Algorithmic Patient Selection for Minimally Invasive Versus Open Lumbar Interbody Fusion Surgery

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KEYWORDS

• Minimally invasive spine surgery • Spine deformity • Selection algorithm

KEY POINTS

- MISDEF2 algorithm guides approach selection for adult spinal deformity.
- Minimally invasive interbody selection algorithm (MIISA) guides technique selection.
- Data driven algorithms help guide patient selection for minimally invasive lumbar interbody fusion

INTRODUCTION

Symptomatic adult spinal deformity (ASD) encompasses a range of spinal alignment disorders that can significantly influence quality of life, with both sagittal and coronal plane deformities recognized as determinants of health status.[1] In extreme cases, the health impact of cervical or thoracolumbar spinal deformity is on par with chronic diseases and disabilities such as low-vision/blindness, emphysema, renal failure, and stroke.[2,3] ASD results from degeneration of structural support elements of the spinal column but can also develop from untreated pediatric or adolescent idiopathic scoliosis, trauma, infection, neoplasm, or earlier spine surgery. ASD can become symptomatic when (1) muscle pain and fatigue result from increased biomechanical work required to maintain upright posture in the setting of spinal malalignment, (2) nociceptive pain resulting from spondylotic disc or zygohypophyseal joint disease accumulates, or (3) when compression of neural elements leads to radicular pain and/or myelopathy. Symptoms also develop from compensatory maneuvers and increased spinopelvic rigidity negatively affecting activities of daily living.[4] ASD is found at a prevalence of up to 32% in the general adult population and up to 68% among the elderly.[5] The elderly population meeting surgical criteria based on symptomatic burden is expected to increase in direct proportion to the aging population structure, which must be considered from a health-care policy and demographic standpoint.[6] Additionally, the elderly are increasingly healthier at older ages, have increased life expectancy,[7] and are acceptable candidates for surgical treatment across multiple specialties at higher rates due to these factors.[8]

In appropriately selected patients, traditional open operative treatment of symptomatic ASD provides improvements in patient reported quality of life compared with conservative (nonoperative) treatment.[9] However, not all patients are candidates for open surgical correction. Earlier studies evaluating open techniques demonstrate significant morbidity due to extensive muscle dissection, blood loss, infection risk, and postoperative narcotic requirement, with many patients requiring discharge to rehabilitation centers rather than home. Further, the most powerful alignment correction techniques are associated with high-complication rates. For example, minor and major complication rates after 3-column osteotomy have been reported to be as high as 78% and 61%,

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respectively.[10] In addition, the cumulative revision rate during 4 years is 18%. Although technical advances in open deformity surgery have mitigated complication rates, it is commonly recognized that perioperative complications have been associated with worse outcomes.[11]

The techniques and technology that have enabled minimally invasive approaches in degenerative spine pathologic condition have been adapted to treat ASD. MIS approaches can offer several potential advantages and noninferior outcomes in appropriately selected patients.[12–14] The MIS approach in this context generally refers to interbody implants used to achieve alignment goal through anterior column reconstruction and facilitation of arthrodesis. Posterior percutaneous pedicle screw instrumentation is also a part of the MIS philosophy resulting in additional correction and stabilization. Variations of posterior MIS techniques may incorporate miniopen approaches for selective osteotomies or facet fusion. Advantages of such strategies include less intraoperative blood loss, decreased transfusion rates, decreased postoperative narcotic use, shorter length of hospital stay, faster rates of postoperative mobilization, and fewer patients discharged to inpatient rehab.[15–17] Additionally, patients presenting with increased preoperative risk stratification may be more suitable candidates for MIS approaches.

Several potential drawbacks are inherent in the MIS approach to spine deformity.[18–20] MIS techniques are evolving rapidly and associated with a significant initial learning curve. Until recently, many surgeons did not receive formal training in these approaches that require selective surgical corridors devoid of traditional anatomic landmarks resulting in orientation loss. Additionally, the smaller MIS corridors targeting the interbody disc space for primary correction may impose limits on the extent of correction given lack of osteotomies that require hybrid approaches. Although providing a more harmonious segmental correction, MIS techniques are limited in ankylosed segments or earlier fusion surgery. Furthermore, given less posterior element exposure, there is decreased surface area for arthrodesis, which can contribute to higher rates of pseudoarthrosis in some cases.[21] Cost is a further barrier as the fundamental instruments and technology require significant upfront investment, such as with intraoperative CT scanners, computer navigation systems, robotics, and sophisticated implants. Finally, optimal patient selection requires proper pairing of the patient-specific spinal alignment goals to the proper MIS technique, as well as recognizing when hybrid or traditional open techniques are optimal.[18–20]

Postoperative outcomes as determined by patient reported symptoms and radiographic parameters are contingent on achieving realistic surgical goals and this begins with appropriate patient selection. There is a lack of consensus among spine surgeons regarding optimal surgical approach and extent of treatment of ASD.[22] To standardize care, multicenter study groups have pooled resources to develop algorithms that provide guidance for determining whether MIS techniques may be able to achieve the desired surgical goals. Patient selection algorithms have evolved considerably during the past decade because intraoperative techniques and technologies have expanded the armamentarium of MIS surgeons and because the goals of deformity surgery have changed. The purpose of this article is to review the algorithms available to surgeons to help guide decision-making regarding MIS versus open surgical approaches for ASD.

Lenke-Silva Levels of Treatment Classification

The Lenke-Silva algorithm describes 6 increasingly invasive levels of treatment of adult degenerative scoliosis based on severity of patient reported symptoms, clinical history, and radiographic findings.[23] Nonoperative management is reserved for patients with radiographic findings including scoliotic curves less than 30° and less than 2 mm subluxation with anterior osteophytes, and a lack of significant clinical symptoms including stenotic, radicular, or back pain. Among operative candidates, the 6 distinct treatment options include the following: (1) decompression of neural elements, (2) decompression + posterior instrumented fusion limited to the levels decompressed, (3) decompression + posterior instrumented fusion of the entire lumbar curve, (4) decompression with both anterior and posterior instrumented fusion of the entire lumbar curve, (5) extension of level 4 treatment into the thoracic spine, and (6) targeted osteotomies.

MiSLAT

In 2013, Mummaneni and colleagues published an MIS adaptation of the Lenke-Silva treatment levels establishing the MiSLAT algorithm.[24] MiSLAT similarly incorporated both clinical symptoms and radiographic findings to establish 6 levels of increasing complexity. Because this algorithm considered the technical capabilities of MIS techniques at the time, it suggests the 2 most complex levels of deformity (5 and 6) are best treated with open surgical correction to extend fusions through the thoracic spine and when osteotomies are required.

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The Minimally Invasive Spinal Deformity Surgery Algorithm

The minimally invasive spinal deformity surgery algorithm (MISDEF) algorithm is a further refinement of MiSLAT designed to increase intraobserver reliability by focusing the decision-making algorithm solely on radiographic findings.[25] MISDEF simplified decision-making by creating 3 radiographically based treatment classes. Patients with class I and II deformities could be treated with MIS surgery involving decompression ± limited fusion or decompression with longer segment fusion with or without interbody grafts. Class III deformities, involving a nonflexible curve or more severe deformity defined by PT greater than 25°, LL-PI mismatch greater than 30°, lateral listhesis greater than 6 mm, or thoracic kyphosis lesser than 60°, were best treated with open surgery for osteotomies and/or fusion extension into the thoracic spine.

MISDEF2

The MISDEF algorithm accounted for the limited capability of MIS to achieve sagittal deformity correction. As MIS techniques continued to be validated, tools and technology to support sagittal correction had emerged and gained acceptance including anterior column release, hyperlordotic interbody cages, and miniopen pedicle subtraction osteotomy.[26–30] With the consideration of these techniques, the MISDEF-2 algorithm was developed.[31] MISDEF2 has 4 treatment levels with class 3 modified to include MIS treatment options for severe and/or rigid deformities using anterior column release (ACR), expandable cages, miniopen pedicle subtraction osteotomy (PSO), and hybrid MIS/open techniques. Class 4 describes deformities best addressed via open techniques due to the requirement of long constructs or revision of previous multilevel fusions (Fig. 1).

Minimally Invasive Interbody Selection Algorithm

Arthrodesis and correction through the interbody space via cage implants and bone grafting is an essential MIS technique. Depending on the surgical goals, interbody grafts can be used to aid in sagittal or coronal deformity correction, anterior column realignment, and both indirect central canal and foraminal decompressions. The most common MIS interbody graft techniques in the lumbar spine include transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF), and lateral lumbar interbody fusion (LLIF) via retroperitoneal transpsoas or prepsoas approaches and with or without anterior longitudinal ligament (ALL) release. The choice of technique requires consideration of the surgical goals, patient anatomy, spinal level, and surgeon comfort.

To aid in technique selection, the minimally invasive interbody selection algorithm (MIISA) was

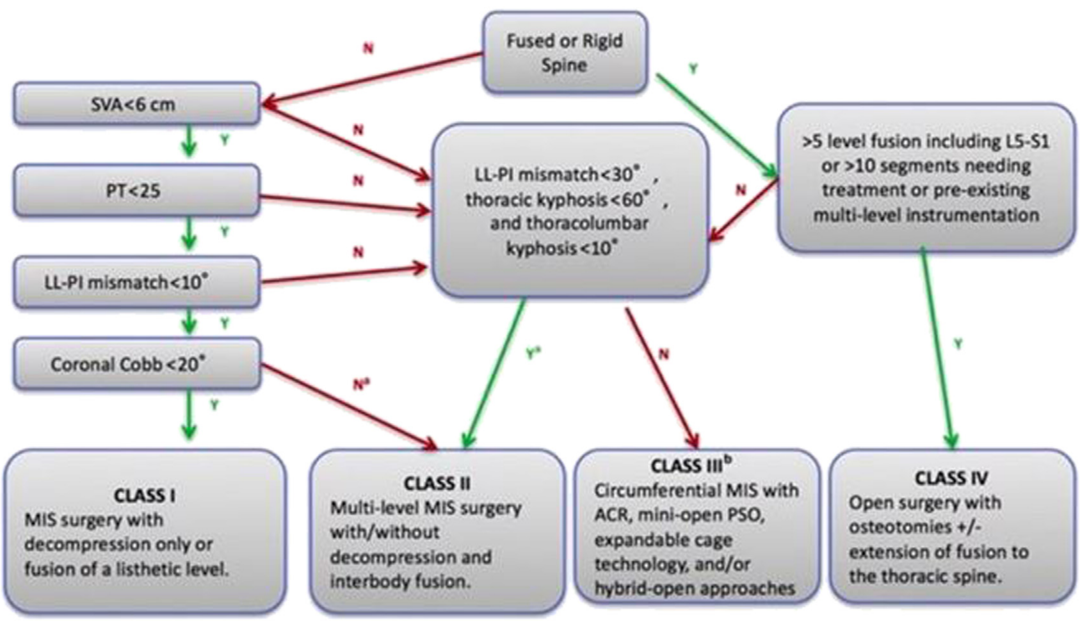

Fig. 1. MISDEF2 decision tree. The MISDEF2 deformity algorithm uses purely radiographic parameters to guide surgical decision-making to 1 of 4 general classes of treatment options. The treatment classes increased in complexity and invasiveness with class 4 being open surgery.

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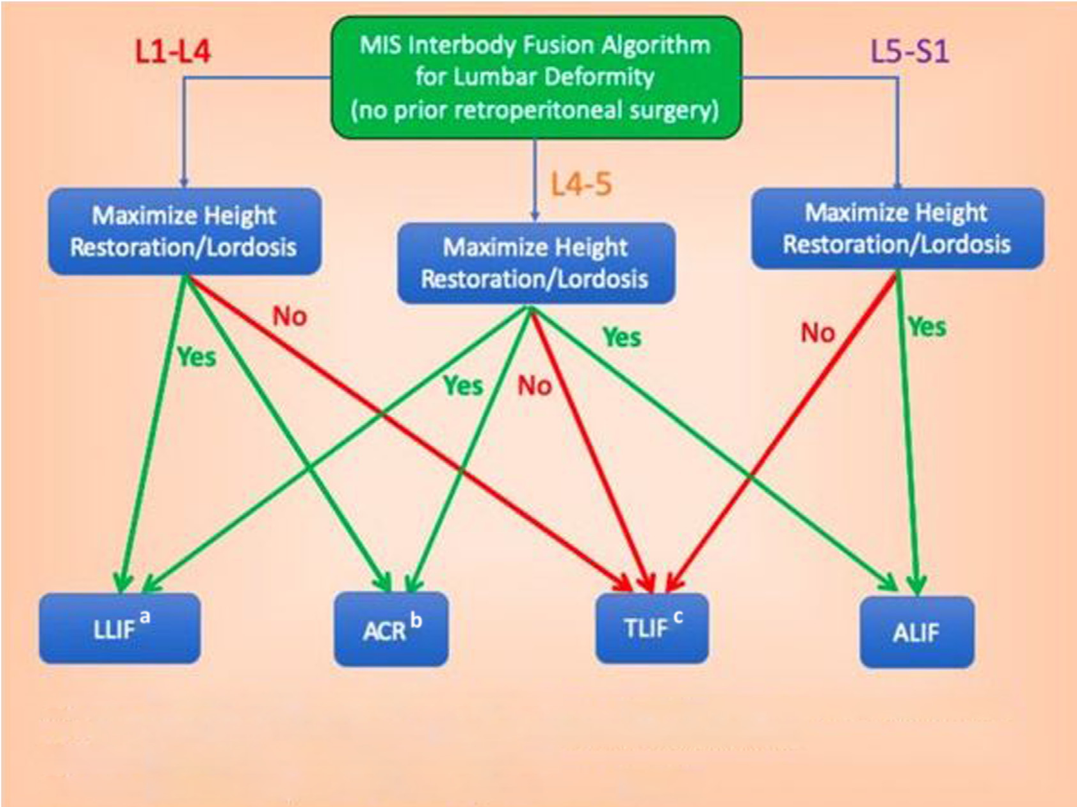

Fig. 2. MIISA decision tree. The MIISA provides a framework for approach and interbody selection based on lumbar spinal level and surgical goal. [a]LLIF: Prepsoas or transpsoas lateral interbody fusion; use when up to 5° of segmental lordosis is desired. Lordosis between L1-L4 is inconsistent while height restoration is consistent. [b]ACR: Use when ≥10° of segmental lordosis is desired. [c]TLF: Allows direct decompression of foraminal/lateral recess stenosis.

created.[32] This algorithm was created by an expert panel of MIS deformity spine surgeons who evaluated greater than 300 interbody grafts placed during 100 MIS ASD surgeries at multiple institutions maintained via the MIS International Spine Study Group database. Both clinical and long-term (2-year) radiographic outcomes were analyzed in the context of the surgical goals. Four interbody graft techniques were considered: ALIF, TLIF, LLIF without ACR, and LLIF with ACR. Among the statistically significant cohort, beneficial impacts were observed in lumbar lordosis, PI-LL mismatch, and coronal cobb angle. Assessment of the overall Oswestry Disability Index scores also demonstrated significant improvement. The expert surgeons preferred LLIF at L1-2, L2-3, L3-4, and L4-5. Overall, LLIF with ACR was performed in 5% of cases and most commonly at L3-4 (8%) and L2-3 (6%). At L5-S1, TLIF and ALIF were most performed at rates of 61% and 39%, respectively.

MIISA provides a framework for MIS lumbar interbody grafting between L1 and S1 spinal levels among patients without prior retroperitoneal surgery (**Fig. 2**). At L1-4, the surgical goals of maximizing interbody height restoration and restoration of lordosis can be most robustly accomplished via LLIF alone (if desired segmental lordosis is 5° or less) and combine with ALL release if more than 10° of segmental lordosis is needed. If maximal interbody height restoration and/or lordosis is not needed, TLIF is a good option for direct lateral recess or foraminal decompression at L1-L4. At the L4-5 level, all 4 techniques can be used. ALIF was found to be the most powerful for restoration of lordosis. LLIF (with or without ALL release) is another powerful technique for lordosis restoration but requires a higher degree of surgeon expertise to avoid complications related to psoas muscle and/or lumbosacral plexus nerve trauma. At L5-S1, the iliac crest obstructs the lateral approach; maximal disc height and lordosis restoration is accomplished via ALIF. If the primary goal is not maximal disc height and lordosis restoration, TLIF is a good option.

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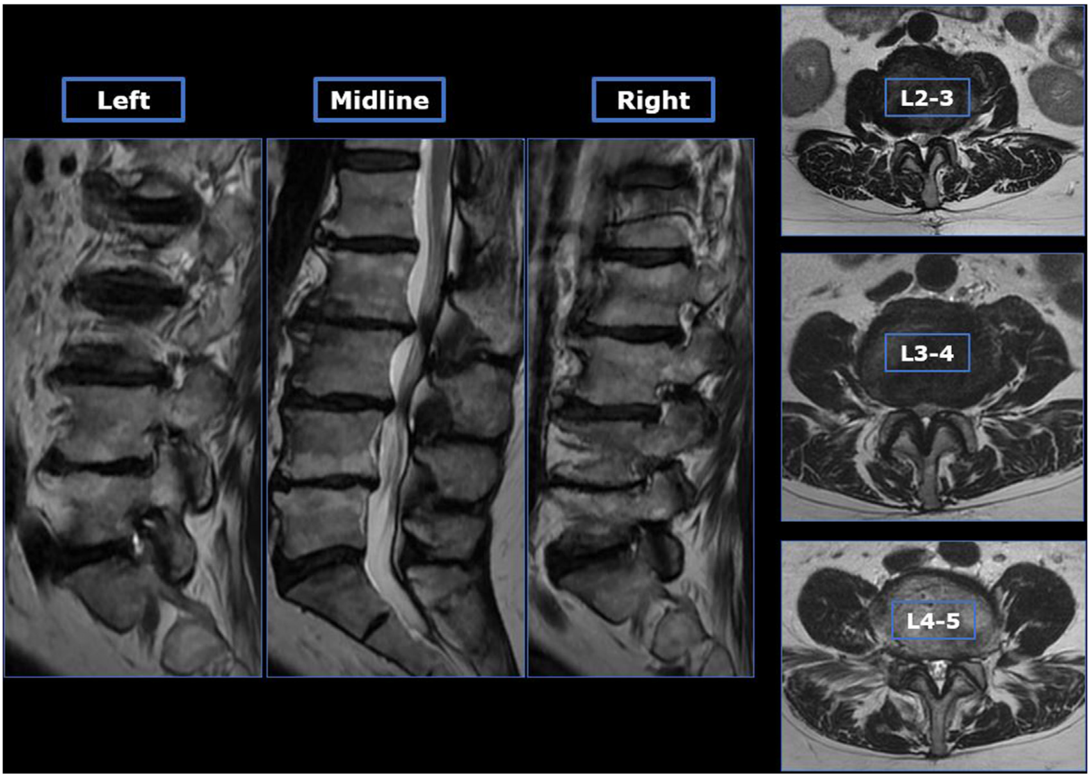

Fig. 3. Preoperative MRI.

TLIF, when combined with posterior column osteotomies, however, can both restore interbody height to accomplish foraminal decompression as well as achieve significant segmental lordosis (see **Fig. 2**).

Global Alignment Proportion Score

The global alignment proportion (GAP) score is a radiographic tool comparing measured pelvic-incidence proportional parameters to ideal spinopelvic parameters to predict mechanical complications.[33] Unlike traditional parameters for sagittal balance, such as correlation between sagittal vertical axis (SVA) and patient reported outcome measure (PROMs), the GAP score focuses on hardware complications rather than quality of life measures.[34] The principle underlying the GAP score is the focus on obtaining correction at ideal physiologic levels. For example, ACRs are generally reserved for L4-5-S1 (predominantly with ALIFs) rather than L2-3-4 (predominantly with LLIFs) to avoid placing the maximum degree of lordosis in a nonphysiological location. Several studies including traditional open deformity techniques have demonstrated a significant correlation between a moderately or severely disproportioned spinopelvic state after surgery for malalignment and higher rates of mechanical complications including proximal and distal junctional kyphosis and hardware failure.[33,35,36] However, 2 recent studies examining patients after open deformity correction found no correlation between GAP score and rates of hardware failure.[37,38] The predictive value of the GAP score in the MIS setting is under active investigation. In a retrospective study of 182 patients who underwent cMIS ASD correction, Gendelberg and colleagues found no correlation between GAP score and mechanical complications.[39] Last, a study of asymptomatic, nonoperative volunteers revealed 26% with a moderately or severely disproportioned GAP score suggesting further refinement of GAP targets is possible.[40] The GAP score remains a potentially powerful tool to aid in decision-making with additional target refinement and study in the MIS setting is ongoing.

Case 1

A 70-year-old woman with past medical history significant only for hypertension and hyperlipidemia presented with 1 year of subjectively worsening right leg weakness, bilateral radicular pain in the posterolateral distribution, neurogenic claudication including bilateral calf and foot

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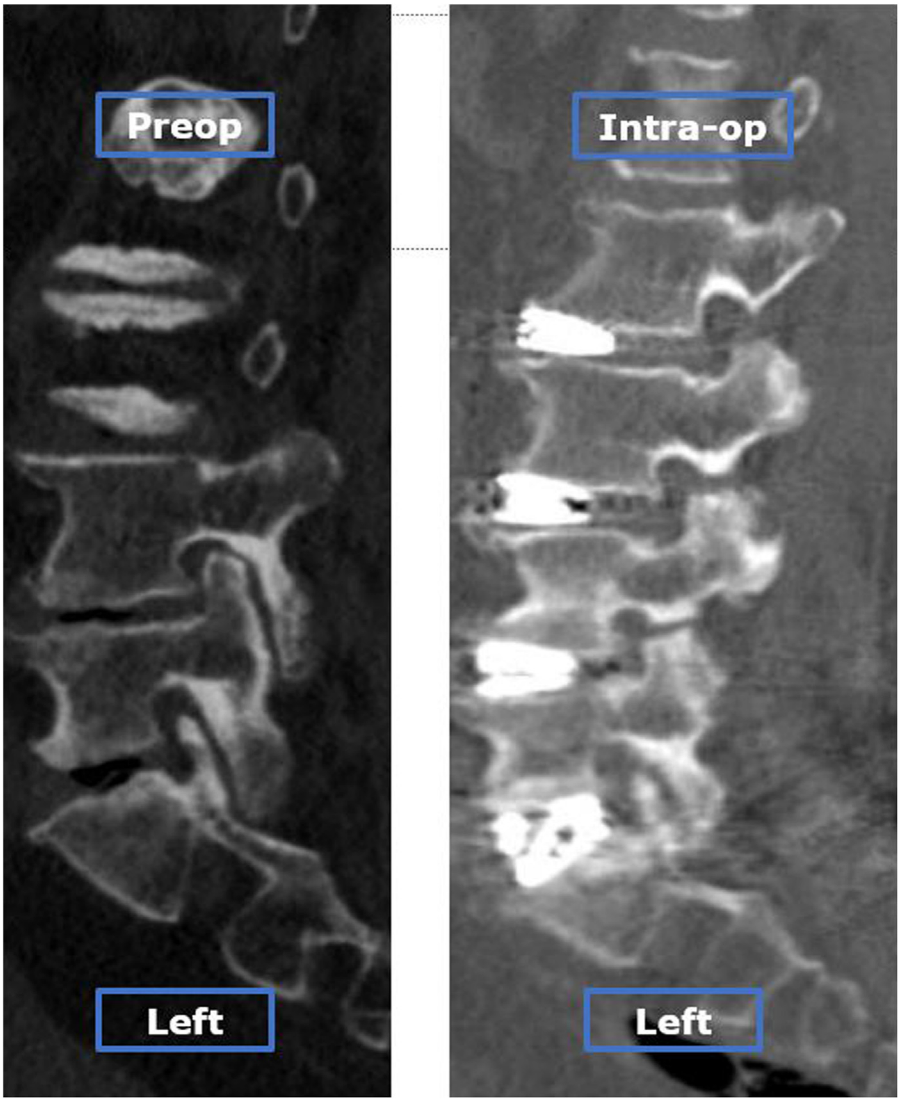

Fig. 4. Indirect decompression achieved via interbody placement.

paresthesias, and severe back pain. She had failed 1 year of oral pain medication, physical therapy, and epidural steroid injections. Her neurologic examination did not reveal any motor deficits. Her MRI demonstrated significant degenerative changes include spondylosis at L2-3, L3-4, and L4-5 with severe central and bilateral foraminal stenosis and severe left L5-S1 foraminal stenosis. Standing plain films revealed a lumbar flat back morphology with a lumbar lordosis of 11°, no significant coronal deformity, and no ankylosis. The primary pathology was thus localized to L2-S1 based on spondylosis, foraminal, and central stenosis (Fig. 3).

She is a MISDEF class 2 and was planned for a multilevel MIS procedure. She was positioned, prepped, and draped in lateral decubitus position. C-arm fluoroscopy was used for this portion of the procedure. A vascular approach surgeon gained access to the L5-S1 disc space via a mini-open, lateral-anterior approach (lateral ALIF). A 15° titanium interbody cage was placed at this level. A lateral, retroperitoneal, transpsoas approach was taken to place 10° titanium interbody cages at L2-3, L3-4, and L4-5 (LLIFs) Fig. 4. The patient was then flipped prone onto a modified Jackson table compatible with intraoperative CT navigation and posterior percutaneous pedicle screws were placed L2-S1. The patient was discharged home on postoperative day 2. At 12 months follow-up, she reports an average pain score of 0 without the use of pain

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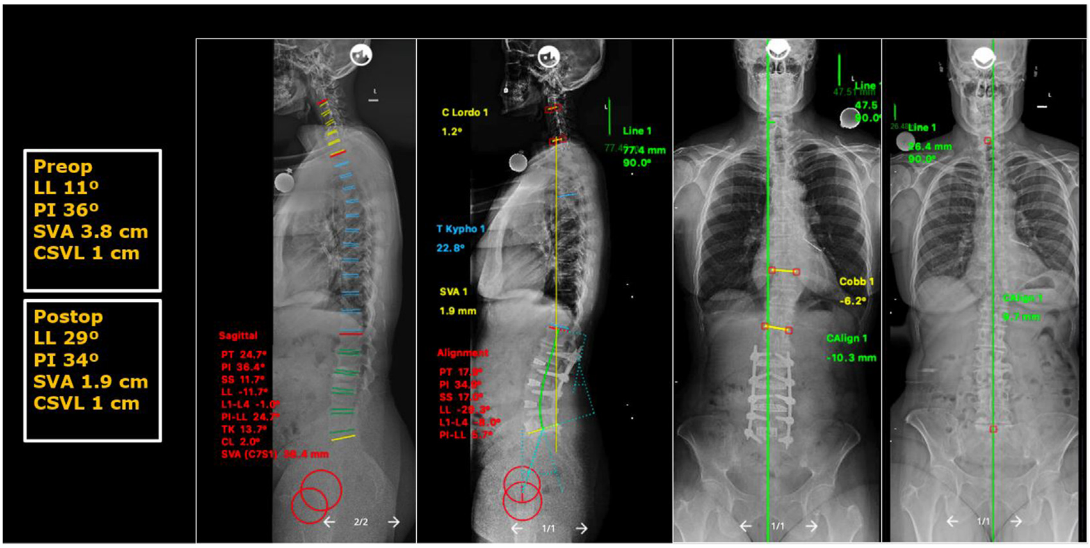

Fig. 5. Preoperative and postoperative standing radiographs for example, case 1 demonstrating a MISDEF class 2.

medication and has no ongoing limitations to her activities of daily living (ODI preop 24, postop 10). Preoperative and 1-year postoperative standing films (**Fig. 5**).

Case 2

A 69-year-old woman with 1.5 years of worsening severe axial back pain with radicular pain radiating into the right leg presented for surgical evaluation after failing conservative management. Her preoperative standing long cassette x-rays were notable for: SVA 3 cm, LL 18°, PI 49°, Coronal cobb 41°, and CSVL 3 cm. She was found to be a MISDEF class 3 and underwent a staged anterior posterior procedure. Stage 1 Anterior: L3-4, 4 to 5, 5 to 1 ALIF. Stage 2 posterior: midline incision with percutaneous pedicle screw placement through thoracolumbar fascia L1-pelvis (L1 and L2 cement augmentation via fenestrated screws), L3-4, 4 to 5 tubular posterior column osteotomies, and L1-2, 2 to 3 facet joint fusion through tubular retractors (**Fig. 6**).

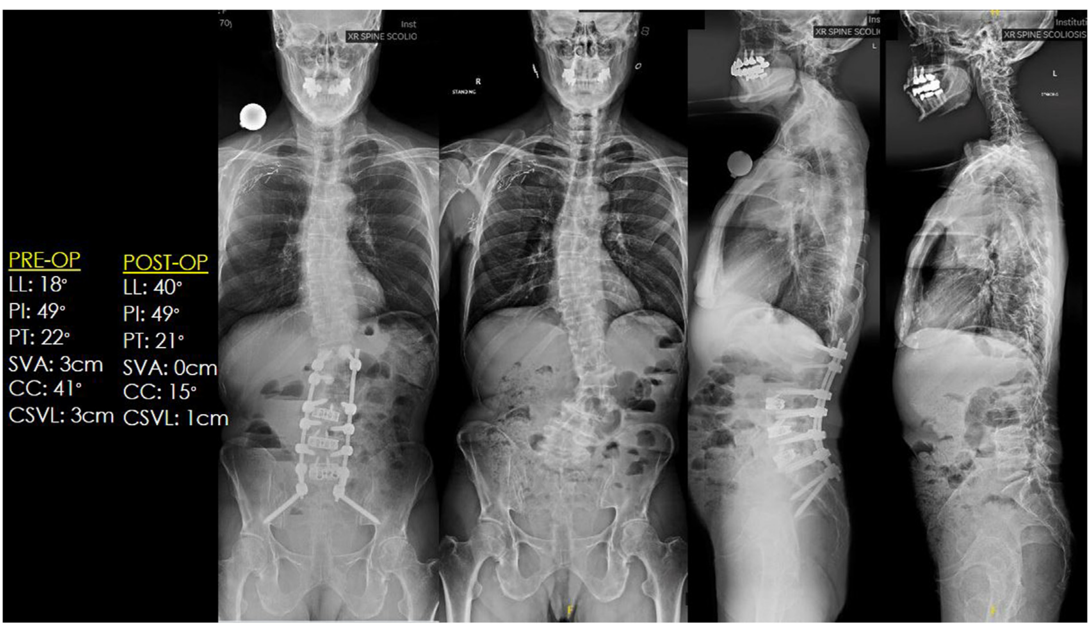

Fig. 6. Preoperative and postoperative standing radiographs for example, case 2 demonstrating a MISDEF class 3.

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SUMMARY

ASD can be associated with significant morbidity and has been found to be comparable with other systemic chronic diseases. Appropriately selected patients can benefit from surgery aimed at decompression of neural elements and restoration of spinal alignment. Traditional open surgery, although often effective, is associated with high rates of certain complications. In select patients with flexible deformities of less severe magnitude, MIS techniques allow for correction with decreased surgical morbidity. Early attempts at MIS deformity correction were hampered by high rates of pseudarthrosis and inadequate deformity correction. The capabilities of MIS deformity surgery have since evolved supported by significant advances in MIS surgical tools, techniques, and intraoperative navigation technology. Decision-making algorithms to guide patient and approach selection have been formed based on data from multi-institution working groups. As patient outcomes data continue to emerge and new technology becomes part of surgical practice, the selection algorithms will continue to evolve. Furthermore, the emergence of artificial intelligence to analyze big data cohorts and variables will continue to drive refinement including predictive metrics, of these algorithms.

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