Complication management with minimally invasive spine procedures

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Spine surgery as we know it has changed dramatically over the past 2 decades. More patients are undergoing minimally invasive procedures. Surgeons are becoming more comfortable with these procedures, and changes in technology have led to several new approaches and products to make surgery safer for patients and improve patient outcomes. As more patients undergo minimally invasive spine surgery, more long-term outcome and complications data have been collected. The authors describe the common complications associated with these minimally invasive surgical procedures and delineate management options for the spine surgeon. (DOI: 10.3171/2011.8.FOCUS11165)

Key Words • minimally invasive • spine surgery • complications

With recent advances in technique and access instrumentation, minimally invasive spine surgery has ushered in a renaissance in spine care. Surgeons are becoming more comfortable with these procedures, and industry-surgeon collaborations have provided a plethora of new products to make surgery safer for patients and improve patient outcomes. As more patients receive minimally invasive spine surgery treatments, stronger long-term outcome data are supporting this change in practice pattern. Patient outcomes are improved compared with traditional open surgery and costs are reduced, partly due to reduced hospital stays and recovery times. Approach-related morbidity is significantly reduced because normal anatomical structures are preserved to a greater extent, reducing the incidence of delayed progressive deformity and degenerative changes. Minimally invasive surgical procedures of the spine can be just as efficacious as traditional open procedures with respect to the operative pathology. Unnecessary approach dissection and ligamentous and muscular disruption are minimized, potentially leading to a reduced incidence of repeated operations and scar formation.

However, minimally invasive surgical procedures require specialized surgeon training and offer many new technical challenges. Adequate training and familiarity with the microsurgical anatomy through retractor ports, coupled with the appropriate level of surgeon skill and manual dexterity, are critical for procedural success. Training courses, specialized fellowship training, animal and cadaveric dissections, and technique guides are all available to help educate surgeons, improve patient outcomes, and reduce complications.

Endoscopic optics, although improving, can limit 3D image representation and provide imperfect color representation. Tissues of similar color and structure are difficult to differentiate, such as nerve roots and the ligamentum flavum. Surgeons mistaking these structures could encounter intraoperative complications such as dural tears or nerve root injury. Recent developments in tubular retractors, which can reduce the need for thoracoscope or endoscope use, permit 3D visualization through loupe magnification and/or the operating microscope. However, these ports expose only a small portion of the spine and relevant anatomy; therefore, surgeons must have a clear understanding of the surrounding anatomy and possible complications that can occur with each approach. Understanding and thus avoiding possible complications are critical in making minimally invasive spine surgery safe and effective.

Cervical Procedures

Anterior Cervical Discectomy and Fusion

Anterior cervical discectomy and fusion is one of the most common spinal surgical procedures. It has a low complication and morbidity rate. First introduced in the 1950s by Cloward, the cervical vertebral bodies are approached through the standard fascial approach medial to the sternocleidomastoid muscle. In a recent series of 1015 patients undergoing anterior cervical discectomy and fu-
The most common complication was dysphagia, which occurred in 9.5% of patients. Postoperative hematoma occurred in 5.6%, and required surgical intervention in 2.4%. Symptomatic recurrent laryngeal nerve palsy occurred in 3.1% of cases, while dural tear was observed in 0.5%. Improvements in cervical retractor design (thinner blades) can potentially reduce postoperative dysphagia. In addition, no- or zero-profile interbody implants made of polyetheretherketone (PEEK) and typically anchored with screws placed through the implant and into the adjacent vertebral body can potentially reduce dysphagia, although clinical data to support this idea are lacking. Laryngeal nerve injury with hoarseness usually resolves after a few days. If hoarseness persists for more than 4 weeks, laryngoscopy should be undertaken to evaluate vocal cord function. Electromyographic, somatosensory, and motor evoked potential monitoring during these procedures can help identify positioning and intraoperative changes. However, it remains controversial as to whether intraoperative monitoring can result in improved patient outcomes (Hussain NS, Rosenblum AR, Kudromi HS: Analysis of 1014 consecutive operative cases to determine the utility of intraoperative neurophysiological data. Paper presented at the AANS Annual Meeting, Denver, Colorado, April 9–14, 2011)5,22

Possible complications that require immediate intraoperative treatment include laceration of the larynx or esophagus. These injuries, if identified immediately, should be closed primarily, followed by wound drainage and nasogastric tube drainage. The patient should then receive a formal swallowing study before discharge and 4 weeks postoperatively to assess for proper closure and function of the esophagus and to rule out aspiration. Misplacement of the retractor may result in carotid artery injury, which should be repaired. Internal jugular vein injury should be managed with primary repair or ligation. Again, as is the case for other procedures, adequate training under experienced surgeons, cadaveric and animal courses, and a 3D “see-through” knowledge of the surrounding anatomy and critical structures are all key to reducing complication risk.

Anterior Cervical Foraminotomy

Initially described by Verbiest24 in the 1960s, anterior cervical foraminotomy has been advocated for unilateral radicular symptoms due to foraminal stenosis from lateralized disc herniation. The benefits of this approach are that a fusion is avoided, thus preserving the motion segment. The disadvantage is that the approach is not familiar to most surgeons and the proximity of the vertebral artery puts it at risk for injury. Jho24 has comprehensively described the primary risk of vertebral artery injury with this procedure. He reported the 3 most likely sites of injury to be at C6–7, in the region lateral to the uncinate process, and at the foramen transversarium. The C6–7 level is a high risk because of the local anatomy. The vertebral artery courses between the transverse process of C-7 and the longus colli muscle. Jho recommends that surgeons incise the longus colli muscle at the level of the C-6 transverse process to avoid vertebral artery injury. The cut muscle stump is then reflected caudally over the C-7 transverse process, exposing the vertebral artery. At the uncinate process, vertebral artery injury can be avoided by drilling down the uncovertebral joint and leaving a thin layer of cortical bone over the vertebral artery. This thin bone can then be removed with a curette. Brisk venous bleeding during drilling can indicate breach of the surrounding venous plexus that surrounds the vertebral artery.

Vertebral artery injury is difficult to repair primarily. Most surgeons will pack the region with Gelfoam, muscle, or bone wax and evaluate using postoperative angiography. Injury to the sympathetic chain, resulting in Horner syndrome, is another risk with this approach for surgery. The cervical sympathetic chain lies anterior to the longus colli muscle. Careful retraction of the longus colli muscle laterally and avoiding any muscle resection can reduce the rate of injury to this structure. Poor patient selection can also lead to poor outcomes. Patients with mechanical neck pain, who would have a better outcome with a fusion procedure, often do not improve with decompressive procedures. Performing the foraminotomy at junctional levels may result in worsening spinal biomechanics with worsening pain due to partial uncovertebral joint removal. In addition, some patients who develop contralateral foraminal narrowing may develop symptoms from this narrowing due to hypermobility induced with the foraminotomy.

Posterior Cervical Foraminotomy

A muscle-splitting approach using sequential tubular muscle dilators has proven to be effective in limiting postoperative pain and spasms when performing posterior cervical procedures. This approach allows this procedure to be performed on an outpatient basis. The posterior foraminotomy maintains the midlines osseous, muscular, and ligamentous structures of the spine. With this type of surgery, prone positioning inherently places pressure on the face. Pressure over the eyes can potentially cause hypoperfusion in the distribution of the central retinal artery, resulting in infarction and vision loss. This may be avoided by using a Mayfield head holder or appropriate padding of all pressure points. Alternatively, the patient can be put in a semisitting position with the head affixed in a Mayfield head holder. This positioning also allows for blood to move out of the tube and not obscure the surgical field of view. Spinal cord injury can occur while docking the K-wire and/or serial muscle dilators, which is a serious complication that can result when instruments are inadvertently placed between the cervical lamina. To minimize this risk, we recommend slowly advancing the K-wire under fluoroscopic control and removing the K-wire after the first dilator is placed over the wire. Do not wait until all dilators are in place because passing each sequentially larger dilator adds the risk of potentially plunging the K-wire in between the lamina or through a small laminar defect.

Placement of the K-wire and subsequent muscle dilators should always be performed using a gentle rotating downward action under spot fluoroscopic guidance. The K-wire is removed after the first muscle dilator is passed. Additionally, particularly in repeated operations in which dense scar tissue and muscle atrophy may exist, not forcefully pushing the K-wire and/or muscle dilators toward the spine can help reduce inadvertent entry into the canal or nerve injury. Typically the K-wire, subsequent muscle dilat-
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![Fig. 1](image)

Intraoperative lateral fluoroscopic views of the cervical spine with proper dilator docking on the laminofacet complex during a minimally invasive posterior foraminotomy.

tors, and tubular retractor are docked approximately 1 cm dorsal to the spine. The remainder of the approach is then performed under direct visualization through the operative microscope starting laterally to identify bone landmarks first. Anterior-posterior fluoroscopic images can be obtained to ensure proper laterality with respect to docking on the correct facet complex. This image can also be used to ensure that one is not docking too laterally because of the risk of injury to the vertebral artery. Vertebral artery injury is very rare and, although primary repair of vertebral artery injury has been described, the procedure itself can prove to be technically difficult. Alternatively, bleeding can be controlled with gentle pressure and packing with muscle or Gelfoam. Postoperative angiography should be performed to rule out pseudoaneurysm or arteriovenous fistula formation.

After appropriate exposure, the posterior cervical fascia should be cut primarily to avoid the need to place the K-wire and subsequent muscle dilators through the fascia with undue pressure. Once this fascia is cut, the K-wire and the muscle dilators can be carefully rotated through the fascial incision to the docking location (Fig. 1). Even though the chance of inadvertent spinal cord injury is significantly reduced, this does not obviate the need for frequent lateral fluoroscopic imaging to assess progress toward the spine. During the foraminotomy, excessive root manipulation can result in root injury, especially for the C-5 and C-8 nerve roots. This often occurs more with repeat operations when adhesions and scar tissue are adherent to the nerve roots. These deficits usually resolve with time, but care should be taken if manipulation is required.

Cerebrospinal fluid leak was reported as the most common complication in the retrospective review of Adamson\(^2\) of 100 cases of posterior cervical foraminotomy. These leaks typically resolve with 2–3 days of lumbar drainage. If the dural violations can be visualized in the operating room, primary repair can be attempted or Gelfoam or Duragen placement along with fibrin glue can be performed. If this complication occurs, a meticulous fascial closure is performed and the skin closed with a running locking nylon suture.

Thoracic Procedures

Anterior Thoracic Procedures

Advances in thoracoscopic instrumentation have led to the development of new anterior approaches to the thoracic spine that were either extremely technically difficult or impossible previously. Cervical and lumbar pathology is more common than thoracic disease, but the true incidence of thoracic pathology has been traditionally underestimated. More recent studies have shown that thoracic disc herniations comprise 14.5% of all disc herniations.\(^2\) While the vast majority of these herniations are asymptomatic, those cases that are symptomatic are usually quite serious, involving myelopathy and long tract signs or severe thoracic radicular pain syndromes. Advantages of the minimally invasive approaches compared with open thoracotomy are a lower incidence of intercostal neuralgia and chest pain along with respiratory complications, such as postoperative effusion, scarring, and atelectasis. In the largest series of thoracoscopic discectomies,\(^26\) the authors reported less approach-related morbidity than an unmatched cohort undergoing excision using thoracotomy. Other complications that can arise with thoracoscopy are related to anesthesia, positioning, port placement and closure, and manipulation of long instruments within the thoracic cavity with the concomitant risks to vascular and lung parenchymal structures. To avoid this type of injury, close attention must be given to preoperative workup, including positioning. Candidates should be selected based on health status and the ability to tolerate single-lung ventilation. Patients with baseline respiratory compromise will have difficulty tolerating the ventilation/perfusion (V/Q) mismatch for even brief periods of time. To reduce organ injury during port placement, all ports after the initial one should be placed under direct endoscopic visualization. When the lung is collapsed, the diaphragm and subdiaphragmatic organs may elevate with the thoracoabdominal cavity slightly. The surgeon should keep this change in mind when correlating the surface anatomy and intraabdominal anatomy when placing the lower ports. Bleeding at port sites almost always resolves without special intervention. However, continued bleeding should be managed with bipolar coagulation and irrigation. The incidence of hemothorax in these cases has been reported to be between 0% and 5%.\(^15\)–\(^7\),\(^20\) A Foley balloon can be inflated to temporarily tamponade a bleeding site until the source is identified. An unrecognized injury to the azygos or an intercostal vessel may require a thoracotomy for proper control.

Recently, the mini-thoracotomy approach has been introduced as another choice for surgeons who need a larger exposure, but do not want to subject patients to the morbidity of a full thoracotomy. Improved retractors allow for excellent minimally invasive thoracic exposure (Fig. 2). Expandable vertebral body cage reconstruction technology has also facilitated this technique. This approach can potentially reduce morbidity compared with more open traditional thoracotomy techniques. Complications associated with this technique are similar to those encountered with traditional thoracotomy approaches and include lung atelectasis and great vessel and spinal cord injury. Early exposure of the spinal cord by drilling of the rib head and underlying pedicle can access and expose the spinal cord to orient the surgeon. Compression of the spinal cord by large disc fragments can be managed by first preparing space into which the herniated disc fragment can be pushed into,
away from the spinal cord. The surgeon should anticipate dural violation where large calcified disc herniations are present. If CSF is encountered, the repair can be done primarily, although it will be difficult because the dural tear is often macerated due to the calcified disc adherence. We typically suture a dural patch graft over the opening and then cover with fibrin glue. If needed, a lumbar drain can be placed to divert CSF flow to allow for healing of the defect. In rare cases, a lumboperitoneal shunt is placed to prevent persistent CSF leak into the chest cavity.

**Posterior Thoracic Microdiscectomy**

The main advantage of using a posterior thoracic microdiscectomy is that it can be performed via a posterior muscle-splitting approach, avoiding the much more morbid transthoracic approach that requires reconstruction and instrumentation. It is ideal for soft lateralized disc herniations, and patients can frequently be discharged within a day. Calcified disc herniations can be identified with preoperative CT/myelogram study using localizing radiographs taken from the sacrum to the level of the pathology for accurate intraoperative localization. Preoperative chest, thoracic, and lumbar anteroposterior and lateral radiographic images are obtained for intraoperative level localization. Adequate fluoroscopic visualization and level localization are of paramount importance. Several techniques for localization such as counting from the sacrum up or counting ribs are used. Evaluation of the preoperative MR imaging or CT scan will determine how laterally the thoracic incision should be made in order to be able to dock on the facet at the level of interest. K-wire and serial muscle dilators are placed under fluoroscopic guidance. The lateral aspect of the facet complex is exposed and drilled to expose the lateral aspect of the dura. By exposing the lateral aspect of the dura, the orientation of the spinal cord is appreciated by the surgeon. After the annulotomy is performed, the discectomy can be started. Disc removal provides the surgeon with more room within the disc space to push herniated disc fragments away from the spinal cord and avoid manipulation of the spinal cord, which could lead to cord injury. Brisk bleeding can be encountered from engorged epidural drains. Gelfoam, or more recently introduced hemostatic agents, can help to control this bleeding. Micropituitary and downgoing curettes are used to facilitate disc removal and avoid cord manipulation.

**Lumbar Procedures**

*Mobilization Invasive Microdiscectomy and Laminectomy*

Recent advances in tubular dilators and optics for visualization have produced several instrumentation sets and techniques for minimally invasive access to posterior lumbar lesions. Proper docking of the K-wire on the laminofacet complex under strict fluoroscopic guidance as the instrument is advanced is critical to avoid placement of the K-wire between adjacent lamina and risk spinal cord and nerve root injury. With proper exposure of the ipsilateral lamina, drilling of bone is then performed. In the case of a de compressive laminectomy, the ligamentum flavum is maintained to avoid injury to the dura with the drill bit. The decompression is started at the more caudal portion of the lamina under which the ligamentum flavum is located. More rostral on the ipsilateral lamina, drilling is performed to expose the rostral edge of the ligamentum flavum that ends medially. This medial portion marks the midline of the canal and serves as a useful anatomical landmark to the medial portion of the canal. Once adequate ipsilateral decompression is performed, the patient is tilted away from the surgeon by 5°–10°, the retractor is moved and properly oriented to view the base of the spinal process, and the spinous process and contralateral lamina are undercut with the drill (Fig. 3). We prefer to use a long, thin, electric...
Facetectomy is completed, the disc space is cleaned and prepared. Bone graft material is placed into the interbody space with a funnel and an expandable cage can be placed.

After bone decompression is performed, the hypertrophied ligamentum flavum is removed. The ipsilateral portion of the ligamentum flavum that underlies the ipsilateral lamina is removed first. This allows more room in the canal to remove the contralateral ligament. Using a small upgoing curette, the contralateral ligamentum flavum is removed with the use of a No. 2 Kerrison punch. It is at this location that most durotomies occur. Using an upgoing curette to detach the ligamentum flavum from any dural adhesions before removing it can help to reduce the incidence of durotomies. Minimally invasive decompressive laminectomy has an excellent clinical outcome because it can be performed with minimal tissue disruption.

**Transforaminal Lumbar Interbody Fusion**

Minimally invasive spinal fusion can be performed from a lateral, anterior, transsacral, or posterior approach. We will focus on the posterior or transforaminal lumbar interbody fusion approach in this section. During the approach, the facet complex is drilled to approach the disc space. The lateral edge of the dura is identified to avoid injuring the traversing nerve root, and enough of the facet is removed to properly place graft material into the disc space without excessive retraction on the nerve root. In many instances, almost the entire facet complex might need to be removed. Neurapraxic injury to the nerve root can occur during interbody preparation and graft placement. This is avoided by removing an adequate amount of the facet so that instruments can be passed safely into the interspace (Fig. 4). Expandable interbody devices have been developed that can limit the amount of bone removal and nerve root retraction necessary because the devices are expanded once inside the disc space.

In higher-grade spondylolisthesis cases, care is taken to avoid injury to the exiting nerve root that can be pushed more medially as it is stretched over the disc space. First identifying the traversing nerve root and then removing bone more laterally over the disc space can help to prevent injury to the exiting nerve root. The realization that the exiting nerve root passes around the medial then caudal portion of the pedicle of the more rostral vertebral body helps to prevent exiting nerve root injury. Interbody placement in these cases can markedly reduce a spondylolisthesis and restore foraminal height and canal diameter in degenerative disc cases (Fig. 5).

In situations in which the disc space is markedly collapsed, a distractor chisel can be placed into the disc space and then rotated 90° to help restore disc space height. Care is taken to avoid advancing any of the interbody disc space cleaning instruments beyond 30 mm to avoid violation of the anterior annulus border of the disc and risking injury to the bowel or intraabdominal vascular structures. Lateral fluoroscopic imaging is useful in determining the depth of instruments within the disc space (Fig. 4). If brisk arterial bleeding is encountered and a major abdominal blood vessel injury is suspected, the interspace can be quickly packed with Gelfoam, emergency vascular consultation requested, the wound superficially closed with staples, the patient repositioned supine, and an emergency laparotomy performed. If a bowel injury is suspected, a gastrointestinal surgeon should be consulted and emergency laparotomy performed to inspect the bowel and repair perforations. Patients with bowel injury undetected at the time of surgery will frequently have considerable abdominal pain and guarding in the postoperative period. Further investigation of bowel injury using CT and/or the identification of free air within the abdomen using lateral decubitus radiography is warranted.

Recent 5-year long-term outcome data have been reported with a cohort of 98 patients undergoing minimally invasive transforaminal lumbar interbody fusion (Perez-Cruet M, Hussain NS, Hiremath G, et al: Long-term prospective analysis of minimally-invasive transforaminal lumbar interbody fusion and percutaneous pedicle screw instrumentation). Intraoperative fluoroscopic views demonstrating the steps involved in the transforaminal lumbar interbody fusion procedure. After a unilateral facetectomy is completed, the disc space is cleaned and prepared. Bone graft material is placed into the interbody space with a funnel and an expandable cage can be placed.
placement. Paper presented at the AANS/CNS Section on Disorders of the Spine and Peripheral Nerves Annual Meeting, Phoenix, Arizona, March 9–12, 2011). Patients experienced statistically significant improvements across all clinical outcomes measures. For the entire patient cohort, complications included cases that required reoperation, as well as other complications. Of the cases that required reoperation, 2 (2%) had instrument failure, 2 (2%) had adjacent segment disease, and 2 (2%) had nonadjacent segment disease. Other complications included neurological deficit in 2 patients (2%), surgical site infection in 1 patient (1%), nonsite infection (urinary tract infection or pneumonia) in 3 patients (3%), postoperative atrial fibrillation in 1 patient (1%), and fever (no source identified) in 3 patients (3%).

Percutaneous Spine Techniques

There are 3 categories of percutaneous spine techniques that are of interest to this discussion: vertebroplasty, kyphoplasty, and percutaneous screw placement. Vertebroplasty and kyphoplasty have gained popularity as useful minimally invasive procedures to treat painful osteoporotic compression fractures. The most common complications reported are pain, radiculopathy, cord compression, adjacent-level vertebral body collapse, and venous embolism. Most mass-effect complications have been linked to cement leakage. There have been reports of an increased incidence of cement leakage and adjacent vertebral body fracture with kyphoplasty. Investigators have hypothesized that this may be due to the high-pressure system required for balloon inflation during kyphoplasty. Agris et al. have reported a statistically significant difference in cement leakage rate—9.7% for vertebroplasty and 11.7% for kyphoplasty—but several more contemporary series dispute this. Differences in the data may be due to recent improvements in technique and instrumentation for kyphoplasty.

In avoiding complications and nerve root injury when placing percutaneous pedicle screws, there are several techniques that can be used. Perhaps the most critical step is adequate fluoroscopic visualization of the targeted pedicle in the anteroposterior view. The endplate of the target vertebrae should be 1 line so that the C-arm gantry is looking straight down the pedicle. This ensures that opposite endplates are lined up. The next steps involve targeting the pedicle and driving a Jamshidi needle through the pedicle in a lateral-to-medial direction. Green circles represent the pedicles, green line indicates the superior endplate of the vertebral body, yellow arrows point to the spinous process (which should be midline when obtaining a proper anteroposterior radiograph), green arrow points to the endplate of the targeted vertebrae, and blue circle indicates the inferior endplate of the vertebral body above.

Fig. 5. Intraoperative fluoroscopic views showing the degree of foraminal and disc height restoration with interbody device placement during transforaminal lumbar interbody fusion.

Fig. 6. Anteroposterior fluoroscopic view showing proper pedicle targeting and aiming the needle in a lateral to medial direction. Green circles represent the pedicles, green line indicates the superior endplate of the vertebral body, yellow arrows point to the spinous process (which should be midline when obtaining a proper anteroposterior radiograph), green arrow points to the endplate of the targeted vertebrae, and blue circle indicates the inferior endplate of the vertebral body above.
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Invasive transforaminal lumbar interbody fusion and percutaneous pedicle screw placement. Paper presented at the AANS/CNS Section on Disorders of the Spine and Peripheral Nerves Annual Meeting, Phoenix, Arizona, March 9–12, 2011. Pedicle screw stimulation using electromyographic monitoring is then performed. Those screws that stimulate at less than 8 mA are repositioned. In most cases this can be performed easily without having to abandon that pedicle for screw placement.

In terms of accuracy of the pedicle screw placement, authors of a recent meta-analysis of 130 studies, involving a total of 37,337 pedicle screws implanted, reported accurate placement of 34,107 screws for a 91.3% accurate placement rate. Three-dimensional neuronavigation has been shown to increase accuracy rates for percutaneous pedicle screw placement. Additionally, percutaneous screw placement does not require extensive muscle dissection, and patients develop much less scarring and atrophy of the paraspinal musculature (Fig. 7) and are left with a much smaller incision (Fig. 8). Because there is less muscle trauma and the surgical incisions are smaller with pedicle screw placement, a lower infection rate is encountered, particularly in obese patients with associated diabetes. Because there is less blood loss and tissue damage, recoveries are generally faster, patients can begin to ambulate, and they are discharged from the hospital sooner. This relatively faster recovery can be a factor in reducing complication rates, especially in the obese patient population.

**Transpsoas Interbody Fusion**

The transpsoas interbody fusion procedure was developed to provide a lateral retroperitoneal approach to achieve spinal fusion in the lumbar spine. The procedure is especially useful for correction of coronal plane deformities (Fig. 9). Possible complications that can occur include inadvertent entry into the peritoneal cavity and subsequent bowel injury while placing dilators. Careful patient positioning and the use of 2 fingers to bluntly dissect to create space in the retroperitoneal area can help to avoid this complication. This approach is used for fusions above the L5–S1 segment because the iliac crest does not allow access to the L5–S1 interspace. The psoas muscle may be injured during dissection with the muscle dilators to reach the disc space. Injury can result in patients experiencing flexor weakness on the side of the approach postoperatively; this weakness is observed in approximately 10% of patients and generally resolves in days to weeks. Patients should be advised of this possible complication and that it generally resolves. Early rehabilitation can help to alleviate this condition.

The psoas muscle contains the lumbosacral plexus posteriorly and the genitofemoral nerve anteriorly. Retraction of the psoas can cause transient postoperative thigh pain, numbness, paresthesias, and weakness due to injury to these nerves as they exit the spine laterally. A recent study followed 59 patients over a 3-year period, with 62.7% having thigh symptoms postoperatively. New thigh symptoms at initial follow-up included burning, aching, or pain in 39%, numbness in 42.4%, paresthesias in 11.9%, and weakness in 23.7%. The number of levels treated had no clear association with thigh symptoms. Half of these patients with complications had symptom resolution at 3 months postoperatively. More than 90% experienced symptom resolution by 1 year.

Cadaveric studies have described safe working zones when performing the transpsoas approach. Between the L1–2 and the L3–4 disc spaces, a safe working area

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**Fig. 7.** Axial MR images showing postoperative scarring and fibrous tissue deposition are much reduced in minimally invasive surgical cases (right) compared with traditional open spinal surgical cases (left).

**Fig. 8.** Minimally invasive approaches to the spine require only small incisions and can be cosmetically appealing. Shown is the immediate postoperative skin closure after a multilevel (3 levels) minimally invasive laminectomy.
is near the middle posterior quarter of the vertebral body. At the L4–5 disc space, the safest working zone is at the midpoint of the vertebral body. There is also a potential risk of injury to the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves in the retroperitoneal space where they travel obliquely. To help reduce nerve injury, various electrophysiological monitoring systems can be used that use muscle dilators attached to a monitoring unit. Additionally, instruments are used that can monitor the area retracted to ensure that no neural elements are present under or adjacent to the retractor or dilator. These electrophysiological monitoring tools have contributed to decreasing the serious complication rate from plexus injury from 30% to less than 1%.24 Repositioning the tissue or retractor can avoid permanent neural injury when neural elements are nearby. This approach affords an indirect decompression of the neural elements. The lateral approach allows for a relatively large implant to be placed into the disc space, similar to an anterior lumbar interbody fusion technique. Thus, the foraminal height can be restored and in many cases the canal decompressed as well. Supplemental instrumentation can be applied via a lateral approach, or posteriorly using percutaneous pedicle screws or facet fixation. In certain cases, a separate posterior decompression is required. There have been scattered reports about the usefulness of the transpsoas approach including a series of 13 patients encountering no complications.4 Other series have reported ureter injury, in which case patients should undergo urological consultation with possible dye study to confirm the injury.

Transsacral Approach

The transsacral approach was developed to avoid injury to the posterior musculature and avoid the need for a transabdominal approach. This approach is indicated to achieve an L5–S1 fusion. Recent developments in the technique have shown that L4–5 fusion can be performed in combination with the L5–S1 level. The primary complication concern is bowel injury because the approach is through the fat pad between the rectum and the sacrum. To reduce this possible complication, a bowel preparation is given to the patient before the surgery. Additionally, those patients with conditions that make the mobilization of the bowel under the sacrum difficult or not possible should be avoided. Therefore, patients with a suspected medical history that could lead to excessive abdominal adhesions, such as multiple prior abdominal surgeries, inflammatory bowel disease, endometriosis, or diverticulitis, should be treated via other approaches.

A careful analysis of preoperative imaging will help to ensure that the angulation of the sacrum with respect to the lumbar vertebrae is adequate to achieve access to the L5–S1 interspace. Blunt dissection on the underside of the sacrum can help to avoid bowel injury. The instruments are specifically designed to allow safe docking on the S1–2 area and introduction of a working channel to pass instruments. Nitinol shavers are introduced through a working channel and circumferential cleaning of the disc space is performed for graft material placement and screw deployment. To avoid pseudoarthrosis, care is taken to adequately prepare the disc space. Bone morphogenetic protein could potentially improve fusion results without involving issues of heterotopic bone formation encountered in more open techniques using bone morphogenetic protein, because this approach affords relative isolation of bone morphogenetic protein sponge application. In a long-term follow-up of 35 patients, bone fusion was achieved in 91% of patients with no reported complications occurring.4

Conclusions

Recent advances in technology, surgical techniques, and anesthesia have led to new advances in the procedures that we can offer our patients. The literature reporting complications with minimally invasive procedures is limited due to the lack of long-term outcome data. As more data become available, we will have a stronger case with regard to recommending these techniques over traditional open surgeries. These procedures will continue to reduce hospital stays and costs provided that patients are carefully selected and thoroughly educated prior to surgery. Minimally invasive spine procedures do offer clinical advantages that have improved outcomes, but there is a steep learning curve with regard to mastering these techniques. Proper patient selection and surgeon education and training will help to match the proper patient to the proper surgery for the best outcomes and reduced complications.

Disclosure

Dr. Perez-Cruet is a patent holder with Mi4Spine, LLC, and Thompson MIS, and serves as a consultant to Zimmer Spine and Aesculap Spine.

Author contributions to the study and manuscript preparation include the following. Concept and design: both authors. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: both authors. Critically
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revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of all authors: Hussain. Statistical analysis: both authors. Administrative/technical/material support: both authors. Study supervision: both authors.

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