle	110	L1-2	36
12°	130	Posterior	3	L2-3	56
20°	5			L3-4	64
				L4-5	54
Total	224		224		224

Table 3. Mean Segmental Lordosis and Global Lumbar Lordosis for Entire Cohort.

	Preoperative	Postoperative	Delta	P value
Mean Segmental Lordosis	4.23	12.17	7.95	.000*
Mean Lumbar Lordosis	39.43	49.32	10.05	.000*

Discussion

Achieving adequate correction in the sagittal plane has often been quoted as the most significant shortcoming of the CMIS philosophy; all the more important considering sagittal imbalance is the primary driver of clinical outcome in ASD patients.[29-33] Mechanistically, excessive stress secondary to imbalance in the sagittal plane exhausts the posterior spinal muscles, translating to lower back pain.[34,53,54] We propose 3 augmenting strategies for CMIS correction of sagittal balance using hyperlordotic cages: (1) utilizing appropriately angled cages, (2) anterior positioning of the implant in the disc space, and (3) concentrating

Table 4. Mean segmental lordosis grouped by lordotic angle of cage.

	Mean Segmental Lordosis			
Lordosis	Preoperative	Postoperative	Delta	P value
6°	1.74	9.00 (4.09-20.26, SD 3.64)	7.26	.000*
10°	5.00	13.09 (6.07-20.57, SD 3.12)	8.08	.000*
12°	5.18	13.23 (4.79-25.38, SD 3.38)	8.03	.000*
20°	4.10	18.23 (16.77-19.75, SD 1.28)	14.22	.000*
ANOVA Postoperative between groups:		.000*		

Table 5. Mean segmental lordosis grouped by relative position of cage in disc space.

	Mean Segmental Lordosis			
Position	Preoperative	Postoperative	Delta	P value
Anterior	4.65	13.02 (4.79-25.38, SD 3.58)	8.36	.000*
Middle	3.89	11.47 (4.09-19.75, SD 4.12)	7.58	.000*
Posterior	1.52	8.23 (5.96-11.43, SD 2.85)	6.71	.036*
ANOVA Postoperative between groups:		.000*		

on lower level lumbar cage placement.

Standard open procedures rely on posterior osteotomies to achieve alignment in the sagittal plane. In order of increasing invasiveness, these include Smith-Peterson Osteotomy (SPO), Pedicle Subtraction Osteotomy (PSO), and Vertebral Column Resection (VCR). SPO is a relatively safe and technically easy procedure that provides about 10° of lordosis per level.[55] Nonetheless, complications including rupture of the great vessels have been reported. PSO and VCR are more difficult techniques, though tried and effective means of achieving sagittal balance. They can achieve 25°-40°[19,20,56] and upwards of 45°[57] of lordosis per level, respectively. However they are associated with significant morbidity and high-risk complications.[58-63]

In an early study, Deukmedjian et al. reported on the feasibility of a minimally invasive lateral retroperitoneal transpsoas approach to anterior longitudinal ligament (ALL) release as an alternative to posterior osteotomies. Seven patients undergoing ALL release resulted in a mean increase in segmental lordosis and global lumbar lordosis of 10.2° and 25°, respectively.[40]

In a retrospective case series of 17 patients who underwent anterior column realignment (ACR) by Akbarnia et al., the mean motion segment angle improved 35° from pre op to post op. Of note, 15 of the patients had an SPO at the ACR level. Compared to posterior-based approaches, the study showed similar correction capacity including segmental mea-

Table 6. Mean segmental lordosis grouped by spinal level of cage placement.

	Mean Segmental Lordosis			
Level	Preoperative	Postoperative	Delta	P value
T12-L1	.98	8.43 (4.09-15.93, SD 2.92)	7.44	.000*
L1-2	1.91	10.02 (4.42-20.26, SD 3.99)	8.12	.000*
L2-3	3.67	11.38 (4.79-18.87, SD 3.74)	7.71	.000*
L3-4	4.82	12.91 (5.96-25.38, SD 3.60)	8.08	.000*
L4-5	6.53	14.58 (6.92-20.79, SD 2.98)	8.05	.000*
ANOVA Postoperative between groups:		.000*		

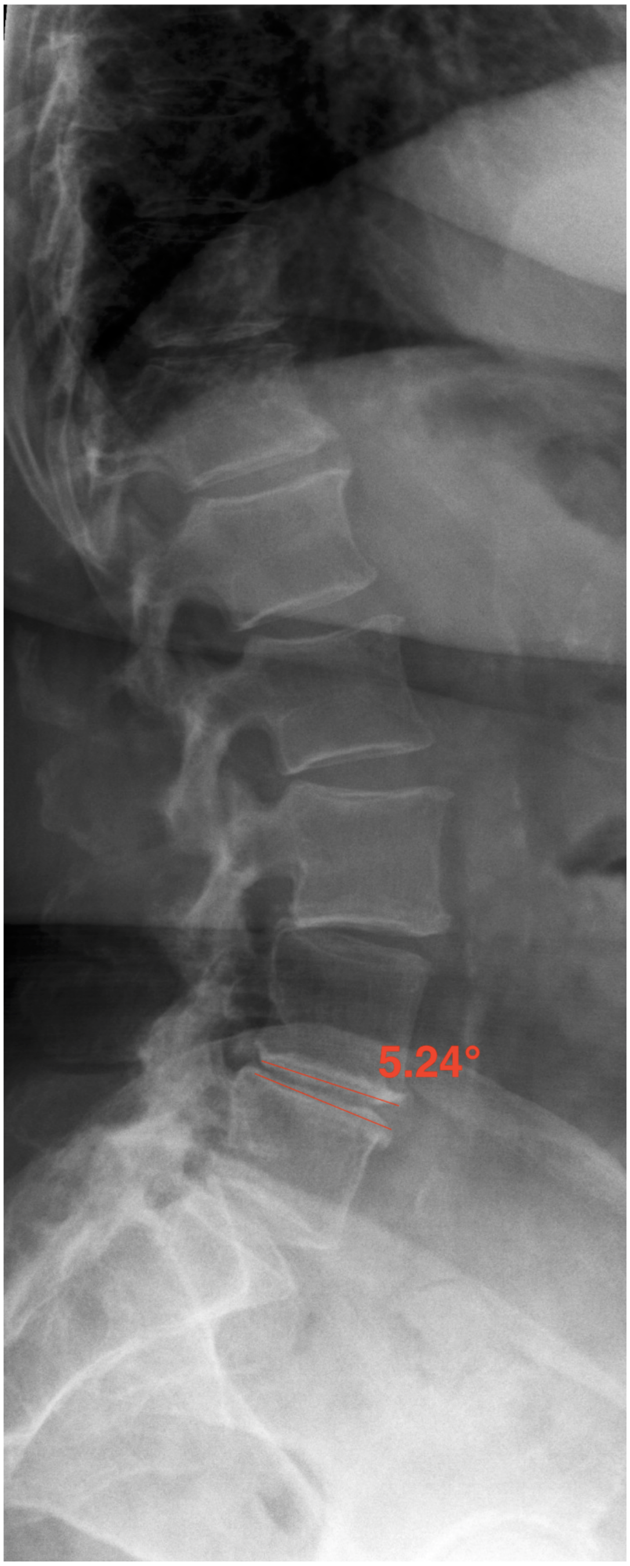

Fig. 1. Preoperative sagittal image of lumbar spine before CMIS correction with hyperlordotic cages.

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sures, lumbar lordosis, and sagittal balance.[37]

A cadaveric study by Uribe et al. looked at varying degrees of lordotic implants on segmental lordosis using the minimally invasive lateral retroperitoneal trans-psoas approach (XLIF). After ALL release, without posterior osteotomies, post-implantation increases in segmental lordosis using 10°, 20°, and 30° cages were 4.1°, 9.5°, and 11.6°, respectively. Mean lumbar lordosis was 33.7°, 43.8°, and 50.3°, respectively.[38]

In a review of 40 patients, Sembrano et al compared 10° lordotic cages to non-lordotic cages. The group found a significant increase in segmental lordosis at the operative level using 10° cages. However, overall lumbar lordosis remained unchanged.

Anand et al.[17] quantified the ceiling effects of CMIS correction in a prior study that included 0° and 6° cages done prior to 2011. In a retrospective study of 90 patients who underwent CMIS correction without osteotomies or ALL release, the study showed an SVA correction ceiling effect of 89 mm. Osteotomies were considered only when pre op SVA was greater than 100 mm and substantial lumbar lordosis was needed.

In this study, using 6°, 10°, 12°, and 20° cages yielded post op segmental lordotic angles of 9.00°, 13.09°, 13.23°, and 18.32°, respectively. The data demonstrates a positive trend between instrumented cage

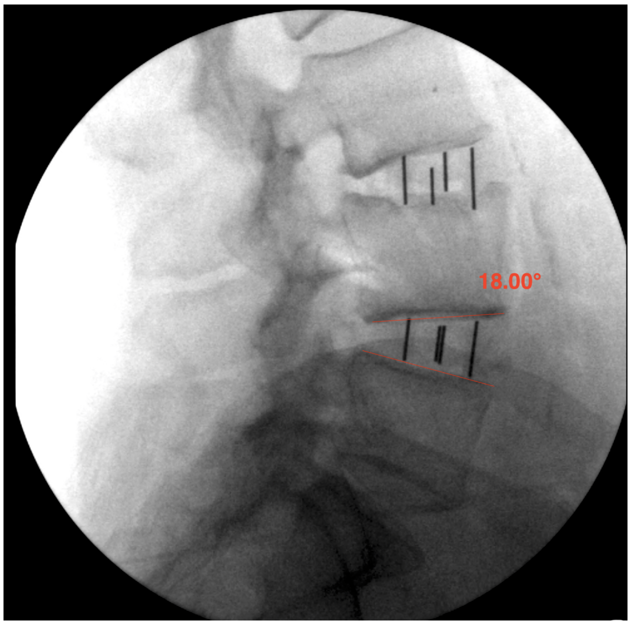

Fig. 2. Intraoperative fluoroscopy after placement of 12° cages at L3-4 and L4-5.

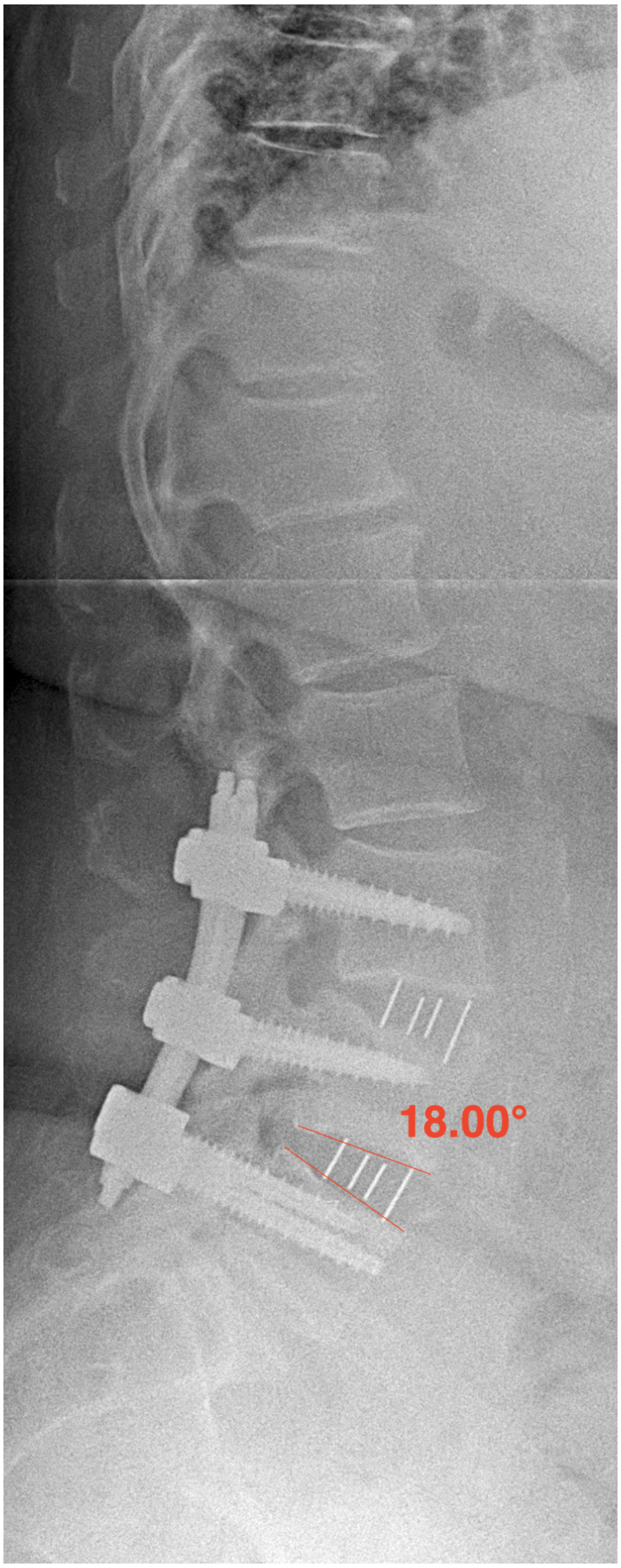

Fig. 3. Postoperative sagittal image of lumbar spine after 2-level cage placement. Segmental lordosis of 18° was achieved at L4-5.

angles and post op lordotic gains. Compared to each other, the post op lordotic angles are statistically significant ($p < .05$). Considering the findings, surgeons may elect to use increasingly lordotic cages when robust sagittal alignment is required. Nonetheless, there are important limitations in cage angle to consider. Extreme angled lordotic cages, including 20° and 30° cages, introduce certain mechanistic challenges by interrupting the natural curvature of the spine, point loading the endplate, and compromising contact between the cage-bone interphase.[34] Moreover, gains in segmental lordosis reach a threshold as higher-level implants are eventually limited by the posterior elements of the vertebrae. Mirroring this point, the 20° cage in our study produced only 18.32° of lordosis post op. This is the only cage in our analysis that yielded a post op segmental measure shy of its known lordotic angle.

Our study shows that a delta change on an average of 8.03° (Table 4) can be achieved with the 12° cages and this when done at each subsequent level results in a progressive harmonious creation of lordosis. We propose the 12° cage as the optimal compromise between lordotic gain and mechanistic challenge. When possible, placing the 12° cage anteriorly achieves significant lordosis that can be augmented beyond its known angle especially at L4-5 and L3-4. More importantly, it avoids the drawbacks of higher level 20° and 30° instrumentation such as anterior point loading. When considering multi-level fusions that require extreme correction in the sagittal plane we avoid fusion with exceedingly lordotic implants but rather perform multi-level instrumentation with the use of 12° cages to help achieve a harmonious correction that follows the natural curvature of the spine. Figures show a Circumferential MIS correction at preoperative (Figure 4) and postoperative (Figure 5) using 12° cages at each level.

Between posterior, middle, and anterior placed cages there was a positive trend between post op segmental lordosis of 8.23°, 11.47°, and 13.02° with anterior placement. When compared to each other these figures were statistically significant on ANOVA ($P < .05$). Cages placed anteriorly demonstrated the highest mean delta at 8.36° (Table 5). Considering the phenomenon mechanistically, anteriorly placing the cage shifts the fulcrum of curvature along the disc space anteriorly and produces a cantilever effect. In our experience, this strategy provides a relatively easy and intuitive method of incrementally increasing sagittal gains.

The level of cage placement also demonstrated significant trends with respect to segmental lordosis. Moving caudally, T12-L1, L1-L2, L2-L3, L3-L4, L4-L5 produced increasing post op lordotic angles of 8.43°, 10.02°, 11.38°, 12.91°, and 14.58°. These post op figures were statistically significant between groups on ANOVA. ($P < .05$) Considering such impressive gains, the L3-L4 and L4-L5 disc spaces are especially attractive targets for hyperlordotic cage instrumentation. Lower level instrumentation must be capitalized on to achieve harmonious instrumentation with as much correction as possible.

Our data is limited in the number of posteriorly placed and higher 20° and 30° constructs. Further studies are needed to directly compare sagittal gains using lower level 6°, 10°, and 12° cages with these higher level angled implants. Also, whether the use of these augmenting strategies improves disability

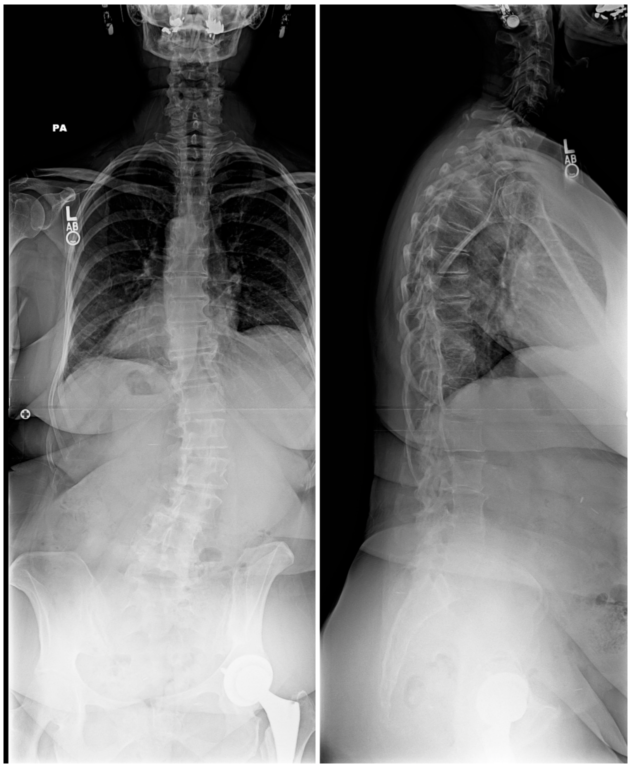

Fig. 4. Preoperative XR imaging before placement of 12° cages for multilevel CMIS correction.

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and overall clinical outcomes remains unknown.

Our analysis was based on a 6-week radiographic follow-up window. Our results do not reflect the influence of future subsidence on the loss of segmental lordosis past this follow-up endpoint. Future studies with longer follow-up are required to quantify the effect of graft subsidence on overall correction.

In our experience, current applications of interbody cages in CMIS correction underestimate the potential for sagittal correction. Specific augmenting strategies, including anterior placement of the cage in the disc space and lower level instrumentation can maximize segmental gains. We prefer 12° cages as an appropriate balance between lordotic gain and mechanistic limitation. Our overall strategy relies on multilevel instrumentation with anterior positioned 12° lordotic cages, providing a harmonious correction that follows the natural curvature of the spine. Along with rod contouring, these strategies can further eliminate the invasiveness of osteotomies, paving the way for truly minimally invasive methods of achieving sagittal correction.

Fig. 5. Postoperative XR imaging after placement of 12° cages for multilevel CMIS correction.

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Disclosures & COI

Neel Anand is a consultant for Medtronic and Theracell, on the scientific advisory board for Globus Medical, owns shares in Medtronics, Globus Medical, Paradigm Spine, Theracell, Atlas Spine, and receives royalties from Globus Medical, Medtronic, and Elsevier. Eli Baron receives royalties from Elsevier and McGraw-Hill. The other authors declare no relevant financial disclosures or conflicts of interest.

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