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The minimally invasive interbody selection algorithm for spinal deformity

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OBJECTIVE Minimally invasive surgery (MIS) for spinal deformity uses interbody techniques for correction, indirect decompression, and arthrodesis. Selection criteria for choosing a particular interbody approach are lacking. The authors created the minimally invasive interbody selection algorithm (MIISA) to provide a framework for rational decision-making in MIS for deformity.

METHODS A retrospective data set of circumferential MIS (cMIS) for adult spinal deformity (ASD) collected over a 5-year period was analyzed by level in the lumbar spine to identify surgeon preferences and evaluate segmental lordosis outcomes. These data were used to inform a Delphi session of minimally invasive deformity surgeons from which the algorithm was created. The algorithm leads to 1 of 4 interbody approaches: anterior lumbar interbody fusion (ALIF), anterior column release (ACR), lateral lumbar interbody fusion (LLIF), and transforaminal lumbar interbody fusion (TLIF). Preoperative and 2-year postoperative radiographic parameters and clinical outcomes were compared.

RESULTS Eleven surgeons completed 100 cMISs for ASD with 338 interbody devices, with a minimum 2-year follow-up. The type of interbody approach used at each level from L1 to S1 was recorded. The MIISA was then created with substantial agreement. The surgeons generally preferred LLIF for L1–2 (91.7%), L2–3 (85.2%), and L3–4 (80.7%). ACR was most commonly performed at L3–4 (8.4%) and L2–3 (6.2%). At L4–5, LLIF (69.5%), TLIF (15.9%), and ALIF (9.8%) were most commonly utilized. TLIF and ALIF were the most selected approaches at L5–S1 (61.4% and 38.6%, respectively). Segmental lordosis at each level varied based on the approach, with greater increases reported using ALIF, especially at L4–5 (9.2°) and L5–S1 (5.3°). A substantial increase in lordosis was achieved with ACR at L2–3 (10.9°) and L3–4 (10.4°). Lateral interbody arthrodesis without the use of an ACR did not generally result in significant lordosis restoration. There were statistically significant improvements in lumbar lordosis (LL), pelvic incidence–LL mismatch, coronal Cobb angle, and Oswestry Disability Index at the 2-year follow-up.

CONCLUSIONS The use of the MIISA provides consistent guidance for surgeons who plan to perform MIS for deformity. For L1–4, the surgeons preferred lateral approaches to TLIF and reserved ACR for patients who needed the greatest

ABBREVIATIONS ACR = anterior column release; ALIF = anterior lumbar interbody fusion; ASD = adult spinal deformity; cMIS = circumferential MIS; LL = lumbar lordosis; LLIF = lateral lumbar interbody fusion; MIISA = minimally invasive interbody selection algorithm; MIS = minimally invasive surgery; ODI = Oswestry Disability Index; PCO = posterior column osteotomy; PI = pelvic incidence; PT = pelvic tilt; SVA = sagittal vertical axis; TLIF = transforaminal lumbar interbody fusion.

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increase in segmental lordosis. For L4–5, the surgeons' order of preference was LLIF, TLIF, and ALIF, but TLIF failed to demonstrate any significant lordosis restoration. At L5–S1, the surgical team typically preferred an ALIF when segmental lordosis was desired and preferred a TLIF if preoperative segmental lordosis was adequate.

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KEYWORDS MIISA; algorithm; adult spinal deformity; interbody; spine surgery; minimally invasive

Adult spinal deformity (ASD) encompasses a variety of deformities in varying planes, including coronal scoliosis and sagittal deformity. It is often present in patients with significant degenerative pathology. The presence of deformity in these patients can have a profoundly negative impact on an individual's well-being, a finding shown in all age groups but especially in the elderly.[1–3] Nonoperative measures do not generally improve patient-reported outcomes.[4–8] At best, they offer maintenance of symptoms given the progressive nature of ASD. Surgical intervention has been shown to be effective in decreasing pain and disability.[5,7–9] However, open surgical interventions often have significant morbidity, with complication rates reportedly as high as 80% for the most complex procedures in the elderly.[10–14] Less invasive or minimally invasive surgery (MIS) has been shown to be effective in patients with degenerative pathology, affording patients treatment with less morbidity.[15,16] The application of these techniques to ASD has continued to improve in the last few years, resulting in more patients potentially being candidates for less invasive spinal deformity surgery.[17,18] The crux of MIS for deformity treatment is the interbody selection for arthrodesis. MIS relies on interbody grafts for arthrodesis, indirect decompression, and segmental alignment correction. These techniques are typically accompanied by posterior pedicle screw–rod fixation. Compared to traditional open procedures, such procedures may allow for decreased posterior paraspinous muscle disruption, blood loss, and postoperative pain, and improved health-related quality-of-life outcomes.[19–22]

The choice of interbody approach encompasses several factors: anatomy of the patient, surgeon comfort with MIS procedures, and the pathology addressed. While there are anatomical constraints for some of these procedures (especially at L5–S1), there remains some variation in technique chosen at each level. In this paper, the minimally invasive interbody selection algorithm (MIISA) is proposed to provide a framework for rational decision-making for surgeons who are considering MIS for deformity. This paper supplements the algorithm with segmental correction values at each treated level to further guide the practicing surgeon in considering different MIS interbody approaches.

Methods

Algorithm Design

The MIISA was developed in a Delphi session by 11 experienced minimally invasive deformity surgeons over multiple meetings during a 3-month span. Surveys were held regarding surgeon preferences for interbody approach based on level. The goals of surgery at each level (height restoration, lordosis restoration, or both) were also factored in on subsequent surveys. A number of iterations of the algorithm were modified until consensus opinion was achieved. The process was informed by an analysis of 338 interbody grafts placed in 100 circumferential MISs (cMISs; interbody and percutaneous segmental pedicle screw instrumentation) for deformity from the MIS–International Spine Study Group database performed between 2015 and 2018. All patients had a minimum of 2 years of postoperative radiographic follow-up. Interbody grafts that were placed in conjunction with open posterior pedicle screw fixation (i.e., open or hybrid surgeries) as well as revision surgeries in previously instrumented spines were excluded. All centers obtained local IRB approval for participation in this study, and patient consent was obtained prior to enrollment in the database. The database factors examined were demographics and procedure description. Pre- and postoperative (2-year minimum) clinical assessment was collected utilizing the Oswestry Disability Index (ODI). Pre- and postoperative upright standing 36-inch long-cassette radiographs were uploaded from each site to an independent site, which measured the sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), lumbar lordosis (LL), PI-LL mismatch, coronal Cobb angle, and segmental lordosis. The segmental lordosis was a radiographic measurement of segmental correction in the sagittal plane and included the level treated and type of approach used. Options included anterior lumbar interbody fusion (ALIF), lateral lumbar interbody fusion (LLIF) including the transpsoas approach, LLIF with anterior column release (ACR) with sectioning of the anterior longitudinal ligament, and transforaminal lumbar interbody fusion (TLIF; Fig. 1). During the Delphi session, the surgeons were queried as to the reasons for their interbody selection.

Statistical Analysis

All statistical analysis was performed using IBM SPSS software (version 25, IBM Corp.). ANOVA was used to determine significance differences between interbody fusion groups. Post hoc Bonferroni correction was applied when comparisons were made between more than two groups. Statistical significance was set at an alpha level of 0.05.

Results

Over a 5-year period, 11 surgeons completed 100 cMIS for ASD with 338 interbody devices. The mean age at the time of surgery was 64.7 years, and 71% of individuals were female. The mean BMI and ODI were 27.8 kg/m^2 and 50.2, respectively. Patients were followed for a minimum of 2 years postoperatively, with a mean follow-up of 39.3 months (Table 1). The database of these cases was reviewed, and the type of interbody approach used at each

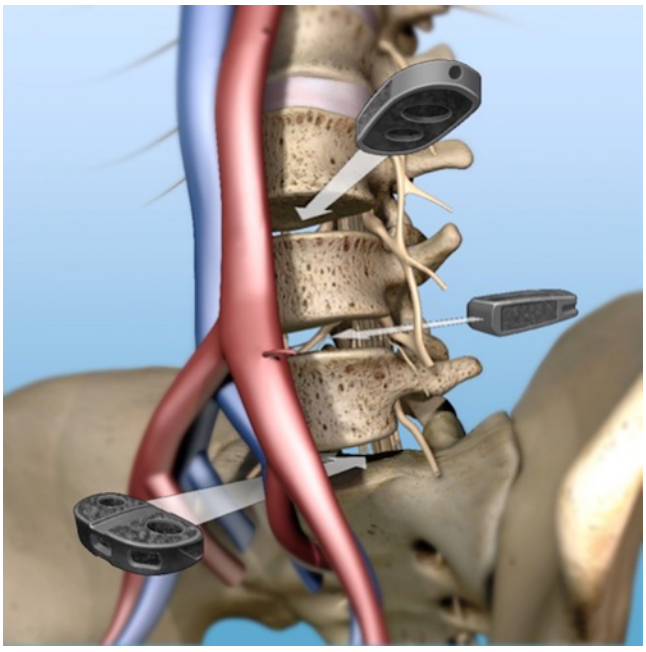

FIG. 1. Minimally invasive interbody approaches: anterior (ALIF), lateral (LLIF and ACR), and posterior (TLIF). Copyright Praveen V. Mummaneni. Published with permission.

level from L1 to S1 was recorded. In addition, the change in segmental lordosis was compared. Of note, there was no significant difference in preoperative segmental lordosis at each level among the four treatment groups.

Level-by-Level Analysis

L1–2

At L1–2, 2 patients underwent MIS TLIF (4.2%), 44 patients had MIS LLIF (91.7%), and 2 patients underwent MIS ACR (4.2%; Table 2). There was no statistically significant change in the segmental lordosis between these interbody types (Table 3). No ALIF procedures were performed at this level. TLIFs resulted in a net change of 2.6° of lordosis per level. LLIF without ACR resulted in a 3.8° change per level, while ACR-treated patients had a 7.4° improvement. The small number of patients in the ACR group likely precluded a statistically significant difference in lordosis change.

L2–3

At L2–3, 1 patient had ALIF (1.2%), 6 patients underwent MIS TLIF (7.4%), 69 patients had MIS LLIF (85.2%), and 5 patients had MIS ACR (6.6%; Table 2). The increase in segmental lordosis at L2–3 was significantly greater with ACR than with LLIF or TLIF (10.9° vs 4.2° vs 1.4°, $p < 0.001$; Table 3).

L3–4

At L3–4, 2 patients underwent ALIF (2.4%), 7 patients underwent MIS TLIF (8.4%), 67 patients had MIS LLIF (80.7%), and 7 patients had MIS ACR (8.4%; Table 1). The increase in segmental lordosis at L3–4 was significantly greater with ACR than with LLIF or TLIF (10.4° vs 4.6° vs 2.1°, $p < 0.001$; Table 3).

TABLE 1. Patient demographics and clinical characteristics

Variable	Value
Mean age (range), yrs	64.7 (48–83)
Sex, n (%)	
Females	71 (71)
Males	29 (29)
Mean BMI (range), kg/m^2	27.8 (16.8–45.4)
Mean preop ODI	50.2
Mean follow-up (range), mos	39.3 (24–74)

L4–5

At L4–5, 8 patients had ALIF (9.8%), 13 patients had MIS TLIF (15.9%), 57 patients underwent MIS LLIF (69.5%), and 4 patients underwent MIS ACR (4.9%; Table 2). The increase in segmental lordosis at L4–5 was significantly greater with ALIF than with LLIF, ACR, or TLIF (9.2° vs 5.4° vs 4.6° vs 0.8°, $p < 0.001$). The difference in segmental lordosis restoration between LLIF and ACR was not statistically significant, whereas the increase in segmental lordosis with LLIF was significantly greater than that with TLIF ($p < 0.001$).

L5–S1

At L5–S1, 17 patients underwent ALIF (38.6%) and 27 patients had MIS TLIF (61.4%). The increase in segmental lordosis at L5–S1 was significantly greater with ALIF than with TLIF (5.3° vs 1.9°, $p = 0.003$). No LLIF procedures were performed at L5–S1.

Global/Regional Radiographic and Clinical Analysis

Patients included for analysis generally demonstrated moderate deformities. The mean baseline SVA and PT were 4.2 cm and 23.6°, respectively. These values did not significantly change postoperatively. The mean PI-LL mismatch and coronal Cobb angles were 15.2° and 22.9°, respectively. Postoperatively, statistically significant decreases in PI-LL mismatch to 10.8° ($p < 0.01$) and the coronal Cobb angle to 10° ($p < 0.01$) were noted. The ODI significantly decreased by 19 points postoperatively ($p < 0.00001$; Table 4).

TABLE 2. Interbody option selected per level treated

Level	ALIF (%)	TLIF (%)	LLIF (%)	ACR (%)
L1–2, n = 48	0 (0)	2 (4.2)	44 (91.7)	2 (4.2)
L2–3, n = 81	1 (1.2)	6 (7.4)	69 (85.2)	5 (6.2)
L3–4, n = 83	2 (2.4)	7 (8.4)	67 (80.7)	7 (8.4)
L4–5, n = 82	8 (9.8)	13 (15.9)	57 (69.5)	4 (4.9)
L5–S1, n = 44	17 (38.6)	27 (61.4)	0 (0)	0 (0)
Total	28 (8.3)	55 (16.2)	237 (70.1)	18 (5.3)

TABLE 3. Segmental lordosis values by level and interbody technique

Level	ALIF (°)	TLIF (°)	LLIF (°)	ACR (°)	p Value
L1–2	NA				
Preop		2.6	3.1	4.7	0.689
Postop		5.2	6.9	12	0.14
Δ		2.6	3.8	7.4	0.445
L2–3					
Preop	0	3.2	4.1	3	0.495
Postop	10	4.7*†	8.4‡	13.9‡	**<0.001**
Δ	10	1.4*†	4.2†‡	10.9*‡	**<0.001**
L3–4					
Preop	2.4	3	4.5	4.2	0.362
Postop	9	5.1*†	9.1†‡	14.7*‡	**<0.001**
Δ	6.6	2.1†	4.6†	10.4*‡	**<0.001**
L4–5					
Preop	4.7	6.3	5.8	9	0.275
Postop	14	7.1*†§	11.2‡	13.6‡	**<0.001**
Δ	9.2	0.8*§	5.4‡	4.6	**<0.001**
L5–S1			NA	NA	
Preop	10.9	7.5			0.098
Postop	16.3	9.4§			**0.001**
Δ	5.3	1.9§			**0.003**

NA = not applicable.
Boldface type indicates statistical significance.
* Significantly different from LLIF.
† Significantly different from ACR.
‡ Significantly different from TLIF.
§ Significantly different from ALIF.

The MIISA

Based on the above data, the MIISA is typically stratified on three lumbar areas needing treatment: L1–4, L4–5, and L5–S1 (Fig. 2). At L1–4, an ALIF is uncommon. However, L3–4 ALIF can be considered if other levels (L4–5 and L5–S1) are treated with an ALIF. The MIS interbody options preferred at L1–4 typically include an MIS LLIF with or without an ACR, depending on surgeon familiarity with the procedure and overall segmental lordosis needs. Otherwise, MIS TLIF is an option at L1–4.

For L4–5, ALIF can be considered as an interbody option that restores disc height and promotes lordosis. The use of LLIF and ACR at L4–5 can also lead to restoration of segmental lordosis, but this depends on surgeon expertise with this technique at a challenging spinal level. The LLIF approaches at L4–5 (with or without ACR) have been reported to be associated with temporary postoperative ipsilateral leg weakness and sensory symptoms from psoas muscle trauma and nerve stretch, so TLIF was chosen by many of our surgeons for this level. Our data show that LLIF (with or without ACR) as well as TLIF at L4–5 demonstrated less lordosis restoration than ALIF.

At L5–S1, a lateral approach is generally not feasible due to obstruction from the iliac crest. Thus, the interbody options here include ALIF for maximization of disc height and lordosis, or MIS TLIF if other goals predominate.

TABLE 4. Mean radiographic and clinical outcomes from preoperative to minimum 2-year postoperative follow-up

Parameter	Preop	Postop	p Value
SVA (cm)	4.2	3.8	0.854
PT (°)	23.6	23.6	0.786
PI (°)*	53.1	52.4	—
LL (°)	37.9	41.6	**0.002**
PI-LL mismatch (°)	15.2	10.8	**0.007**
Coronal Cobb angle (°)	22.9	10.0	**<0.00001**
ODI	50.2	31.1	**<0.00001**

Boldface type indicates statistical significance.
* Within 1.5% standard of error for a static radiographic parameter.

Discussion

In this study, a group of experienced minimally invasive deformity surgeons retrospectively reviewed a database of 100 patients treated with 338 interbody devices. Patients predominantly had moderate deformities (mean SVA < 5 cm, PT < 25°, PI-LL mismatch of 15°, and coronal Cobb angle > 20°). Overall, the 2-year follow-up demonstrated significant improvement in PI-LL mismatch, coronal Cobb angle, and clinical status based on the ODI. Minimally invasive LLIF was the most common technique between L1 and L4. At the L4–5 level, LLIF was not as common as at L1–4 and surgeons utilized TLIF and ALIF instead. Rationales for these choices included difficulty with the lateral approach at this level as well as the potential need for direct decompression (TLIF). The most common procedure at L5–S1 was MIS TLIF, followed by ALIF. The greatest segmental lordosis was accomplished via ACR at L2–3 and L3–4, and ALIF at L4–5 and L5–S1. The choice of interbody approach did not significantly impact lordosis at L1–2. Overall, most LLIFs did not include an ACR, and this is likely due to surgeon comfort with the procedure. ACR did result in significant improvement in lordosis at L2–3 and L3–4, although not at L4–5, suggesting that those two levels are the most likely candidates for an ACR. There was no statistically significant difference in lordosis increase at L4–5 between LLIF and ACR. The lower delta (change) achieved by ACR at this level may be partly due to the low number of cases performed (n = 4).

Overall, our results are consistent with previously reported values gained for segmental lordosis across different interbody approaches. Studies examining the degree of segmental lordosis gained with ALIF range from 5.4° to 15° depending on the level.[23–25] Significant final lordosis can be achieved at L5–S1 with this approach, but given the higher baseline lordosis inherently present at this level, there is a lower delta from preoperative to postoperative measures when compared to ALIF at L4–5.[25] This effect is reflected in our data as well. For MIS TLIF, a systematic review and meta-analysis by Alvi et al. found mean increases in segmental lordosis for static and expandable cages of 2.1° and 5.0°, respectively.[26] Similarly, Hawasli et al. demonstrated increases in segmental lordosis using static and expandable cages of 2.3° and 5.2°, respectively.[27] In a separate systemic review, Carlson et al. found a

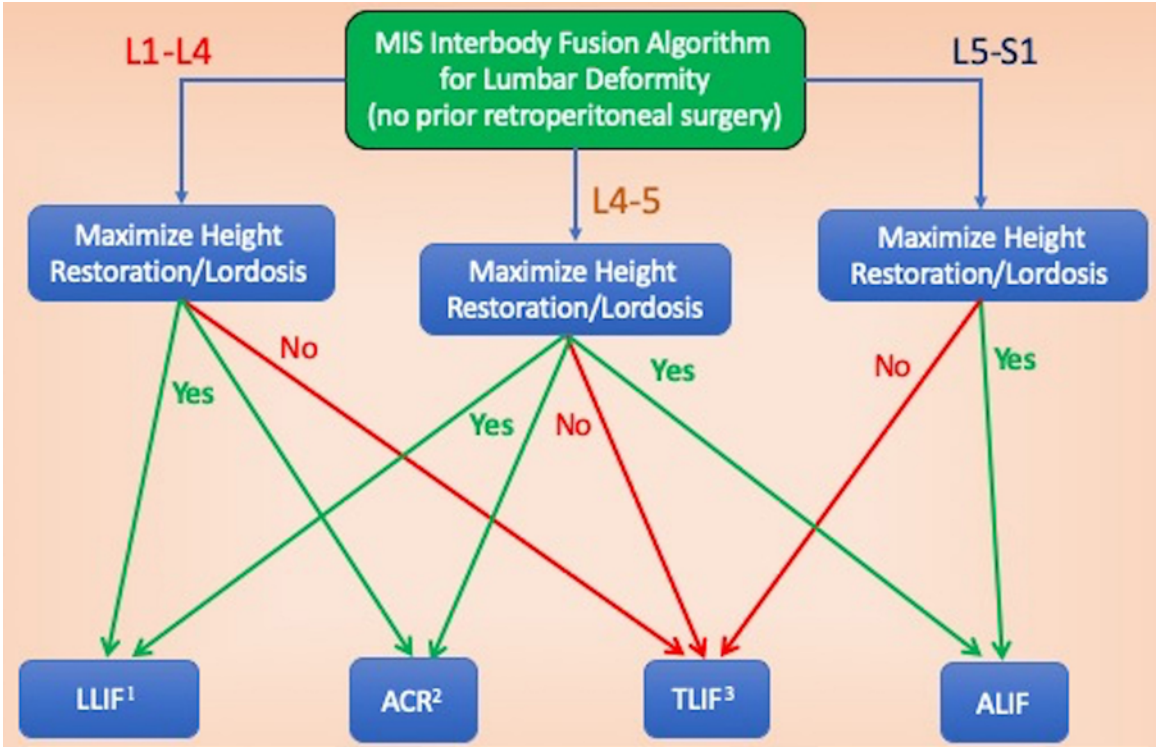

FIG. 2. The MIISA for spinal deformity. LLIF[1] = Prepsoas or transpsoas lateral interbody fusion; use when up to 5° of segmental lordosis is desired. Lordosis between L1 and L4 is inconsistent, while height restoration is consistent. ACR[2] = Use when ≥ 10° of segmental lordosis is desired. TLIF[3] = Allows direct decompression of foramina/lateral recess stenosis.

weighted average increase in segmental lordosis of 2.1° across all types of cages, and found a proportional trend of increased postoperative segmental lordosis the closer the cage was implanted to the anterior cortex of the vertebral body.[28] Other factors that have been implicated in achieving greater segmental lordosis with MIS TLIF include bilateral facetectomies and unilateral pedicle screw instrumentation.[24,29]

For LLIF without ACR, Xu et al. found an average increase in segmental lordosis of 5.6° in patients with grade II spondylolisthesis, with 75% achieving complete reduction.[23] Miscusi et al. found a lower average gain in segmental lordosis with LLIF of 2.0°, but demonstrated a significant average coronal Cobb angle correction of 11.3°.[30] LLIF with ACR can restore higher degrees of segmental lordosis and can serve as an adjunct or minimally invasive alternative to posterior osteotomy techniques in select patients.[31,32] Turner et al. found average increases in segmental lordosis of LLIF with and without ACR of 16.3° and 5.7°, respectively.[33] Patients with ACR and MIS percutaneous pedicle screw stabilization had a segmental lordosis increase of 9.9°. In another study, an average of 11.8° of segmental lordosis was gained by ACR, the majority of which were performed at the L3–4 level, as was the case in our study.[34] It is important to distinguish segmental lordosis achieved utilizing ACR with open pedicle instrumentation and posterior column osteotomies (PCOs) and MIS percutaneous pedicle fixation without PCO (i.e., the cMIS technique). Patients treated with ACR and Scoliosis Research Society–Schwab grades 1 or 2 posterior osteotomies can achieve segmental lordosis increases of 17.3°–18.7°.[33,34] However, performing PCO with ACR is associated with an almost 7-fold increase in subsidence rates.[34]

In our study, patients who had ACR performed as part of a cMIS procedure demonstrated lower than expected values for increase in segmental lordosis (4°–10°) as compared with previous reports.[33,34] However ACR performed at the cranial lumbar levels can still achieve greater lordosis than TLIF, which may help reduce construct length and often has an approach corridor that is more favorable than ALIF. Complications from ACR have been reported and can be catastrophic, such as injury to the iliac vein or artery, and necessitate immediate vascular surgery intervention.[35] As ACR becomes more widely utilized by experienced surgeons, major vascular, visceral, and neurological complications are exceedingly rare (< 1%).[33,34,36] Ultimately, the level of interest, anatomical relationship of the great vessels to the spine, and surgeon comfort with the ACR technique need to be considered on a case-by-case basis.

Increasing segmental lordosis via minimally invasive interbody approaches correlates with improved patient-reported outcomes.[23,27,33,37] The mechanism through which this occurs is likely multifactorial. Achieving direct decompression of neural elements through discectomy and indirect decompression of foraminal stenosis are the major contributors. The degree to which an increase in segmen-

tal lordosis contributes to changes in regional LL and improvement in PI-LL mismatch varies based on interbody selection. Xu et al. demonstrated that LL increased by 52% of the segmental lordosis gained with LLIF, as opposed to 34% with ALIF.[34] With ACR, LL can increase by 81% of the segmental lordosis gain when using hyperlordotic cages, with an improvement in PI-LL mismatch of 8.3°.[34] Changes in LL with MIS TLIF vary based on static versus expandable cages, with reports of LL change ranging from 45% to 200% of segmental lordosis gain.[26–28] Overall, it is difficult to make direct correlations between changes in segmental lordosis with LL and PI-LL mismatch due to the complex interactions between non–index-level biomechanical and global sagittal alignment changes.

One interesting finding is that ALIF may not give the same amount of segmental correction as the hyperlordotic cage that the surgeon uses because, in a cMIS procedure, facetectomies are often not performed during posterior percutaneous instrumentation. A similar phenomenon occurs with LLIF and ACR. Leveque et al. demonstrated that segmental lordosis correction with ACR is on average 54% of the implanted cage lordosis.[32] A second interesting finding is that our MIS TLIF data are consistent with other published works and represent a reproducible average for what can be expected using this technique.[26,27,29,38] However, this does not necessarily represent a ceiling for the technique, and certain patients may have a better segmental lordosis restoration with TLIF, especially in the setting of collapsed disc spaces or vacuum phenomena, as has been shown for LLIF.[39] Nonetheless, TLIF at L4–5 and L5–S1 showed very little lordosis restoration in our data set.

A critical underpinning of the MIISA is identifying which patients can be appropriately treated via minimally invasive strategies rather than open correction. Initial studies of MIS techniques in ASD demonstrated suboptimal results in those with SVA greater than 9.5 cm and those requiring greater than 34° of coronal curve correction.[37,40] The minimally invasive spinal deformity surgery (MISDEF) algorithm was developed through a similar Delphi approach of experienced minimally invasive deformity surgeons. The most recent iteration, the MISDEF-2, divides ASD patients into 1 of 4 classes. Class I and II patients, with mild to moderate deformities, can be treated with MIS decompression and/or interbody fusion. Class III patients, with more than 1 negative predictive sagittal parameter, or those with rigid spines or previous instrumentation requiring short constructs can be treated with cMIS with anterior longitudinal ligament release, expandable cages, mini-open pedicle subtraction osteotomy, and hybrid approaches. Class IV patients should not be treated with MIS strategies, as they require open surgery with osteotomies and potential extension to the thoracic spine.[41] Applying the MISDEF-2 algorithm with the MIISA to patients with ASD can help determine which overall MIS strategy is most appropriately indicated. Treating appropriately selected patients with minimal invasive interbodies in this study resulted in improved PI-LL mismatch and coronal Cobb angle, as well as significant improvements in ODI. This indicates that these patients can achieve significant clinical improvement with less invasive techniques.

There are a number of limitations in this study that must be acknowledged. First, its retrospective study design and the data review of a relatively small number of surgeons from a multicenter study introduce a level of variability that is difficult to control for with respect to data collection. Second, one nonsurgeon was involved in radiographic measurements; therefore, interrater agreement could not be calculated. Third, the study did not differentiate between the use of static, expandable, lordotic, and hyperlordotic cages, which contribute to the degree of segmental lordosis that can be achieved. Choices for interbody approach are evolving as larger degrees of hyperlordosis are becoming available with lateral approaches and ALIF. Significant variability exists in the choice to use these types of grafts or not and anatomical constraints encountered intraoperatively, which may preclude their use or influence the lordotic angle of the graft that can be placed. Our goal of the study was to provide a general overview and framework of approaches for interbody placement per level and what average segmental lordosis can be achieved by each approach. Further studies will be required that parse out the frequency and outcomes of using lordotic versus 0° interbody cages in MIS for ASD. Fourth, patients may have had multiple interbody approaches based on level (e.g., they may have had LLIF performed at L3–4 and L4–5, but ALIF at L5–S1). Given this heterogeneity, it was not possible to identify preoperative and postoperative pelvic parameter changes or PI-LL mismatch changes based on a single interbody approach alone. Furthermore, there was an unequal number of interbody grafts based on approach, with LLIF dominating as the choice in 70% of cases. While this is a reflection of the current practice of the surgeons contributing to this database, the lack of standardization across interbody approaches may bias what mean segmental lordosis is demonstrated by our data. Fifth, decision-making in MIS for ASD is a more complex process than what is captured through the MIISA. Factors such as the apex of the scoliotic curve, the degree/location of neural element compression, the presence of foraminal osteophytic hooks, vascular anatomy relative to the spine, and prior abdominal/retroperitoneal surgeries can highly influence the choice of approach and need to be strongly considered in conjunction with the data used to develop the MIISA.

Conclusions

This study improves upon our current understanding of interbody selection in cMIS and hybrid ASD surgery. The MIISA provides a framework that should be coupled with careful patient selection and attention to individual factors, including comorbidities, anatomical approach constraints, baseline radiographic parameters, and ultimate goals of surgery. For L1–4, the surgeon team preferred lateral approaches to TLIF and reserved ACR for patients who needed the greatest increase in segmental lordosis. For L4–5, the surgeon team's order of preference was LLIF, TLIF, and ALIF, but TLIF failed to demonstrate any significant lordosis restoration. At L5–S1, the surgeon team typically preferred an ALIF when segmental lordosis was desired and a TLIF if preoperative segmental lordosis

was adequate. Future prospective studies involving larger numbers of patients and correlations with health-related quality-of-life measures will help to support the findings presented in this study.

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Disclosures

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Conception and design: Fu, Mummaneni. Acquisition of data: Fu, Mummaneni, Shaffrey, Eastlack, Mundis, Uribe, Fessler, Park, Robinson, Rivera, Chou, Kanter, Okonkwo, Nunley, Wang, La Marca, Than. Analysis and interpretation of data: Mummaneni, Hussain, Chou. Drafting the article: Fu, Mummaneni, Hussain. Critically revising the article: Fu, Mummaneni, Hussain, Chou, Than. Reviewed submitted version of manuscript: Fu, Mummaneni, Hussain, Chou. Approved the final version of the manuscript on behalf of all authors: Fu. Administrative/technical/material support: Fu, Mummaneni. Study supervision: Fu, Mummaneni.

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