Semin Spine Surg 31 (2019) 106–111

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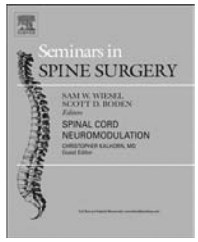

Revision surgery for adult spine deformity

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A B S T R A C T

Adult spinal deformity is a common problem that affects 60% of the population aged 65 and older and can be physically and mentally disabling. The primary focus of this chapter is to discuss the advances of revision spine surgery and the difficulties that spine surgeons encounter. Spine surgeries are demanding on the surgeon and on the patient with complication rates close to 40% and secondary spine surgeries becoming more prevalent. Complex medical patients also pose another inherent barrier to successful revision surgery. The following chapter outlines the process of revision surgery and current techniques.

1. Introduction

Adult spinal deformity is a common problem that affects 60% of the population aged 65 and older and can be physically and mentally disabling.[1] There is a wide range of deformity including cervical, thoracic, and lumbar levels in coronal, sagittal, and axial planes. However, the scope of this chapter will focus on thoracic and lumbar adult spinal deformity. Positive sagittal balance greater than 5 centimeters has been shown to be an important radiographic predictor of health status in regards to pain, function, and self-image).[2,3] Flexing the knees or extending the hips to compensate for sagittal imbalance places unnecessary stress on the lower extremity musculature leading to pain and fatigue. Surgical intervention is focused on improving walking tolerance and minimizing energy expenditure, which has been shown to improve patient reported outcomes.[4] Ultimately, adult deformity correction is a lifestyle improving intervention to address these functional limitations. However, not every patient with spinal deformity is a surgical candidate, and contra-indications are generally based on the patients' medical status.

Once the patient has elected to proceed with surgery, there are multiple surgical techniques that can be divided into two main categories: indirect reduction with graft placement and direct correction with osteotomies. The specifics of these techniques will be discussed later in the chapter. Regardless of the chosen procedure, these are demanding medically for the patient and technically for the surgeon, and complications are common with an estimated overall complication rate of 41.2%.[5,14] These complications may necessitate a revision procedure.

Indications and contra-indications are similar to those for the index procedure and are focused on lifestyle improvement. This is especially important in revision surgery as the patient may wish to defer a second surgical intervention. Also, the complication leading to the revision either may be due to the patient's medical status or may worsen it postoperatively. Either way, these are often medically complex patients. At the most basic level, the patient must be able to

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https://doi.org/10.1053/j.semss.2019.03.009
1040-7383/

complete rehabilitation and recover from a major, revision surgery with serious potential complications.

2. Deformity revision

Researchers have continuously sought new techniques or interventions to improve outcomes for these difficult cases. In 1945, the Smith Peterson Osteotomy was first described to treat rheumatoid arthritis patients with fixed kyphotic deformity.[5] In 1985, Thomasen described the pedicle subtraction osteotomy for patients with ankylosing spondylitis.[6] Shortly after, Bradford described the vertebral column resection.[7] Although gaining popularity in other areas of contemporary spinal surgery, minimally invasive exposures should generally be avoided for deformity revision. Due to the altered anatomy, adequate exposure and visualization is paramount, and this may not be available with the use of dilators or small incisions. However, interbody fusions may allow for a less invasive procedure when combined with other techniques.

These interbody fusions include far lateral, anterior, and posterior and can be combined with different types of osteotomies to generate significant correction. Posterior interbody fusion include postero-lateral (PLIF) and trans-foraminal (TLIF), and they can obtain 5–10° of deformity correction.[20] However, the anterior lumbar interbody fusion and lateral interbody fusion have certain advantages over the posterior technique. These include 10–15° of correction, a larger surface area of fusion with larger graft and/or cage, and maintenance of the posterior spinal ligaments and musculature.[20,9,8] Lateral and anterior grafts have been shown to be biomechanically equivalent.[8] The ALIF was first described in the 1930s and has been well documented.[9] However, the lateral technique was first published in 2006 and continues to gain popularity.[9,10]

Common osteotomies include Smith-Peterson, pedicle subtraction, and vertebral column resection. The specific techniques and indications of each are outside the scope of this chapter, but Gill et al discuss the current concepts of corrective osteotomies in their comprehensive review.[5] Briefly, Smith-Peterson osteotomy (Ponte or posterior element wedge resection) allows approximately 10° of correction per level. However, this may be limited by the loss of disc space height. A mobile and open disc space is needed to make and then close the osteotomy. This also precludes future fusion as the inferior facet is removed. Pedicle subtraction osteotomy, or three column wedge resection, allows approximately 30–40° of correction per level,[11] and it can be used to correct rigid deformity. Unlike the Smith-Peterson, the spinal canal is shortened in this technique [13] and the spinal column will be temporarily destabilized. When neither of these techniques is indicated, a vertebral column resection technique can be utilized. As the name implies, the vertebral body is completely resected, and it must be reconstructed using a cage, autograft, or allograft for structural support.[5]

When deciding on the operative technique, there are multiple considerations. The mobility of the deformity will dictate the technique used. Mobile deformities can be treated with Smith-Peterson osteotomy as well as any of the interbody fusion techniques. Rigid deformities are best treated with PSO or VCR. Positioning, re-prepping and draping, and order of correction must also be planned. This may necessitate staged procedures. The patient's bone health will also play a role. If the patient is osteoporotic, large correction or limited instrumentation should be avoided. These complex procedures and patients require an operative plan tailored to each individual case.

3. Risk factors for complications

There is conflicting literature regarding "revision" as a risk factor for complications in the "revision" surgery. Two different reports focusing on short term (<6 months) and long term (>6 months) complications concluded that "revision" was not a risk factor, but Glassmen et al noted "revision" to be a risk factor for major complication.[2,12,14] Due to the difficult nature of the surgical techniques, inherent altered bony anatomy surrounding the canal, scar tissue formation, and altered vascular anatomy, revision deformity surgery should intuitively lead to a higher risk of complication.

Like other aspects of surgical complications, risk factors can generally be divided into those relating to the patient and to the surgeon. In regards to the patient, the risk factors can be further divided to those relating to medical comorbidities and those of spine deformity. Certain medical diagnoses lead to increased risk for any surgery that requires general anesthesia and include coronary artery disease and pulmonary disease. There are others that pertain to the actual surgery such as healing potential, and, specific to spine or orthopaedic procedures, bone health. The issues that affect both include tobacco abuse, diabetes mellitus, chronic kidney disease, and nutritional deficiency. Osteoporosis affects does not affect healing potential but is integral to fixation.

Although these increase the risk, healthy patients are also at risk of complications relating to the surgeon. As with any surgery, all aspect of the procedure can carry risk including positioning, approach and dissection, hemostasis, deformity correction, fixation, and closure.

The posterior approach familiar to most spine surgeons, but there will be distorted anatomy due to the nature of revision surgery. The prone position carries its own risks and complications including potential blindness, compressive or positional neuropathies, shoulder injury, and difficult anesthesia access. The anterior approach will not have the same positioning difficulties, but the anatomy leads to an increased risk of other complications.

Prior to considering an anterior lumbar approach, a comprehensive and detailed past medical history must be obtained. Previous abdominal surgeries can lead to adhesions and scar tissue formation that could complicate the approach. At our institution, general surgeons perform the approach due to their comfort with the anatomy. This can lead to difficulty with availability and coordination. The iliac vein, artery, and ureter must be protected throughout the surgery, and the ureter can be distinguished from the vessels by peristalsis with stimulation. Even with the help of surgeons familiar with this approach, these structures can be injured leading to significant post-operative issues. These include genitourinary complications and increased risk of deep

venous thrombosis from retraction of the vessels. Similarly, there is an increased risk of ileus from manipulation and retraction of the peritoneal contents.

Pre-operative advanced imaging must also be obtained to scrutinize the level of bifurcation and position of the vessels. This may dictate the available levels of surgery. The dissection is usually from the left side to avoid the IVC and liver. Injury to superior hypogastric plexus can occur, and, if injury occurs at L5-S1, then retrograde ejaculation can take place. However, if an injury deeper in the pelvis or more distal on sacrum, then impotence is more likely. If the sympathetic trunk is injured, then the patient may have hyperthermia of the ipsilateral lower extremity.

The anterior and lateral thoracic approaches can provide wide exposure but are rarely done due to the relevant anatomy. A right-sided approach can avoid the subclavian vessels and carotid artery, but a left sided thoracotomy is most often performed.[17] A transthoracic exposure may require a rib resection with an increased risk of bleeding from the intercostal vessels. Finally, the anesthesia team must deflate the lung in the operative field to improve exposure. This obviously has pulmonary risks and requires a skilled surgeon and anesthetic team.

The lateral approach has several advantages include no nerve root retraction, no epidural fibrosis, and the ability to spare the ALL. Again, pre-operative imaging is important to determine the level of the ribs and iliac crest, which may preclude access to certain levels. The psoas position must also be carefully evaluated on MRI. Complications mainly result from manipulation of lumbar plexus and include Psoas weakness, L4 nerve injury, and genitofemoral nerve injury. Also, thoraco-abdominal nerve injury can lead to abdominal wall weakness. Excessive side bending can lead to L4 neuropraxia as a result of increased psoas tension and reduced nerve root perfusion.[15] Tilting the table 45° away from the surgeon can decrease the stretch of the psoas.[18] This approach is usually done with neuro monitoring to mitigate these complications.

After the approach and dissection are complete, the chosen operative plan and technique present a different set of risk factors. Statistically significant risk factors for major complications peri-operatively and at follow up are related to pedicle subtraction osteotomy or change relative to the pre-operative deformity. For peri-operative, the risk factors include pre-operative lumbar lordosis greater than negative 30° and immediate change in thoracolumbar or lumbar scoliosis greater than 20°. For follow up, these include pre-operative thoracolumbar kyphosis greater than 20°, immediate change in thoracolumbar kyphosis greater than 20°, and immediate change in thoracolumbar or lumbar scoliosis greater than 20°.[14] Also, the interbody grafts used to achieve such a correction have certain associated risks. Incomplete discectomy can lead to displacement of disc material when the graft is placed, and, if placed incorrectly, the graft can impinge upon neural structures. Neurologic complications have also been associated with over distraction of the disc space and encroachment of the graft into the neural foramen.[15]

In their review of neurologic complications in deformity surgery, Iorio et al noted other risk factors related to technique. These include use of bone morphogeic protein, malpositioned screws, 2 or more 3 Column osteotomies, thoracic 3 column osteotomy (compared to lumbar), multi-level lateral interbody fusion, lateral interbody fusion at L4–L5, spinal cord shortening greater than 100% of one vertebral body height, and posterior spinal fusion greater than 5 levels.[15]

Revision anatomy requires meticulous dissection and challenging technique. These two factors can lead to increased operative time, and, therefore, more blood loss. Estimated blood loss greater than 3 liters and operative time greater than 200 min have been associated with increased complications. However, it is unclear if this is anesthesia time or procedural time. If multiple approaches are used, then the anesthesia time will almost certainly exceed 200 min due to re-prepping, draping, and positioning. Prolonged lateral interbody fusion as also been associated with neurologic complications as previously discussed.[4]

4. Complications

Cho et al retrospectively reviewed 166 consecutive adult patients who had major revision surgery for deformity at a one institution between 2002 and 2007. The minimum follow-up was 2 years. Major revision surgery was defined as greater than or equal to 6 levels, and complications were defined as either major or minor. They reported only one intra-operative major complication, cardiac arrest. The other major complications that occurred in 3 or more instances in the peri-operative period pertained to the patients' medical status and include deep wound infection (6), pulmonary embolism (6), motor deficit (5), stroke (4), re-intubation (3), and sepsis (3).[14]

Although they are associated with significant morbidity and possible mortality, these are treatable medical complications, and a consulting service is generally called for assistance. Specifically, corticosteroids such as decadron can be used to treat radiculitis with motor deficits as well as airway edema and re-intubation. At our institution, we give 10 mg of dexamethasone every 6 h for 24–48 h. This can be initiated by anesthesia intra-operatively if needed. Although initial fusion was delayed, corticosteroids had no long term effect on fusion rates in ACDF, and this same logic can be applied to deformity revision, with the understanding of the differences in degree of fusion required in the two procedures.[16] However, there are other negative side effects of corticosteroids, and their use must be assessed on individual cases. Pulmonary embolism or DVTs require chemoprophylaxis, but this may lead to wound complications or hematoma formation. Prolonged use of subcutaneous and subfacial drains or incisional wound vacuum with close monitoring by the hospital staff may help mitigate this. There should be a low threshold for a return to the operating room for irrigation and debridement. Overall, 19.3% of patients reviewed had a major complication in the peri-operative period.[14]

Intra-operative minor complications reported in their review include cerebrospinal fluid (CSF) leak (4), excessive bleeding (4), pedicle infraction (2), and intra-operative alert (2). The treatment options and algorithms for excessive bleeding and intra-operative alert will be discussed in the prevention section. If a durotomy is encountered, then it should be repaired using the surgeons preferred technique. Post-operatively, we routinely use the algorithm recommended by

Mustafa et al.[19] The patient is keep head of bed flat for 24–48 h followed by head of bed to 30° for 12 h. The patient is then allowed to be upright for 12 h followed by up ad lib for 24 h. If the patient complains of headache or there is significant drain output during this sequence, then the patient regresses to the previous stage with continued monitoring.

Peri-operative minor complications included radiculopathy (4), prolonged ileus (4), superficial wound infection (4), pleural effusion (2), psychosis (2), retained drain (1), fever of unknown origin (1), and urologic (1). These are treated similarly to the major complications including corticosteroids, low threshold to return to the operating room, and consultations. At our institution, an ileus prompts a GI or surgery consult. This will be discussed further in the Prevention section.

Major and minor post-operative complications occurring greater than 6 weeks from surgery are related to either infection or instrumentation failure. The major complications include instrumentation failure or pseudoarthrosis (22), adjacent segment disease (10), fracture (3), and deep wound infection (1). The minor complications include symptomatic iliac screw (10), broken unilateral iliac screw (4), painful prominent instrumentation (2), superficial wound infection (1), sacral ulcer (1), and seroma (1).[14] Those relating to instrumentation are treated with pain/symptom management and possible future revision surgery. Those relating to infection are treated with antibiotics with irrigation and debridement. If infection is considered or suspected, then an irrigation and debridement should be done with cultures obtained intra-operatively, ideally before antibiotics have been given. Infectious disease consult with appropriate antibiotic stewardship is recommended. The wound can be closed or left open with a negative pressure dressing for a planned return to the operating room. CRP should be obtained pre-operatively and every 48 h to monitor clinical condition.[14]

Reviewing the outcomes of the complications they reported, Cho et al noted statistically significant worse outcomes in the post-operative complications but in the peri-operative complications (check statistically significant). This is expected as the majority of the peri-operative complications are typically treated with medicines while the post-operative complications typically require further surgical intervention.

5. Prevention

The first and most reliable method to prevent surgical complication is to not perform surgery. Although failed deformity correction can lead to significant pain and disability, it remains a quality of life decision, assuming the patient does not have cauda equina or myelopathy. The core medical principle of “Do no harm” must be considered in every case. Surgery always has the potential of worsening the patients clinical condition, and this must be discussed prior to pursuing further intervention. Truly informed consent and shared-decision making are mandatory, particularly in high risk procedures.

If the patient elects to proceed with surgery, then pre-operative measures to optimize the patient outcome should be initiated. To begin, medical evaluation from the patients' primary care provided and other indicated specialists should be obtained. We also have a pre-operative visit 1–2 weeks before the scheduled surgery to obtain labs and to ensure other evaluations have been completed. Adequate nutrition should be addressed, and albumin, pre-albumin, and total protein should be checked and supplemented as needed. Bone health should also be evaluated. Vitamin D and calcium levels should be checked and supplemented as indicated. A DEXA scan can also provide valuable information regarding osteoporosis and osteopenia. If available and indicated, a bone health referral to an endocrinologist or medical provider can further prepare the patient for surgery. Along with vitamin D and calcium, other pharmacologic agents like disphosphonates, denosumab, and parathyroid hormone (teriparatide) are current treatment options for osteoporosis. Although there has been concern for a deleterious effect on bony healing, recent studies regarding disphosphonates have not shown these effects in distal radius fractures treated with volar plates but has shown improved fixation in the cancellous bone in osteoporotic proximal femur fractures.[22,23] Denosumab has also not been shown to affect bone healing based on the results of the FREEDOM trial.[24] Furthermore, PTH has been shown to accelerate healing in pelvic insufficiency fractures.[25] An internist or endocrinologist typically prescribes these medications, but the surgeon should be aware of their potential effect on the planned fusion construct.

If osteoporosis is identified, then the surgeon should employ techniques to increase surface area for fusion and to minimize screw pullout. Anterior and far lateral cages can increase the surface area for fusion thereby decreased the risk of subsidence. Cortical screw trajectory, rather than traditional pedicle screw trajectory, allows for increased purchase in cortical bone in the pedicle and pars interarticularis.[26] This has been shown to increase the mean load to failure.[27] This trajectory has a more medial starting point as well as a medial to lateral and caudad to cephalad path (Grant). Polymethylmethacrylate (PMMA) cement augmentation has also been shown to increase the pullout strength by 149%.[28] This can be done open at the instrumented level or using fenestrated screws.[29] Other strategies including multiple sites of fixation, reduced deformity correction, and continuing instrumentation past kyphotic segments (Youssef). These techniques will help mitigate many of the complications seen > 6 weeks from surgery when instrumentation fails due to inadequate fixation in osteoporotic bone.

A computer tomography scan should be obtained to assess for pseudarthosis of any previously fused levels and associated preoperative planning. In addition to a CT scan, upright full length 36-inch radiographs or scoliosis series should be obtained for pre-operative planning. To compensate for deformity, patients may have a retroverted pelvis, flexed knees, or flexed hips, which will affect the overall alignment and subsequent correction. These radiographs must be obtained without knee flexion as this may obscure the needed correction. Good communication with the radiology staff is necessary to consistently obtain the correct images.

Visualization of the pelvis and femoral head allows for calculation of the pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS). All of this data obtained in pre-operative radiographs allows for surgical planning for the amount of

correction needed and the subsequent technique to obtain said correction (Youssef). The PI does not change regardless of deformity and should be measured for each case. It can be used to determine the lumbar lordosis using the formula Lumbar Lordosis = PI ± 9.[20] However, the revision cases may have a more complex patter with thoracic kyphosis as well. This should also be measured for every case using cobb angles. The correction needed for cases with a thoracic kyphosis component can be measured with the formula PI + lumbar lordosis + thoracic kyphosis < 45°.[20] After these parameters have been measured, the pelvis radiograph should be closely evaluated for any pathology that could be causing chronic pain wrongfully attributed to the spine.

It is paramount that the patient stops smoking or using any other form of nicotine. This affects bone healing potential but also affect pulmonary function, vascular status, and overall healing potential. Nicotine level can be checked on the day of surgery with delaying the case at the surgeons' discretion. The morbidity and potential mortality associated with revision deformity correction are too significant to gamble with a variable such as nicotine.

Peri-operative planning is also paramount to a favorable outcome. This includes staging procedures when appropriate with potential intensive care unit management between operative days. This is especially important if multiple approaches or techniques are planned. The specific case and institution dictate length of time between surgeries. During the procedure, recent technological advancements have allowed for improved patient safety through use of navigation techniques as well as neuro monitoring. Navigation can assist with accurate screw placement in distorted anatomy, and intraoperative imaging should be utilized to verify degree of deformity correction. The neuoromonitoring allows for quick identification of neural injury with subsequent management.

If there are neuromonitoring changes, then all members of the operative team should simultaneously evaluate the individual variables they control. The surgeon should stop or reverse any manipulative maneuvers and check for any misplaced instrumentation. The anesthesia provider can confirm an adequate hemoglobin of greater than 9, increase the MAP to greater than 90, withhold inhalation agents, reduce IV anesthetics, confirm no neuromuscular blockade, and apply muscular twitches for further evaluation. Additionally, the patient should be evaluated for malpositioning or peripheral nerve tension/compression with appropriate corrective action taken. The neurophysiologist can repeat signals to rule out false positive, confirm placement of leads, check for equipment malfunction, and assess for symmetric vs. asymmetric changes. Symmetric changes imply anesthesia while asymmetric implies a spinal cord or nerve root injury.[21] Lastly, a wake-up test should be utilized if changes in neuromonitoring cannot be resolved through these means.

Revision deformity correction may require large exposures, multiple exposures, or osteotomies. Significant blood loss should be expected. Hemoglobin should be adequate for each case, and the patient should be typed and crossed with units available as indicated. Our institution routinely uses transexemic acid (TXA) to prevent clot degradation by plasmin. An initial dose of 20 mcg/kg is given intra-venously at incision with re-dosing depending on duration of surgery. Other modalities include autologous blood recycling, variations of electrocautery, and thrombin soaked sponges. The specific indications and contra-indications for each modality is beyond the scope of this chapter and should be investigated further prior to intra-operative use. They should know when the surgeon is irrigating and how much irrigation is being used. This allows for an accurate estimated blood loss when the volume of irrigation is subtracted from the overall volume in the suction canister. Finally, chemoprophylaxis for DVT should be avoided if able with exceptions such as major vein injury or pulmonary embolus.

If chemoprophylaxis is warranted, then fascial or subfascial drains with or without an incision negative pressure dressing may be used to prevent hematoma formation and seroma formation which can lead to pressure on the neural structures or infection. We routinely place a fascial and subfascial drain with discontinuation on a case by case basis. Careful attention is also paid to the fascial closure, which is done with a barbed suture in a running technique. Also, vancomycin powder (1 g each for subfacial and facial layers) is utilized to decrease infection. An incisional wound VAC can provide an occlusive dressing and also to decrease closing time.

Post-operatively, the decision to extubate is made by the anesthesia team. We prefer a wake up test with visualized confirmation of all extremities moving prior to extubation. If the patient cannot be extubated, then intensive care team should be consulted for further management. The medical team should be consulted early to assist with complicated comorbidities. For example, patients with diabetes mellitus should have their blood sugar closely monitored and regulated to decrease post-operative complication.

Several retrospective studies have aimed to evaluate surgical complication rates in patients with elevated A1c levels preoperatively (Rollins). These studies were heterogeneous in surgical specialty but offer an interesting analysis of diabetic patient complications. Most of these studies have failed to show statistically significant data due to low study numbers, but they do show a trend in increased complication rates in hyperglycemic patients with A1c levels above 7.0. When analyzing the rates of infection in diabetic patients after total knee arthroplasty, England et al. reported higher rates of infection and revision and overall worse outcomes. Although no direct correlation has been reported, several retrospective studies showed a trend of increased complications in patients with a Hemoglobin A1C greater than 7. Unfortunately, heterogeneous populations and small samples sizes preclude statistically significant data. However, a level less than 7 is a reasonable pre-operative benchmark.

Gastroenterology dysfunction can occur post-operatively leading to discomfort and possible ileus. Patients with a large anterior exposure have a NG tube placed intraoperatively for bowel rest. Outside of this, we routinely progress the patients diet slowly, and they receive a clear liquid diet until the return of bowel function. There is a low threshold to regress their diet if they are distended or are not passing flatus. Belching with no flatus can also be an early sign of an impending ileus. If they progress to an ileus, then surgery or gastroenterology teams are consulted for assistance. However, this approach can affect post-operative nutrition status. Pre-operative

nutrition labs are reviewed with subsequent nutrition team consult if needed. Vitamin D and calcium should also be supplemented as needed to promote bone health.

6. Conclusion

As the population continues to age and the life expectancy continues to rise, the need for revision deformity correction may rise as well. Revision deformity surgery carries a significant risk of complication, and the prevalence of major complications is 34.3% (Cho). Therefore, the patient must be appropriately informed and counselled regarding the nature of these complications, especially regarding timing. However, correction of the deformity measured on pre-operative imaging is correlated with an increased in health reported quality of life measures. Complications occur at a similar rate in the peri-operative (19.3%) and post-operative/follow up (18.7%) periods.[14] The patient and surgeon must both be willing to maximally optimize the clinical scenario prior to intervention to address known risk factors. They both should both be aware of these risk factors, especially pedicle subtraction osteotomy and significant correction/change from pre-operative alignment as these are common to major peri-operative and post-operative complications.[14] Due to the nature of revision deformity surgery as well as the common medical comorbidities, these are often medically complex patients and require assistance from other services such as the ICU, anesthesia, internal medicine, gastroenterology, surgery, cardiology, nutrition, physical and occupational therapy, respiratory, and radiology. Communication, with the patient and with other providers, is paramount to achieve a satisfactory surgical outcome.

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