Maximizing the potential of minimally invasive spine surgery in complex spinal disorders

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Minimally invasive surgery (MIS) in the spine was primarily developed to reduce approach-related morbidity and to improve clinical outcomes compared with those following conventional open spine surgery. Over the past several years, minimally invasive spinal procedures have gained recognition and their utilization has increased. In particular, MIS is now routinely used in the treatment of degenerative spine disorders and has been shown to be as effective as conventional open spine surgeries. Although the procedures are not yet widely recognized in the context of complex spine surgery, the true potential in minimizing approach-related morbidity is far greater in the treatment of complex spinal diseases such as spinal trauma, spinal deformities, and spinal oncology. Conventional open spine surgeries for complex spinal disorders are often associated with significant soft tissue disruption, blood loss, prolonged recovery time, and postsurgical pain. In this article the authors review numerous cases of complex spine disorders managed with MIS techniques and discuss the current and future implications of these approaches for complex spinal pathologies.

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Key Words • complex spine disorder • deformity • minimally invasive spine surgery • oncology • trauma

Conventional open surgeries have been widely used for decades in the treatment of various spinal disorders. Although conventional open spinal surgery has been considered the standard for most spinal disorders, the clinical outcomes following open surgery can vary. Suboptimal clinical results often occur even after technically successful open spine surgeries. Although contributing factors to the suboptimal outcomes in those cases may be related to poor patient selection, postsurgical scarring, or adjacent level disease, the significant soft tissue and muscle injuries that occur during exposure for open spine surgeries may also be important contributing factors.

Minimally invasive spine surgery was developed to decrease the rate of approach-related morbidity associated with conventional open spine surgery in an effort to improve clinical outcomes.10,20,35,39 Based on that philosophy, various approaches and techniques have evolved to minimize the disruption of normal surrounding tissues. Although the approach and techniques can differ between open spine surgery and MIS, the surgical goals are equivalent and should not be compromised in MISs.

Over the past several decades, MISs have been gaining momentum and popularity in many surgical specialties, including spine surgery. In 1991 Obenchain27 first reported a case of laproscopic lumbar discectomy. Since that initial report, MIS has become routinely used in the treatment of degenerative spine diseases, as in herniated disc removal, decompression of spinal stenosis, and fusions for degenerative spinal disorders. Compared with those in conventional open spine surgeries, the clinical outcomes of MISs have indicated that the procedure is at least equally effective. Moreover, recovery time, pain, and the time required to return to work after surgery are reduced for MIS of the spine in several clinical series involving degenerative pathology.9,11,19 Although we have witnessed favorable preliminary clinical results in applying minimally invasive strategies, long-term outcome studies supported by validated outcome measuring instruments are pending. Moreover, it would be interesting to determine the impact of MIS on fusion rates, adjacent segment disease, and sustained pain relief. As spine surgeons become more experienced with the techniques and technology associated with MIS, the indications for MIS continue to expand.13 Interestingly, the benefit of decreasing approach-related morbidity might be far greater for more complex surgeries in spinal trauma, spinal deformity, and spinal oncology. In this report, we discuss the techniques in, and the rationale for, using MIS in these complex spinal disorders and provide illustrative cases for each.

Abbreviations used in this paper: MIS = minimally invasive surgery; SPO = Smith–Petersen osteotomy.
Spinal Trauma

More than 150,000 Americans annually suffer from traumatic injuries to the spine. These injuries are often related to high-velocity and high-impact incidents such as motor vehicle collisions or traumatic falls. Spinal cord injuries, pain, and deformity can result from trauma to the spinal column. In addition, spinal injuries are often associated with other musculoskeletal or visceral injuries based on the mechanism of injury. Early surgical interventions can prevent neurological deterioration or perhaps even reverse neurological injury. Surgery can also improve pain when bracing and other nonsurgical therapies fail, and it can provide immediate spinal stability for unstable injuries in a critically ill patient and prevent delayed spinal deformities.

Injuries to the cervical spine account for one-third of all spinal fractures and one-half to two-thirds of all spinal cord injuries. In cervical spine injuries, the traditional Smith–Robinson anterolateral approach to the anterior spine is a prime example of a minimally invasive strategy. Although this approach has been used to address pathology in the anterior cervical spine for many years, it has not been widely recognized as a minimally invasive tactic. Interestingly, however, the Smith–Robinson approach exemplifies the underlying principle of MIS to minimize approach-related morbidity. The procedure involves a direct route of dissection through natural tissue planes to reach the spine without significant soft tissue or muscle injury. The Smith–Robinson approach for anterior cervical spine surgery is widely accepted as one of the most successful and gratifying procedures in spine surgery. One reason for its success is the limited approach-related soft tissue and muscle injuries from surgical exposure. For posterior cervical spine injuries, both decompression and instrumented fusions can be performed via a muscle-splitting approach with minimal-access retractors. As is the case for degenerative cervical disease, central and foraminal decompression and instrumented fusion can be performed via minimally invasive approaches for cervical spine injuries.

Of all spine injuries, 30% involve the thoracic spine and 42.5% the lumbosacral spine. Thoracolumbar injuries are often associated with high-impact and high-velocity traumas. Injury to the thoracolumbar spine can range from compression fractures and burst fractures to flexion distraction injuries with fracture dislocation. Various classification systems have been formulated to stratify thoracolumbar spine injuries in an attempt both to offer a mechanically sound description of the insult and to provide a framework for treatment. In general, stable fractures are treated with medical observation and bracing, whereas unstable fractures are treated with operative interventions.

Open surgical treatments with anterior, posterior, or combined approaches have been widely used for thoracolumbar spine injuries over the years. Although these therapeutic approaches are successful in providing neural decompression and stabilization, they are associated with prolonged surgical time, significant blood loss, increased infection rate, and significant approach-related soft tissue and muscle destruction. In addition, patients are often afflicted with significant pain despite successful surgical recovery.

In an effort to improve clinical outcomes, several minimally invasive approaches and techniques have been developed to minimize approach-related morbidity. The most common application of MIS for thoracolumbar injuries is in percutaneous cement augmentation by vertebroplasty or kyphoplasty of compression fractures and burst fractures. These percutaneous interventions have been shown to be highly effective in improving spinal stability from vertebral insufficiency and pain relief. Moreover,
kyphoplasty has been shown to improve spinal deformity by the restoration of vertebral body height.\textsuperscript{32} In addition to percutaneous cement augmentation, percutaneous instrumentation with or without fusion is now being performed for spinal stabilization following thoracolumbar injuries.\textsuperscript{33,34,37} Compared with conventional open spine surgeries, percutaneous instrumentation procedures are associated with minimal soft tissue disruption, decreased blood loss, reduced infection rate, and less operative time in most cases. Particularly in patients with polytrauma or those with significant medical comorbidities, complex open spine surgery may not be possible. Unlike open surgery, percutaneous instrumentation is an alternative that can provide spinal stabilization of thoracolumbar injuries with a decreased perioperative morbidity rate.

\textit{Illustrative Cases}

\textit{Case 1.} This 87-year-old man with ankylosing spondylitis and multiple medical comorbidities fell while at home and presented to our institution with severe back pain and lower-extremity weakness. A CT scan demonstrated a highly unstable flexion distraction injury (AO Type C injury) at T-11 without spinal canal compromise (Fig. 1). An open multilevel instrumented thoracolumbar fusion was initially recommended to the patient; however, during the preoperative medical clearance, the perioperative morbidity and mortality risks associated with a prolonged and extensive surgical intervention was considered by the medical service to be too great. Given the highly unstable T-11 fracture surgical intervention was required, and percutaneous instrumented fusion of T-9 to L-1 was recommended and performed without arthrodesis, without complication. Because the patient had preexisting ankylosis of the spine from ankylosing spondylitis, arthrodesis was felt to be unnecessary and thus not performed. The surgery was completed in 2 hours and 53 minutes, and the total blood loss for this procedure was 150 ml. Spinal fracture reduction and stabilization was achieved following the percutaneous instrumentation (Fig. 2). Postoperatively, the patient did not require any blood transfusions or fluid resuscitation. He was able to participate in physical therapy, and he was transferred to a rehabilitation facility after the hospitalization.

\textit{Case 2.} This 18-year-old man suffered an L-5 burst fracture after skydiving (Fig. 3). He was initially treated with orthotic bracing; however, increasing back pain subsequently developed together with a foot drop. Surgical decompression and stabilization of the fracture was offered to the patient. An L-5 anterior vertebrectomy was also discussed, and minimally invasive decompression and pedicle screw fixation of L4–S1 were also offered to allow healing of the L-5 body fracture. The patient underwent a minimally invasive L-5 laminectomy and L4–S1 percutaneous instrumentation placement without any complications (Fig. 4). Given the goal of instrumentation removal after healing of the L-5 vertebral body fracture, arthrodesis was not performed in this case. The patient had an uncomplicated post-surgical recovery, and he was discharged home 3 days after surgery with significant pain and neurological improvement. Three months after surgery, a CT scan demonstrated healing of the L-5 vertebral fracture, and thus the percutaneous instrumentation was subsequently removed. Flexion and extension radiographs obtained following instrumentation removal revealed a normal range of motion in the lumbosacral spine (Fig. 5). Six years after the initial surgery, the patient was still extremely satisfied with the operation. He is without any significant lower-back pain and requires no routine analgesics.

\textit{Cases Review.} These illustrative cases demonstrate that MIS can be applied to traumatic spine injuries and lead to operative goals identical to those sought in conventional open surgeries. In both patients, spinal fixation was achieved with percutaneous instrumentation. In our experi-

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\caption{Case 1. \textit{Left:} Lateral radiograph demonstrating percutaneous placement of pedicle screws and rod. \textit{Right:} Anteroposterior radiograph showing the percutaneous pedicle screw instrumentation construct.}
\end{figure}
ence, percutaneous instrumentation and minimally invasive decompression, compared with open surgeries, lead to a substantial reduction in the infection rate, blood loss, the transfusion rate, and cardiopulmonary complications from fluid resuscitation. These advantages are particularly valuable in patients with medical comorbidities or those with multiorgan traumas who are at risk for significant medical complications perioperatively.

In contrast, a potential disadvantage of MIS feared by spine surgeons is the inability to perform adequate arthrodesis and achieve long-term osseous fusion. In actuality, excellent arthrodesis can be successfully achieved through MIS by facet joint arthrodesis or interbody arthrodesis. Moreover, our illustrative cases revealed that the biological milieu of the patient has a significant impact. In patients with ankylosing spondylitis, as in the patient in Case 1, ankylosis is likely to ensue with spinal stabilization and apposition of the fracture sites. With ankylosis of the spine from ankylosing spondylitis and subsequent healing of the T-11 fracture, instrumentation removal was unnecessary in our patient. In addition, the removal of percutaneous instrumentation is challenging with current minimally invasive techniques. In the patient in Case 2, the L-5 fractured body was allowed to heal with internal fixation. With the healed vertebral body a posterior fusion was unnecessary, and instrumentation could be removed subsequently to salvage spinal mobility across the previously fractured level. This scenario is far more desirable in a young individual compared with a fusion across the lumbosacral junction.

**Spinal Deformity**

Spinal deformity with imbalance of coronal and sagittal alignment of the spine from various causes can result in neurological compromise, poor cosmesis, and pain. These factors can impart significant debilitation of psychosocial and functional well-being. In cases of severe spinal deformity, patients can suffer considerable physiological compromise, including a decline in cardiopulmonary capacity. Surgical treatment for spinal deformity is indicated in patients with severe kyphoscoliosis, rapid curve progression, severe pain, or poor cosmesis.

Dating back to the early 20th century, traditional surgical treatment for spinal deformity involves long-segment...
spinal fusions. Surgeries for the correction of a spinal deformity are time-consuming and technically demanding. In addition, these surgeries are often associated with a high perioperative morbidity rate. The overall complication rate in adult patients undergoing spinal deformity surgery ranges from 40 to 86%, and major morbidities occur in ~20% of cases. Other than neurological injury, major complications include infection, myocardial infarction, cardiac failure, pulmonary embolism, acute respiratory distress syndrome, transfusion-related lung injury, renal failure, and even death. Patients older than 60 years with medical comorbidities have a particularly increased risk. 

It has been projected that adults 55–64-years-old are the fastest growing segment of our population. As the elderly population expands over the next decade, there will be an increasing number of patients presenting with degenerative spine diseases and adult degenerative scoliosis. More patients will seek surgical treatment to improve pain symptoms and quality of life. Most of the elderly patients will have medical comorbidities and an increased risk of perioperative complications; therefore, any intervention that can reduce the perioperative morbidity associated with spinal deformity surgery in the elderly may have a significant impact on clinical outcomes and reduce healthcare costs.

The first attempt to utilize minimally invasive procedures in spinal deformity surgery occurred in 1993 with the use of endoscopic techniques in thoracic spine surgery. Thoracoscope-assisted procedures for spinal deformity are performed for anterior releases to increase both the flexibility of the spine and the fusion surface area with anterior intervertebral fusions. Advantages of thoracoscopic surgery for spinal deformity include decreased surgical trauma, scarring, postoperative pain, and perioperative morbidity. In addition, compared with posterior approaches, anterior procedures in spinal deformity surgeries can reduce the number of fusion segments required to achieve curve correction.

Over the past several years, minimal-access lateral approaches to the lumbar spine have been developed for lumbar interbody fusion. Through small flank incisions and by using the retroperitoneal approach, anterior lumbar disectomy and interbody fusion can be performed from...
L1–2 down to L4–5 through minimal-access retractors. With variation in the approaches, direct access to the thoracolumbar segments and even the thoracic spine can be performed safely and with ease. These lateral approaches are particularly useful in the treatment of lumbar or thoracolumbar curves that are associated with adult degenerative scoliosis. They allow anterior releases to increase the flexibility of the spine in patients with rigid curves, and they allow placement of large intervertebral grafts to increase the fusion surface area. Strategically placed interbody grafts can result in substantial sagittal and coronal corrections. Furthermore, similar to the experience with thoracoscope-assisted surgeries, anterior releases and correction of curves via minimally invasive lateral approaches in the lumbar spine can result in a decreased number of fusion levels.

Minimally invasive techniques can be applied in spinal deformity surgery via posterior approaches as well as the anterior approaches. Percutaneous instrumentation can be applied for additional segmental stabilization following anterior releases and intervertebral fusions. Moreover, SPOs can be performed through minimal-access retractors with decreased disruption of normal soft tissues. With the latest percutaneous instrumentation technologies, safe closure of osteotomies can be performed to increase segmental lordosis and to allow apposition of osseous surfaces for subsequent fusion.

Illustrative Case

Case 3. This 61-year-old woman with a history of adolescent idiopathic scoliosis had been monitored for her spinal deformity for many years (Fig. 6). Over the last few years, she experienced late progression of the adolescent idiopathic scoliosis (Lenke Curve Type 5) with increasing pain and deformity. After nonsurgical management of her symptoms failed, surgical correction of the deformity and instrumented fusion of the spine were recommended. A 2-stage minimally invasive approach was then applied. In the first stage, she underwent the placement of percutaneous instrumentation from T10–L3 in conjunction with SPOs at T11–12, T12–L1, and L1–2 through a minimal access tubular retractor. Posterior deformity correction was performed using segmental instrumentation after the SPO releases. To provide anterior support and fusion, the second stage of the procedure was performed 8 days after the first stage. Direct lateral discectomies and interbody arthrodesis with cage placement were performed through minimal-access retractors at T12–L1, L1–2, and L2–3. The total operative time was 8 hours for the first-stage procedure and 5 hours for the second. Estimated blood loss in the patient was 1 L over both procedures, and the patient received only 2 units of transfused blood during both perioperative periods. Postoperative standing long-cassette radiographs demonstrated balanced coronal and sagittal alignment (Fig. 7). The patient had an uncomplicated recovery, and she was discharged from the hospital 11 days following the first-stage procedure.

Case Review. Over recent years, minimally invasive surgical approaches, techniques, and technologies have evolved to allow spinal deformity surgeons to accomplish traditional goals through smaller incisions, with limited normal tissue disruption and minimal-access retractors. Our illustrative case reveals that deformity correction and stabilization of the spine while preserving coronal and sagittal balance are possible with MISs. In degenerative disease, MIS has been shown to decrease blood loss, the hospitalization stay, and the postoperative recovery period. Minimally invasive surgery in spinal deformity is still in its infancy and experience with the procedure is too limited to draw generalized conclusions; however, our early experience with minimally invasive procedures in spinal deformity has been associated with decreased perioperative blood loss and need for transfusions. The reduced blood loss will decrease the cardiopulmonary morbidity that typically follows aggressive fluid resuscitation. Moreover, the decreased transfusion rate will reduce the likelihood of transfusion-related lung injuries, which has become the most common cause of death after blood transfusion. Additional clinical experience with minimally invasive procedures in spinal deformity will determine if these factors can truly decrease major perioperative complication rates in the elderly and improve their clinical outcomes.

Spinal Oncology

Currently, > 1.4 million new cases of cancer are diagnosed annually in the U.S., with ~ 500,000 patients in these cases dying annually from metastatic disease. Although primary tumors of the spine are not common, improve-
ments in the treatment of systemic cancer combined with advancements in imaging technology will likely result in an increasing incidence of spine metastases. Symptomatic lesions may contribute to substantial pain and neurological dysfunction in a large proportion of patients, and thus sound treatment of spinal metastases is especially relevant.

In general, the treatment of metastatic lesions in the spine is considered palliative at best, with survival chiefly affected by the extent and control of systemic disease. Nonetheless, the management of metastatic spinal lesions can drastically improve quality of life, especially as it pertains to debilitating pain and loss of ambulatory ability. Although the treatment of these tumors has involved radiation therapy as the primary modality, surgical intervention has become an essential component of care. In a recent prospective randomized trial Patchel et al. showed that surgical decompression plus radiation therapy was superior to radiation therapy alone in the treatment of metastatic epidural spinal cord compression with regard to neurological function. Surgeries performed in that study involved direct decompressive procedures with spinal reconstruction. Although these procedures were not minimally invasive, the application of techniques less destructive to the paraspinal soft tissues would likely provide similar results if the goals of decompression and stabilization were equally met.

Patients with systemic cancer face a greater likelihood of surgical complications and postoperative morbidity. Factors likely contributing to such perioperative morbidity include lower preoperative functional status, poorer nutrition, immunosuppression, chronic steroid use, and in some cases previous radiation to the site of surgery. Thus, for cases in which surgery is being considered, large tissue dissection can lead to increased wound complications. Minimally invasive spine surgeries through smaller incisions can mitigate such wound complications by limiting collateral damage to surrounding soft tissues during exposure and instrumentation.

One of the first minimally invasive techniques used to treat spine tumors was percutaneous placement of polymethylmethacrylate cement. With fluoroscopic guidance, this cement can be placed percutaneously to fill the vertebral body directly (vertebroplasty) or after kyphosis has been reduced via internal expansion of a balloon device (kyphoplasty). The application of cement often provides immediate pain relief, likely as a result of the stabilization of fractures and reduction in micromobility, but also possibly due to thermal damage to small pain fibers resulting from the exothermic reaction involved during cement curing. Regardless, although such treatment can provide excellent and immediate pain relief via a noninvasive percutaneous approach, it does nothing to treat the local oncological disease.

Hence, cement augmentation techniques are often com-
bined with radiation therapy.\textsuperscript{16} Classically, such treatment involves the standard delivery of ionizing radiation to the diseased spinal segment and to 2 segments above and below the index level. In cases of local tumor recurrence, however, such radiation therapy cannot be repeated because of the potentially supratherapeutic dosage of radiation directed at the spinal cord and neighboring tissues. Therefore, radiation that can be delivered in a focal manner has been used more recently to overcome this problem. Such techniques, commonly referred to as “radiosurgery” or “image-modulated radiation therapy,” are used to deliver multiple doses of radiation to the lesion, with each dose representing only a small proportion of the total dose. By changing the trajectory through normal tissue during each exposure (radiosurgery) or by carefully collimating the radiation so that there is a steep decline in radiation intensity around the lesion (image-modulated radiation therapy), larger doses of ionizing energy can be delivered to the pathological segment while minimizing damage to surrounding nonneoplastic tissues. Such techniques thus allow treatment of recurrent spine lesions and tumors usually considered radiation insensitive.\textsuperscript{17}

Although both percutaneous vertebroplasty/kyphoplasty and radiosurgery are effective in addressing pain or local disease control, they do not address the spinal instability and deformity resulting from metastatic tumor involvement. The evolution of MIS for spinal tumors in recent years has involved direct removal of the lesion with instrumented fixation of the spine. Through minimal-access tubular retractors placed at the diseased levels, direct tumor resection and spinal cord decompression can be performed with limited soft tissue and muscle dissection. Moreover, stabilization can be achieved in a similar minimally invasive manner by using simultaneous percutaneous instrumentation with cement reconstruction and/or placement of an intervertebral structural graft.

**Illustrative Case**

Case 4. This 39-year-old man with a 6-month history of back pain presented to an outside hospital with increasing back pain associated with lower-extremity paresthesia. During a medical workup, the patient was found to have T4 and -5 vertebral fractures and a right lung mass on radiography. A biopsy specimen of the lung mass indicated primary lung adenocarcinoma. Computed tomography and MR imaging of his spine demonstrated pathological fractures of T4 and -5 vertebral bodies from metastasis with significant epidural disease (Fig. 8). The patient also had intermittent paresthesia and mild lower-extremity weakness of 4+/5 in strength. He was offered a minimally invasive laminectomy and vertebrectomy of T4–5 for decompression with an instrumented fusion of the thoracic spine involving T1–8. After obtaining informed consent, the patient underwent percutaneous instrumented fusion of T1–8 with laminectomy and costotransversectomy for vertebrectomy of the T-4 and -5 metastatic tumor through bilateral expandable minimal-access retractors (Fig. 9). An intervertebral distractible cage was placed through the minimal-access retractor for reconstruction of the T4–5 anterior and middle columns following vertebrectomy. The patient tolerated the procedure well without complications. The total operative time was ~ 7 hours, and the total estimated blood loss was 1.2 L. The patient had preoperative anemia, and he subsequently required 2 units of transfused blood during the perioperative period. A postoperative CT
demonstrated circumferential decompression of the disease at T-4 and -5 with circumferential instrumented reconstruction of the spine (Fig. 10). The patient had an uncomplicated postoperative course, and he was discharged from the hospital 5 days after his surgery.

**Case Review.** In the surgical treatment of patients with metastatic spine tumors, the theoretical limitation of osseous fusion with MIS is insignificant. Patients with symptomatic metastatic spine tumors generally have an average lifespan of ~ 6–12 months. Treatment goals in these patients are the preservation of neurological function, stabilization of the spine, and improvement in pain. Generally, decompression and instrumentation without arthrodesis are sufficient to achieve these goals in most of these patients. Furthermore, almost all of these patients will receive steroids and chemotherapy and undergo radiation treatment. Therefore, even the most meticulous arthrodesis techniques may not result in osseous fusion in long-term survivors.

In our illustrative case, a 2-level thoracic laminectomy and vertebrectomy for a symptomatic metastatic spinal tumor was performed with successful decompression of the spinal cord through bilateral minimal-access retractors. Final instrumented reconstruction and stabilization of the spinal column was performed with the placement of a distractable cage through the minimal-access retractor and the placement of percutaneous pedicle screw instrumentation. In the patient in this case, circumferential decompression and reconstruction of the spinal column was completed successfully without complications. In our early experience, compared with the open procedures, MIS of the spine for these cases resulted in decreased blood loss and faster recovery in the subacute recovery phase at ~ 2–4 weeks following surgery. Furthermore, the smaller incisions and limited soft tissue disruption led to a reduction in the infection rate and wound complications. Overall, a wide variety of MIS options are now available for the treatment of patients with metastatic spine tumors. Combinations of the various MIS options with medical therapies, such as chemotherapy and radiation therapy, will likely continue to improve our ability to treat patients with cancer.

**Conclusions**

As spine surgeons become more experienced and facile with MIS techniques and procedures, the application of these strategies for complex spinal disorders will continue to increase. Currently, advancements in surgical technology and techniques as well as early clinical results have driven surgeons to expand the use of MIS in the spine. Nevertheless, prospective and long-term clinical studies are needed to demonstrate the true clinical benefits. Although the case illustrations herein were presented to outline the great potential of using MIS in severe spinal pathologies, future prospective studies on outcomes following open spine surgery vs. MISs for such disorders will likely demonstrate the tangible benefits of the different approaches.

**References**
