A Staged Protocol for Circumferential Minimally Invasive Surgical Correction of Adult Spinal Deformity

**BACKGROUND:** Minimally invasive surgery (MIS) techniques used for management of adult spinal deformity (ASD) aim to decrease the physiological demand on patients and minimize postoperative complications. A circumferential MIS (cMIS) protocol offers the potential to maximize this advantage over standard open approaches, through the concurrent use of multiple MIS techniques.

**OBJECTIVE:** To demonstrate through a case example the execution of a cMIS protocol for management of an ASD patient with severe deformity.

**METHODS:** Thorough preoperative assessment, surgical planning, and medical optimization were completed. Deformity correction was performed over 2 stages. During the first stage, interbody fusion was performed via an oblique lateral approach at all levels of the lumbar spine intended to be included in the final construct. The patient was kept as an inpatient and mobilized postoperatively. They were then re-imaged with standing films. The second stage occurred after 3 d and involved percutaneous instrumentation of all levels. Posterior fusion of the thoracic levels was achieved through decortication of pars and facets. These areas were accessed through the intermuscular plane established by the percutaneous screws. The patient was mobilizing on their first postoperative day.

**RESULTS:** In a 66-yr-old female with severe sagittal imbalance and debilitating back pain, effective use of this cMIS protocol allowed for correction of the Cobb angle from $52^\circ$ to $4^\circ$ correction of spinopelvic parameters and 13 cm of sagittal vertical axis improvement. No complications were identified by 2 yr postoperative.

**CONCLUSION:** As a systematization of multiple MIS techniques combined, in a specific and staged manner, this cMIS protocol could provide a safe and effective approach to the management of ASD.

KEY WORDS: Adult spinal deformity, Circumferential minimally invasive spine surgery, Spinal fusion, Staged spinal surgery, Scoliosis, Lateral lumbar fusion, Percutaneous pedicle screws

Over the past 10 yr, development of minimally invasive surgery (MIS) techniques for management of adult spinal deformity (ASD) has been driven by a need to decrease the risk of complications typically encountered in open deformity surgery.1-3 Today, multiple MIS techniques and technologies are available for a spine surgeon to combine in order to reach this goal. This variety of options in turn has led to the development of multiple different operative protocols and opinions, including those that have suggested that comparable deformity correction is not achievable using MIS techniques.4-7

The surgeon who is looking to adopt a new minimally invasive approach to spinal deformity surgery is confronted with 2 major obstacles.

**ABBREVIATIONS:** ALL, anterior longitudinal ligament; ASD, adult spinal deformity; BMP, bone morphogenic protein; cMIS, circumferential MIS; DBM, demineralized bone matrix; ICU, intensive care unit; ISSG, International Spine Study Group; LL, lumbar lordosis; MIS, minimally invasive surgery; PI, pelvic incidence; PJK, proximal junctional kyphosis; PEEK, polyetheretherketone; PT, pelvic tilt; SVA, sagittal vertical axis; TFO, transforaminal osteotomies; TK, thoracic kyphosis
METHODS

Preoperative Assessment and Management

After thorough history taking and physical examination, every patient is evaluated with standing 36° scoliosis series X-rays. These are used to measure the patient’s deformity and spinopelvic parameters. There is no limit to or combination of spinopelvic parameters that contraindicate the use of this protocol.

Next, an MRI is obtained and if there is suspicion that any segment appears fused, a CT scan is obtained. The CT assesses for fusions of the facets or interbody segment, which would interfere with deformity correction through the use of interbody spacers. The MRI is useful to document spinal stenosis and also to make sure that there are no sequestered disc fragments in the spinal canal. The latter would be a contraindication to indirect decompression of the lumbar spine through a lateral approach.

In planning the extent of the fusion, all vertebrae contained within the Cobb angle are included. The upper instrumented level is the vertebra below the first normal parallel disc on MRI and X-ray. Distally, the L5-S1 level is spanned if there is any local stenosis, instability, obliquity, degenerative changes, sagittal imbalance greater than 10 cm, or osteoporosis.

All patients are also evaluated for osteoporosis with a bone density scan. We consider a T-score less than –3 to be a contraindication to using a cMIS approach. If the T-score is between –2 and –3, patients are referred to an endocrinologist and started on teriparatide (Forteo, Eli Lilly and Company, Indianapolis, Indiana) preoperatively if not otherwise contraindicated.

Interbody Fusion

The first stage of surgery consists of minimally invasive lateral lumbar interbody fusions. This is performed at every lumbar interbody space that is to be spanned by the final posterior construct.

Following induction of general anesthesia, the patient is positioned lateral on a radiolucent table in the left lateral decubitus position. The patient is secured in place with tape, and no break in the table is applied. Prior to draping, fluoroscopy is used to confirm the disc levels and the incisions are marked. We prefer to use an oblique antepsoas approach for the lateral lumbar interbody fusion as this avoids the bulk of the psoas muscle and possible injury to the lumbosacral plexus. In a similar fashion, an anterior-oblique approach in the lateral position is used to access the L5-S1 disc space when needed. This allows for all lumbar disc spaces to be addressed without the need for repositioning or redraping.

Intervertebral levels are addressed from distal to proximal. At the L5-S1 level, following anterior disectomy and endplate preparation, the posterior longitudinal ligament is released off the inferior vertebra. This facilitates restoration of disc space height in addition to angular correction.

For each interbody fusion, polyetheretherketone (PEEK) cages packed with 2 to 4 mg of bone morphogenic protein (RhBMP-2/ACS; INFUSE, Medtronic Sofamor Danek, Memphis, Tennessee) and Grafton putty demineralized bone matrix (DBM; Osteotech, Eatontown, New Jersey) are used. It should be noted that all BMP mentioned in this protocol is used in an off-label fashion. Following placement of each cage, 4 mg of dexamethasone in 1 mL of normal saline is applied locally to the intervertebral space. The spaces are then packed with additional DBM. Twelve-degree lordotic cages are used at all the levels up to L2-3. At L1-2 and T12-L1, either 12° or 6° cages are used as indicated by the patient’s spinopelvic parameters.

Each incision allows access to at least 2 levels. After dividing skin and subcutaneous tissue, the external and internal oblique muscles are encountered separately and split bluntly along their fibers. The transversalis fascia is entered bluntly against the inner wall of the iliac crest. The surgeon’s finger is then swept along the iliac crest inner wall from posterior to anterior thereby moving the peritoneal contents anteriorly and sweeping it off the psoas muscle. Keeping the finger under the abdominal wall, all contents are swept anteriorly while the underside...
of the 12th rib and the inner wall of the iliac crest are palpated. These 2 anatomical landmarks ensure that one is in the retroperitoneal space, especially in very obese patients. The retroperitoneal space is further opened with the help of an anterior retractor and the anterior border of the psoas is visualized. This approach avoids transgressing the bulk of the psoas muscle while accessing the disc anterior to the psoas. Furthermore, the surgeon’s finger can confirm the location of the aorta by feeling pulsations similar to how one would feel for carotid pulsations when performing an anterior approach to the cervical spine. Sequential dilators are then guided down onto the intervertebral disc space anterior to the anterior margin of the psoas. Once the trajectory and access to the disc space is confirmed, lateral interbody fusion is performed in the typical fashion. Additional care is taken to place the interbody device and instruments in an orthogonal manner from left to right in the interbody space.

We have found that sequential multilevel lateral lumbar interbody fusion with 12° cages seems to obviate the need for routine anterior longitudinal ligament (ALL) release in most patients with de novo or adult idiopathic scoliosis.12,13 Our most frequently used cage is 12 mm by 12°.

Mobilization and Restaging

Postoperatively, the patient is admitted as an inpatient and mobilized on the same day on the floor. New standing lumbar and 36° scoliosis series X-rays are obtained on their second or third postoperative day. New spinopelvic parameters are measured. The preoperative plan for their second stage of surgery is adjusted as needed based on these parameters (see Figure 1). If for any reason age appropriate sagittal alignment and spinopelvic parameters are still grossly off, posterior column osteotomies (see Figure 1) and sagittal alignment with fusion can be added in the second stage. Thoracic instrumentation to T2 with thoracic transforaminal osteotomies (TFO) is used in the setting of persistent thoracic kyphosis.12

The staging also allows for direct clinical assessment of indirect decompression. The absence of radicular or claudicatory symptoms is noted as patients ambulate after the first stage. If lower extremity symptoms persist, this is investigated with an MRI. If a region of residual stenosis is identified, a microdecompression is added to the patient’s second-stage surgery. Only 4 patients have ever needed a microdecompression after the first stage.

Posterior Instrumentation and Fusion

The second stage of surgery is performed 2 to 3 d later with the patient prone on a Jackson table. Lordosis is emphasized with the positioning. If a prior midline incision exists, then the same incision is used, skin is mobilized laterally, and pedicles are cannulated perfascial. If no midline incision exists, we prefer multiple small skin incisions to percutaneously cannulate the pedicles. If iliac bolts are being placed, they are placed minimally invasively into the pelvis at the posterior inferior iliac spine. Pedicles are then instrumented from distal to proximal using either a percutaneous or transfascial muscle sparing technique.

Posterior column or TFO, in the form of partial facetectomies, can now be performed if necessary. These can also be done minimally invasively using the same portals created by the percutaneously placed screws. The facets are resected aggressively with a chevron osteotomy done from lateral to medial. The main difference from a Ponte osteotomy is that the midline is kept intact. Compression maneuvers can then be done to gain more lordosis at each segmental level as needed. Facet resection or osteotomy is very rarely if ever indicated. In our experience, we have never required facet resection and have performed TFOs in the thoracic spine in 3 patients who had persistent thoracic kyphosis after their first-stage surgery.

Five and one-half millimeter titanium alloy rods are then measured, cut, and contoured to the intended final curvature. The rod is exclusively contoured in the sagittal plane with no coronal bend. We also try to overcontour the rod to allow for some give, as the reduction maneuvers are done. The nature of the reduction is such that the spine derotates and translates to the sagitally contoured rod. We do not use cobalt-chrome rods. Our experience suggests that these rods are too stiff, and can lead to screw pull-out either during or following the reduction process.

Once the rod is appropriately contoured, it is then guided into the screw extenders from proximal to distal. Care is taken to specifically pass the rod subfascial. The intervening fascia between screw incisions is sometimes released to facilitate the passage of the rod. This can be particularly useful when there is excessive lordosis.

Rod reduction and aggressive curve correction are facilitated by the technology of the percutaneous rod reduction system. It is important to use a modern instrumentation system that uses large reduction windows and significant reduction strength. The contoured rod is reduced into the tulips of the screws with initial reduction performed at the apex of the lordosis thereby maximizing the lordosis to be obtained and decrease any flattening of the rod. Sequential reduction of the rod to the tulips of the screw at each level is then performed. This allows for derotation and translation of the spine to the rod with strict sagittal orientation maintained. The construct is then examined with fluoroscopy to confirm that no screws have pulled out and then the set screws are torque tightened.

Paramedian posterior fusion is carried out at all levels that do not have an interbody fusion. Access is gained to the pars and facets of each level. Again, this is facilitated by the established fascial windows and intramuscular plane already developed by placement of the percutaneous screws. The pars and facets are decorticated with a high-speed Burr and packed with a combination of local bone graft, 1 mg of RhBMP-2, and DBM at each level. No drain is placed. Blood loss during this procedure is typically less than 300 mL. Minimal fluid resuscitation is required and patients are extubated and neurologically examined before being brought to the recovery room.

Postoperative Management

All patients are mobilized out of bed on their first day postoperatively. No braces are used. Discharge home or to a rehabilitation facility typically occurs at postoperative day 3 to 5. Standing scoliosis films are obtained on the day of discharge. If the patient is taking Forteo (Eli Lilly and Company), this is continued for 1 yr postoperatively.

IRB approval was obtained for this study. The patient described in the following case example provided both written and verbal consent to have their de-identified demographic and clinical information presented in this article.

RESULTS

Case Example

This patient was a 66-yr-old female with thoracolumbar degenerative scoliosis. She had a 4-yr history of progressive and persistent middle and lower back pain. This was accompanied by neurogenic claudication and lumbar radicular pain. She complained of feeling pitched forward with a right truncal shift.
Her spinopelvic parameters were as follows: pelvic incidence (PI) 47°, lumbar lordosis (LL) 56°, thoracic kyphosis (TK) 70°, pelvic tilt (PT) 25°, C7 coronal plumbline 5.2 cm to the right, and sagittal vertical axis (SVA) 13.1 cm. The Cobb angle of her thoracolumbar dextroscoliosis was 52°. Preoperative plain films are shown on Figures 2A and 2B. A lumbar MRI (not shown) demonstrated multilevel foraminal stenosis secondary to scoliosis.

Her first-stage surgery was performed using a minianterior-oblique approach to access L5-S1. Two separate lateral incisions were used to gain oblique-lateral access to L4-L5 and L3-4, L2-L3, L1-L2, T12-L1, respectively. We placed 12° lordotic cages at levels L2-3 to L5-S1, and 6° lordotic cages at levels T12-L1 and L1-L2.

She was then admitted as an inpatient and mobilized with the assistance of physical therapy. She denied any leg pain and she did not demonstrate any neurological deficits. New upright films were taken to reassess her spinal balance. In this patient’s case, a CT scan was performed amidst workup for abdominal pain that later resolved. The Cobb images demonstrate the deformity correction obtained after the first-stage surgery (see Figures 3A and 3B). The Cobb angle was already reduced to 16°. This was one of the rare cases where a standing film could not be obtained following the first stage due to abdominal discomfort and hence the preop X-rays were used to make decisions regarding the second stage especially regarding the presence of significant thoracic kyphosis.

On her third postoperative day, she was brought back to the operating room for her second-stage surgery. A midline skin incision was used. Screws and rods were placed in a trans-fascial, muscle sparing manner under fluoroscopic guidance. T2 to T12 was then accessed through the paramedian intermuscular plane created by the pedicle screws. TFOs were performed from T2 to T12. The pars and facets were decorticated and packed with local bone dust, RhBMP-2, and Grafton DBM. Rods were measured, cut, contoured, and introduced into the screw extenders freehand. This was followed by graduated reduction and translation maneuvers.

The patient recovered on the floor postoperatively before being transferred to an acute rehabilitation center. At 6-wk follow-up, she was able to walk independently. She was off all narcotics by 4 wk. Postoperative images at 2 yr are shown in Figures 4A and 4B. Final spinopelvic parameters at 2 yr areas follows: LL 52°, TK 56°, PT 17°, Cobb angle 4°, C7 coronal plumbline 1.8 cm to the right, and SVA 0 cm. At 18 mo postoperatively, a CT scan was performed to assess the fusion. This showed consolidation of the fusion mass spanning the full length of the construct (see Figures 5A and 5B).

**DISCUSSION**

Traditional open surgical management of ASD has been identified as carrying an 8.4% risk of major perioperative complication and a 40% to 86% risk of long-term complication. Multiple studies have shown that MIS techniques are associated with relative decreases in these risks. The protocol for cMIS management of ASD described in this paper comprises multiple MIS techniques used in a strategic staged manner.
Early postoperative mobilization and minimization of narcotic use are crucial to the avoidance of early complications. The application of steroids locally to the disc space following lumbar interbody fusion has been shown to improve immediate post operative pain.\textsuperscript{17,18} We therefore consider this to be an important adjunct to our protocol and it has not appeared to have any deleterious effect on achieving fusion.\textsuperscript{3}

Anaesthesia literature has shown that total fluid resuscitation administered during spine surgery is correlated with the need for, and length of stay in the intensive care unit (ICU).\textsuperscript{19} The use of staged surgeries in this protocol with low volume blood loss allows patients to avoid admissions to the ICU.

Transpsoas lateral lumbar interbody fusion has been shown to be associated with a risk of lumbar plexopathy.\textsuperscript{20} Cadaveric studies have shown that this plexus can be avoided using approaches anterior to the muscle.\textsuperscript{21} Since the adoption of this approach to interbody device placement, we have not encountered any cases of postoperative quadriceps palsies.\textsuperscript{3}

Consistent with previous literature, with hyperlordotic interbody device placement we are able to reliably obtain a delta change of 10° of correction at L5/S1 and delta correction of 5° to 6° at each level above that.\textsuperscript{12,22,23} If additional correction is still needed, an ALL release can be performed. Uribe et al\textsuperscript{24} demonstrated in a cadaveric study that ALL release does allow for increased segmental lordosis. In our experience, we have not yet found this to be necessary to achieve our sagittal alignment goals.\textsuperscript{3}

Compared to open pedicle screw placement, percutaneous screw placement has been shown to preserve the multifidus muscle and improve postoperative trunk muscle performance.\textsuperscript{25} This may be yet another factor contributing toward improved postoperative mobilization and pain control in this population.

A multicenter case series published by the International Spine Study Group (ISSG) in 2016\textsuperscript{26} showed that proximal junctional kyphosis (PJK) was significantly less common following deformity surgery that used all percutaneous screws compared to surgery that used open screw placement. This superiority was lost however when subjects from the 2 groups were matched according to the number of levels fused. This suggests that percutaneous screw placement alone is not sufficient to avoid this complication, and it highlights the importance of a comprehensive protocol.

Literature reviews on long fusion constructs have shown that high construct rigidity can contribute to increased rates of junctional kyphosis.\textsuperscript{27} We have continued to use exclusively 5.5 mm titanium alloy rods. This combined with a midline sparing posterior approach may explain the lower rate of PJK with cMIS techniques for ASD.\textsuperscript{3,7}
Limitations
Some prior studies on MIS techniques for ASD have suggested that they are inferior in correcting sagittal parameters when compared to traditional open surgery. While the use of hyperlordotic cages and aggressive rod contouring appear to have addressed this concern, it is important to appreciate that there is an increasing risk of PJK as the degree of deformity correction rises. We therefore aim to restore sagittal alignment to values more compatible with the patient’s age group. As we have recently reported, this protocol has yielded a rate of PJK below that of traditional open techniques.

Adoption of this protocol may certainly be subject to a learning curve. First, while every technique described in this paper has been available for many years, inexperience with any 1 step may not only lengthen operative time, but ultimately limit a surgeon’s success with this protocol significantly. We therefore recommend achieving proficiency with each individual technique separately before combining them into this full, 2-stage protocol. Second, multilevel use of PEEK interbody cages and RhBMP-2 may introduce issues with operative cost management. Our expectation is that this implant cost will eventually be offset by avoidance of ICU admissions, decreased blood transfusion, decreased complications, with decreased rates of readmission and reoperation. As our experience with this protocol continues to grow, further research dedicated to addressing this question will need to be performed.

CONCLUSION
The protocol outlined in this paper provides a comprehensive method for managing ASD using circumferential MIS techniques. The systematic application of its individual steps makes it an accessible option to surgeons previously unfamiliar with MIS for management of adult deformity. It also allows for sequential harmonic correction of coronal and sagittal balance in a methodical manner. As an alternative to traditional open deformity surgery, it appears to be associated with fewer postoperative complications. This will be better clarified in future reports as patient follow-up continues.

Disclosures
Dr Anand is on the Scientific Advisory Board for Globus Medical and Theraceq, is a consultant for Globus Medical and Medtronic, is on the Speaker’s Bureau for DePuy Synthes, Stryker Spine, and Paradigm Spine, receives royalties from Globus Medical, Medtronic, and Elsevier, and has stocks/options in Paradigm Spine, Theraceq, Medtronic, and Globus Medical. Dr Fessler has royalties that Medtronic, Stryker, and DePuy, and is the owner of In Queue Innovation. Dr Kong has no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES


COMMENT

In this article, a protocol is provided to optimally treat patients with thoracolumbar spinal deformity via a completely MIS fashion. The strength of this protocol is that it appears to address one of the biggest concerns of an MIS approach for deformity, specifically, whether adequate correction of the spino-pelvic parameters can be achieved. Radiographic assessment between stages as outlined in the protocol is a key step to determine what is needed in the second stage to maximize correction. Important preoperative assessment recommendations including evaluation of osteoporosis in addition to use of hyperlordotic cages and technical nuances such as rod contouring and reduction as well as the need of biologics to optimize fusion are outlined. It cannot be overemphasized, however, that there is a high learning curve associated with MIS deformity surgery. In addition, there are downsides including the potential for increased operative time, radiation exposure, and costs that need to be factored into deciding on the best approach to treat the patient with symptomatic deformity.

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