The MISDEF2 algorithm: an updated algorithm for patient selection in minimally invasive deformity surgery

Praveen V. Mummaneni, MD,1 Paul Park, MD,2 Christopher I. Shaffrey, MD,3 Michael Y. Wang, MD,4 Juan S. Uribe, MD,5 Richard G. Fessler, MD, PhD,6 Dean Chou, MD,7 Adam S. Kanter, MD,7 David O. Okonkwo, MD, PhD,7 Gregory M. Mundis Jr., MD,8 Robert K. Eastlack, MD,8 Pierce D. Nunley, MD,9 Neel Anand, MD,10 Michael S. Virk, MD, PhD,11 Lawrence G. Lenke, MD,12 Khoi D. Than, MD,13 Leslie C. Robinson, MD, PharmD, MBA,1 Kai-Ming Fu, MD, PhD,11 and the International Spine Study Group (ISSG)

1Department of Neurological Surgery, University of California, San Francisco, California; 2Department of Neurosurgery, University of Michigan, Ann Arbor, Michigan; 3Department of Neurosurgery, University of Virginia Health System, Charlottesville, Virginia; 4Department of Neurosurgery, University of Miami, Florida; 5Department of Neurosurgery, Barrow Neurological Institute, St. Joseph’s Hospital and Medical Center, Phoenix, Arizona; 6Department of Neurological Surgery, Rush University Medical Center, Chicago, Illinois; 7Department of Neurological Surgery, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania; 8Scripps Clinic, La Jolla, California; 9Spine Institute of Louisiana, Shreveport, Louisiana; 10Department of Orthopaedics, Cedars-Sinai Medical Center, Los Angeles, California; 11Department of Neurosurgery, Cornell Medical Center, New York, New York; 12Columbia University Medical Center, New York, New York; and 13Department of Neurological Surgery, Oregon Health & Science University, Portland, Oregon

OBJECTIVE Minimally invasive surgery (MIS) can be used as an alternative or adjunct to traditional open techniques for the treatment of patients with adult spinal deformity. Recent advances in MIS techniques, including advanced anterior approaches, have increased the range of candidates for MIS deformity surgery. The minimally invasive spinal deformity surgery (MISDEF2) algorithm was created to provide an updated framework for decision-making when considering MIS techniques in correction of adult spinal deformity.

METHODS A modified algorithm was developed that incorporates a patient’s preoperative radiographic parameters and leads to one of 4 general plans ranging from basic to advanced MIS techniques to open deformity surgery with osteotomies. The authors surveyed 14 fellowship-trained spine surgeons experienced with spinal deformity surgery to validate the algorithm using a set of 24 cases to establish interobserver reliability. They then re-surveyed the same surgeons 2 months later with the same cases presented in a different sequence to establish intraobserver reliability. Responses were collected and analyzed. Correlation values were determined using SPSS software.

RESULTS Over a 3-month period, 14 fellowship-trained deformity surgeons completed the surveys. Responses for MISDEF2 algorithm case review demonstrated an interobserver kappa of 0.85 for the first round of surveys and an interobserver kappa of 0.82 for the second round of surveys, consistent with substantial agreement. In at least 7 cases, there was perfect agreement between the reviewing surgeons. The mean intraobserver kappa for the 2 surveys was 0.8.

CONCLUSIONS The MISDEF2 algorithm was found to have substantial inter- and intraobserver agreement. The MISDEF2 algorithm incorporates recent advances in MIS surgery. The use of the MISDEF2 algorithm provides reliable guidance for surgeons who are considering either an MIS or an open approach for the treatment of patients with adult spinal deformity.

https://thejns.org/doi/abs/10.3171/2019.7.SPINE181104

KEYWORDS MISDEF; MISDEF2; adult spinal deformity; minimally invasive; spine surgery

ABBREVIATIONS ACR = anterior column realignment; ASD = adult spinal deformity; LL-PI = lumbar lordosis–pelvic incidence; LLIF = lateral lumbar interbody fusion; MIS = minimally invasive surgery; MISDEF = MIS deformity; MISDEF2 = MISDEF revision 2; PT = pelvic tilt; SVA = sagittal vertical axis; TLIF = transforaminal lumbar interbody fusion.
Adult spinal deformity (ASD) affects a significant number of patients, resulting in severe pain and morbidity. Patients with ASD can report health-related quality of life comparable to those suffering from cancer or significant heart disease. Furthermore, the presence of spinal deformity can result in less-optimal outcomes for patients treated for degenerative spinal disease. Therefore, the awareness of spinal deformity has increased, and more patients are being treated with a deformity-cognizant approach.

However, treatment of deformity by open techniques can result in significant morbidity. Complication rates are relatively high due to the extensive nature of spinal reconstruction. Some patients, especially elderly patients, may not be considered candidates due to the morbidity associated with these approaches. Less-invasive techniques may allow more patients to undergo operative treatment of their deformity. Previously, we developed a minimally invasive surgery (MIS) deformity (MISDEF) algorithm to assist in patient selection for MIS for treatment of the deformity (Fig. 1). This algorithm focused on sagittal parameters in the determination of the suitability of MIS techniques for deformity patients. Patients with significant sagittal imbalance were not considered candidates for MIS at the time. Since the publication of this algorithm, advances in MIS techniques and a better understanding of sagittal plane parameters in older patients have potentially broadened the range of patients who may be candidates for less-invasive deformity surgery. We therefore revised the algorithm using a Delphi process to incorporate newer technique options and developed the minimally invasive spinal deformity revision 2 (MISDEF2) algorithm.

**Methods**

**Design by Modified Delphi Technique**

A panel of 10 senior surgeons with expertise in deformity and/or MIS techniques met regarding the creation of the MISDEF2 algorithm (Fig. 2). A survey of important factors informed the draft algorithm. Through multiple meetings over the course of 3 months, the factors known to influence decision-making in deformity were identified and stratified into the algorithm. Advances in MIS techniques for deformity were delineated and incorporated into the algorithm. Through the course of the Delphi process, several iterations of the algorithm were created and modified. At the conclusion of the process, 4 distinct types of patients were classified.

**MISDEF2 Algorithm**

Multiple factors are considered while progressing through the algorithm. The first concern is whether or not the deformity is fixed or flexible. This can be done by assessing the deformity with supine radiographs and/or CT scout views and comparing them with standing 36-inch long cassette radiographs to evaluate the degree of change from standing to supine. If the deformity is fixed, the patient will classify as class III or IV. If the patient has a
Class I

Class I patients often present with a significant component of radicular pain (Fig. 3). Axial back pain is not the primary complaint. These patients have minimal, if any, sagittal plane deformity. Sagittal balance is within accepted normal parameters, less than 6 cm positive. The lumbar lordosis–pelvic incidence (LL-PI) mismatch is less than 10°, and the pelvic tilt (PT) is under 25°. The coronal Cobb angle is less than 20°. The patient’s main complaints stem from compression of the neural elements. Surgical treatment is planned for this indication and can be performed with a minimally invasive decompression with or without a focal fusion at the level of interest.

Class II

Class II patients are similar to class I patients with the exception that the coronal Cobb angle is more significant (Fig. 4). These patients may have an increased sagittal malalignment, but pelvic parameters are within the range of normal. Specifically, the patients eligible for class II treatment have an LL-PI mismatch up to 30°, thoracic kyphosis less than 60°, and thoracolumbar junction kyphosis less than 10°. These patients do not have a fixed deformity and can be treated with MIS multilevel fusion techniques addressing the area of lumbar deformity.

Class III

Class III patients have significant sagittal deformity (Fig. 5). Increased sagittal vertical axis (SVA) coupled with increased PT and LL-PI mismatch is present. These patients may have fixed deformities. Specifically, the LL-PI mismatch is greater than 30°, the thoracic kyphosis may be over 60°, and the thoracolumbar junction kyphosis may be over 10° as long as there is no preexisting hardware that needs to be revised and as long as the patient has not had more than 5 levels of prior fusion that included L5–S1. In addition, the patient should not need more than 10 segments requiring treatment, since achieving solid fusion
for over 10 segments with MIS techniques is a challenge. These patients can be treated with open techniques, but circumferential MIS techniques such as anterior column release may also be an option for the surgeon experienced in advanced MIS techniques.

Class IV

Class IV patients have significant deformity (Fig. 6). They may have had prior surgery with instrumentation that needs to be revised or they have instrumentation of 5 levels or more of prior fusion including L5–S1. The pa-
tients have significant sagittal plane abnormalities and require more than 10 segments to be instrumented. These patients are not candidates for MIS techniques and should be treated with open deformity surgery.

Analysis

In order to test the reliability and reproducibility of the algorithm, 24 cases were developed from already published literature. The case information included anteroposterior and lateral standing scoliosis radiographs, and MR images when available. Standard parameters such as SVA, LL-PI, PT, coronal Cobb angle, and thoracic kyphosis were measured and reported. These 24 cases included multiple examples from each class. The cases were then graded by 14 evaluators who are MIS and/or deformity spine surgeons and included a spectrum of spine surgeons.
who had completed training within the past year as well as those in practice for over a decade. The 14 evaluators were chosen to be representative of surgeons who would be treating deformity with both open and less-invasive approaches. These 14 evaluators were chosen from a variety of groups and centers so as to obtain a broad sampling of spinal deformity surgeons. All evaluators were either orthopedic- or neurosurgical-trained surgeons with a postresidency fellowship. Each evaluator performed 2 rounds of grading separated by a minimum of 1 month per round. The cases were randomized between rounds 1 and 2. Each evaluator assessed all cases. The evaluators included 10 surgeons who were not involved in the creation of the algorithm. The surgeon who chose the cases was not included in the evaluation. Statistical analysis was performed by Fleiss kappa correlation for interreviewer reliability and kappa correlation analysis for intrareviewer reliability. Correlation values were determined using IBM SPSS (version 25, IBM Corp.).

Results

Over a 3-month period, 14 fellowship-trained deformity surgeons completed the surveys. Correlation values for each reviewer were obtained. The intraobserver kappa values averaged 0.8, which corresponds to a value in the significant correlation range. Eleven of the 14 reviewers had kappa values of 0.8 or greater. One reviewer had a kappa value of 0.78. Two others had kappa values around 0.3; one of these surgeons was a predominantly MIS surgeon and the other a traditional open deformity surgeon.

In terms of interobserver correlation, the kappa value was 0.85 for round 1, with a 95% CI of 0.76–0.92. For round 2, the kappa value was 0.82 with a 95% CI of 0.74–0.9. There was perfect agreement between the reviewers in 7 cases. The interobserver correlation values fall in the significant correlation range.

Discussion

There has been increasing evidence that minimally invasive approaches are effective for the treatment of ASD. A recent study evaluated 71 patients with ASD who underwent circumferential MIS deformity correction. An average of 4.4 levels were treated with a mean follow-up of 39 months. Overall, the mean preoperative coronal Cobb angle of 24.7° was corrected to a mean of 9.5°, while the mean preoperative SVA of 31.7 mm was corrected to 10.7 mm. In another investigation analyzing hybrid and circumferential MIS, 105 patients treated for ASD were studied, 43 of whom underwent circumferential MIS. In this cohort, a mean of 5.1 levels were treated, and the mean follow-up was 38.3 months. There was significant improvement in the Oswestry Disability Index score from 48.0 to 23.2 as well as in back and leg pain, with visual analog scale scores improving from 6.7 to 2.9 and 6.0 to 1.8, respectively. Radiographically, the coronal Cobb angle significantly decreased from 19.7° to 9.4°. With regard to SVA, PT, and LL-PI mismatch, there were no significant changes; however, the preoperative parameters of SVA (30.0 mm), PT (22.2°), and LL-PI mismatch (10.2°) were either close to or within normal thresholds.

Although the degree of coronal curvature correction has been shown to be significant, the major concern with minimally invasive approaches has been its impact on sagittal alignment. Early minimally invasive approaches consisted mainly of multilevel LLIF or MIS transforaminal lumbar interbody fusion (TLIF) in conjunction with percutaneous fixation. These interbody techniques, however, in many cases result in relatively small increases in segmental and regional lordosis. Consequently, in cases in which there is significant spinopelvic malalignment, justifiably there would be concern for insufficient sagittal correction. Based on the concern that early MIS approaches could not adequately address significant sagittal malalignment, the MISDEF algorithm was proposed. Based on key radiographic parameters, the MISDEF algorithm was designed to help guide decision-making on whether an MIS approach to a particular deformity was a reasonable option. This algorithm took into account the constraints of MIS techniques in obtaining extensive sagittal correction.

While the original MISDEF algorithm was an appropriate reflection of the existing MIS approaches being performed at the time of its publication, in recent years there have been advances in both MIS techniques and device technology. These advances have allowed increased sagittal correction. One newer technique is that of anterior column realignment (ACR) involving sectioning of the anterior longitudinal ligament. In contrast to the traditional lateral lumbar interbody fusion (LLIF), ACR results in significantly more lordosis. Manwaring et al. evaluated 9 patients who underwent 15 ACR levels and found a mean of 12° of increased segmental lordosis and 3.1 cm of increased SVA per ACR level. In a multicenter study evaluating ACR in ASD surgery, segmental lordosis increased on average 9.9° with ACR, compared with only a 3.3° improvement with traditional LLIF. Moreover, there was a mean 17.1° increase in segmental lordosis when a posterior column osteotomy was performed at the level of the ACR, as could be done in a hybrid-type procedure. Overall, the use of ACR resulted in significant improvements in lumbar lordosis, PT, and LL-PI mismatch. Other MIS techniques that have more recently been reported to achieve significant sagittal realignment include the mini-open pedicle subtraction osteotomy.

Along with techniques such as ACR, hyperlordotic and expandable cages are examples of new implant technologies that have positively influenced the degree of sagittal correction that can be achieved through MIS approaches. In one study of 66 patients treated with circumferential MIS surgery, 224 cages of differing lordotic angles were placed via LLIF. Increased segmental lordosis was noted with increasing cage angle sizes of 6°, 10°, 12°, and 20° in which there were increases of 7.26°, 8.08°, 8.03°, and 14.22°, respectively. In another investigation, static versus expandable cages placed via the MIS TLIF technique were evaluated. With expandable cages, segmental lordosis changed significantly more (5.8° to 11.0°) when compared with static cages (5.8° to 8.1°).

With these advances in MIS techniques and implant technology, the basis of the original MISDEF algorithm has become outdated. Compared with the first-generation MIS approaches, evolving techniques have allowed for
more effective coronal and sagittal realignment. Consequently, the premise of this study was to develop a modified MISDEF algorithm to incorporate contemporary techniques and technology. Compared with the original algorithm, this new algorithm has 4 classes rather than 3, which reflects the current breadth of options now available, spanning tubular MIS approaches to mini-open, hybrid, and traditional open surgeries. As can be seen in the new algorithm, techniques such as ACR, mini-open pedicle subtraction osteotomy, hybrid MIS, and open procedures in addition to technology such as expandable cages are included. Like the original algorithm, spinopelvic parameters are the key variables used to determine the most appropriate surgical approach. Also similar is that the development process of the algorithm incorporated the experience of a large number of surgeons experienced in MIS and traditional open deformity surgery. As reflected in the high intraclass correlation, this modified algorithm is very reproducible. In addition, interclass correlation in both rounds of this study was high, reflecting the reliability and consistency between individual surgeon interpretations. Although overall interclass agreement was high, there were cases of lesser agreement, mainly in regard to classes III and IV. One example is shown in Fig. 7, where the patient has a high SVA and history of uninstrumented fusion. Based on the modified algorithm, this patient would have been in class IV if the fusion involved a large segment. Without instrumentation, the likely disagreement stemmed from differing interpretations of the number of levels fused.

Similar to the original version, this new algorithm determines the appropriate surgical approach based mainly on key radiographic parameters such the SVA, PT, and LL-PI mismatch, which have been shown to correlate strongly with pain and disability measures. The algorithm does not incorporate significant comorbidities such as osteoporosis, which are essential factors in the surgery decision-making process. Consequently, this modified algorithm should be used in conjunction with the overall clinical picture to determine if surgery is reasonable and ultimately select the most suitable operation. Another important point is that idealized radiographic parameters were utilized. Elderly patients likely will require less correction, so radiographic alignment goals should be modified with consideration of the patient’s age.

Conclusions

Less-invasive techniques for spinal deformity continue to advance. Consequently, more patients may be candidates for less-invasive deformity surgery, even those with significant sagittal imbalance. The MISDEF2 algorithm provides a reliable framework, using the best available metrics, for identifying patients amenable to minimally invasive deformity surgery using the latest state-of-the-art implants and techniques.

Appendix

Members of ISSG


References

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Disclosures

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

Supplemental Information
Previous Presentations
Portions of this paper were presented at the 34th Annual Meeting of the AANS/CNS Section on Disorders of the Spine and Peripheral Nerves, Orlando, Florida, March 14–17, 2018.

Correspondence
Kai-Ming Fu: Cornell Medical Center, New York, NY. kaimingfu@gmail.com.