Contemporary Spine Surgery

VOLUME 21 ■ NUMBER 3 ■ MARCH 2020

Minimally Invasive Surgery of the Thoracic Spine

Michael Yayac, MD, Max Detweiler, BA, John M. DePasse, MD, Matthew S. Galetta, BA, Srikanth N. Divi, MD, Dhruv K.C. Goyal, BA, Christopher K. Kepler, MD, MBA, Gregory D. Schroeder, MD, and Alexander R. Vaccaro, MD, PhD, MBA

LEARNING OBJECTIVES: After participating in this CME activity, the spine surgeon should be better able to:

1. **Evaluate indications for minimally invasive surgery of the thoracic spine.**
2. **Describe the benefits of minimally invasive surgery for the thoracic spine.**
3. **Explain how to incorporate minimally invasive surgery for the thoracic spine into practice.**

Key Words: Corpectomy, Fixation, Fusion, Metastases, Minimally invasive surgery, Thoracic spine

Dr. Yayac is Research Fellow, Mr. Detweiler, Mr. Galetta, and Mr. Goyal are Spine Research Fellows, Dr. DePasse and Dr. Divi are Spine Surgery Fellows, Dr. Kepler is Associate Professor of Orthopaedic Surgery, Dr. Schroeder is Assistant Professor of Orthopaedic Surgery, and Dr. Vaccaro is Professor and Chairman, Department of Orthopaedic Surgery, Rothman Orthopaedic Institute at Thomas Jefferson University, 125 S 9th St, Ste 1000, Philadelphia, PA 19107; E-mail: dhruvkcgoyal@gmail.com.

The authors, faculty, and staff in a position to control the content of this CME activity, and their spouses/life partners (if any), have disclosed that they have no financial relationships with, or financial interests in, any commercial organizations relevant to this CME activity.

Spine surgery is a continually evolving surgical subspecialty. In the 1990s, the philosophy of minimizing risk while maximizing efficiency gave rise to minimally invasive surgery (MIS), which employs smaller incisions and muscle-spreading techniques to maintain the integrity of the overlying muscular apparatus, while still providing enough access to the underlying structures of interest. The nuance of preserving tissue while maintaining visibility of the target has been the focus of collective efforts to improve MIS.

There has been an exponential upsurge of clinical evidence in the recent literature documenting the benefits of MIS over conventional open surgery with over 500 publications in 2018 alone—including improved outcomes and decreased complications after cases of trauma, malignancy, deformity, etc.[1] Some of the most commonly used MIS techniques for addressing various spinal pathologies include discectomy, vertebrectomy, neurolysis, tumor resection, and reduction maneuvers.[2] As MIS techniques are continually expanded and refined, this particular scope of practice within spine surgery has seen a rise in popularity, backed by an overwhelming clinical advantage to conventional surgical alternatives in a particular set of circumstances.

The goal of this review is to outline how MIS has shown great promise in improving the treatment of certain disorders of the thoracic spine. By the end of this article, the reader should be able to evaluate when MIS for the thoracic spine is appropriate, appreciate the benefits of MIS for the thoracic spine, and understand how to incorporate MIS for the thoracic spine into their practice.

FUSION AND FIXATION

Spinal fusion is one of the most common procedures performed due to the array of indications. Various degrees of deformity, degeneration, tumor, infection, or trauma can all contribute to instability and weakness of the thoracic spine. Instability of the spine can also be the product of prior procedures, such as corpectomy or tumor resection. By fusing and stabilizing the thoracic spine in these scenarios, pain relief can be swift and effective. However, conventional open procedures are often accompanied by approach-related morbidity, which is why MIS has become indispensable.

Pedicle screws, hooks, and cages are commonly used instrumentation to stabilize the thoracic spine. They increase the rigidity of the thoracic spine, aiding in successful spinal fusion. With traditional open thoracic posterolateral spinal fusion procedures, a midline incision is made and the dissection is carried down to the spinal column exposing the pedicles bilaterally for all levels to be fused. Although this allows for direct visualization of the pedicle screw during placement, it often results in considerable blood loss, muscular denervation, and postoperative pain. Minimally invasive transmuscular pedicle screw fixation of the thoracic spine has been found to be feasible with the use of standard equipment.[3] Minimally invasive stabilization of the thoracic spine may also be achieved through percutaneous transpedicular fixation,[4] which can be attained without the customized instruments and navigation systems of other MIS techniques.

Although technically challenging and potentially intimidating to the inexperienced surgeon, percutaneous techniques have several potential benefits, including reduced soft tissue injury, postoperative complications, length of stay, and time to return to work. With percutaneous insertion, a small skin incision is made lateral to the pedicle and a Jamshidi needle is inserted through the incision and advanced anteromedially down to the lateral border of the pedicle under image guidance. The needle is then advanced into the pedicle, with considerable care taken to avoid the medial pedicle wall, as violation of the medial cortex puts the patient at considerably greater risk of neurologic injury. Once the needle is within the vertebral body, a Kirschner wire can be passed down the needle to serve as a guidewire for the insertion of a cannulated pedicle screw.[5] After all pedicle screws have been placed, reduction can be performed and the rod is inserted, often without the need for an additional incision.[6] Tubular retractors attached to tulip of each screw allow for adequate visualization of the screw head during rod and set-screw insertion. Indications for percutaneous pedicle screw fixation have expanded and now include degenerative disease, trauma, neoplasm, and revision procedures.[6] The importance of developing MIS techniques that do not require customized equipment is paramount. It is this advance that will enable providers, regardless of economic or technical constraints, the ability to perform these surgeries.

Similar to spinal fixation, fusion of thoracic vertebrae has shifted toward minimally invasive approaches. As the focus began to shift away from conventional open approaches, thoracoscopic and video-assisted thoracoscopic surgery became the mainstay of many practices. As with any anterior approach to the thoracic spine, however, the risk of pulmonary involvement and other complications are a

This continuing education activity is intended for orthopaedic and neurologic surgeons and other physicians with an interest in spine surgery.

Wolters Kluwer

Contemporary Spine Surgery (ISSN 1527-4268) is published monthly by Wolters Kluwer Health, Inc., at 14700 Citicorp Drive, Bldg 3, Hagerstown, MD 21742. **Customer Service: Phone (800) 638-3030, Fax (301) 223-2400, or E-mail customerservice@lww.com.** Visit our website at LWW.com.

Publisher: Randi Davis

Suscription rates: *Individual:* US $522; international $683. *Institutional:* US $1142, international $1402. In-training: US resident $169 with no CME, international $193. Single Copies $118. Registration Number: 895524239.

serious concern.[7] Hence, the need for an MIS posterior approach became apparent. There are a number of MIS posterior approaches that have been found to decrease the associated approach morbidities of conventional open thoracic fusion.

One of such procedures has been described by Abbasi *and* Abbasi.[8] Through the use of biplanar fluoroscopic imaging and electrophysiological monitoring, an MIS direct thoracic interbody fusion (MIS-DTIF) was successfully accomplished on 6 thoracic spinal levels among 4 patients, 2 of which were single-level fusions, and the other 2 were two-level fusions. MIS posterior pedicle screw fixation was placed through preformed muscle gaps, which allowed for a simpler alternative to the established MIS technique. In the 4 cases in this study, surgery time, blood loss, fluoroscopy time, complications, and patient-reported pain were all lower in MIS-DTIF than what is currently reported in the literature for open fusion of the thoracic spine. Figure 1 displays a diagram that details landmarks used to guide skin incision. Figure 2 shows lateral fluoroscopic views at different steps during the fusion. Again, the alterations to current MIS techniques can and will continue to improve clinical outcomes and decrease economic and technical burdens for providers.

CORPECTOMY

For nearly every clinical situation that calls for a corpectomy, there are one or more MIS approaches that may be favored over a traditional open approach. One of these scenarios is for the repair of an acute traumatic thoracic fracture. Conventional treatment of these injuries, often approached through open thoracotomy, includes a wide array of morbidities, which have spurred the use of MIS procedures.

Smith et al[9] conducted a prospective study of treating traumatic burst fractures with instability and neurologic deficit by mini-open lateral corpectomies. In these cases, a lateral transpleural or retropleural approach was used along with sequential tube dilators and an expandable retractor to gain access to the anterior spinal column. The injuries ranged from T7 to L4 and

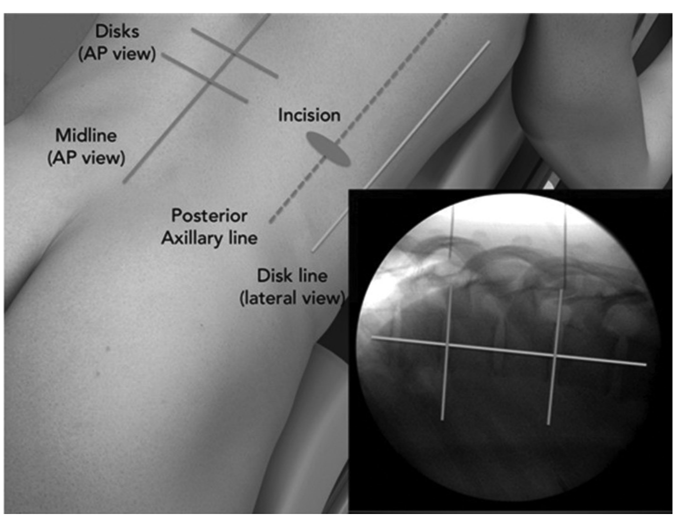

Fig. 1 *MIS-DTIF diagram.*

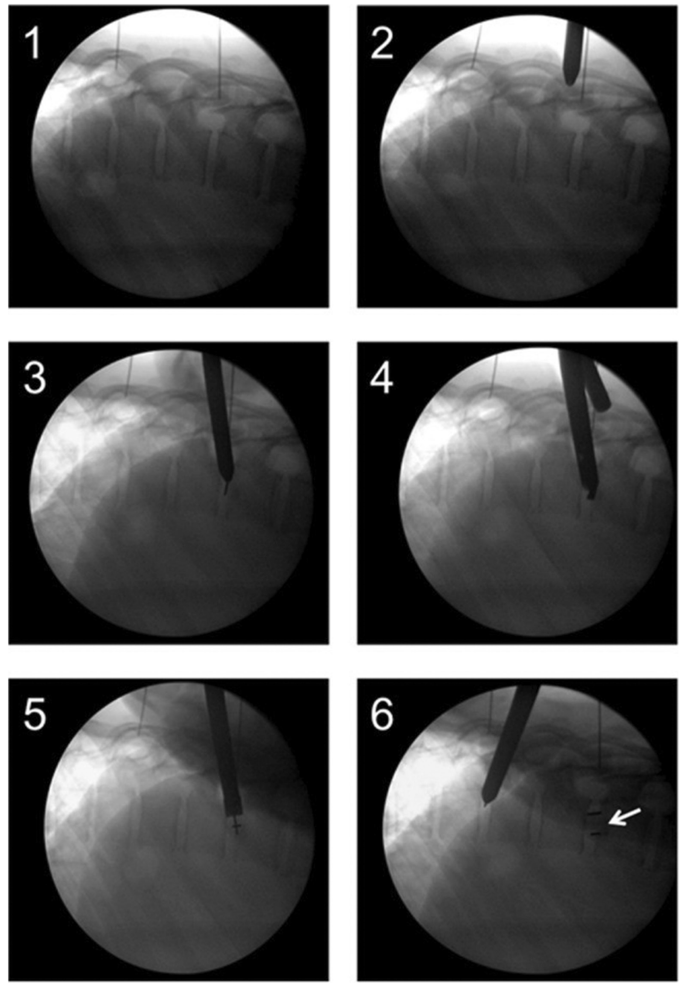

Fig. 2 *Lateral fluoroscopic views during MIS-DTIF.*

clinical outcomes were based on treatment and in-hospital complications. At 2-year follow-up, there were no reoperations necessary and no neurologic deterioration among any of the patients. Based on median operative time, estimated blood loss, hospital stay, and complication rates, the mini-open lateral approach for thoracic corpectomy was found to be a viable alternative for traumatic thoracic spine fractures. The mini-open approach also decreased the associated morbidities of thoracotomies and open posterior approaches. Additionally, MIS endoscopic techniques through a retroperitoneal route for thoracolumbar corpectomies were found to be feasible and preferred to the open alternative.[10] By demonstrating the wide applications of minimally invasive corpectomies for the thoracic spine, their clinical efficacy has congruently been confirmed.

As the list of surgical indications that warrant an MIS approach grows, so does the number of MIS approaches. The past decade has seen immense refinement and amendment to the established minimally invasive techniques. These revisions served to both improve clinical outcomes and decrease procedural complexities. With success comes community focus, which has prompted the development of guidelines for approaching thoracic spine corpectomies. Namely, Ogden et al[11] studied 3 MIS approaches to the anterior thoracic spine to determine which approach yielded the greatest decrease in operative morbidities. It was found that not only is MIS thoracic corpectomy viable, a 6-cm approach off the midline is best. This approach was the least technically difficult and best suited for the length of conventional surgical equipment. The main boundary to the complete acceptance of MIS for the thoracic spine is the need for specialized training and instruments. By defining which approaches decrease this deterrent, MIS for the thoracic spine will face little reproach for its acceptance into practice.

METASTASES

Spinal metastases are a driving force behind the increased focus and demand on MIS for the thoracic spine. Patients presenting with spinal metastases are at greater risk of complications and poor recovery. These patients are often immunocompromised, putting them at increased risk of surgical site infections. This vulnerability makes conventional surgical approaches tremendously risky and often ill advised. By decreasing incision length and soft tissue dissection through use of MIS approaches, this risk can be minimized and tumor resection in the thoracic spine can be more confidently and competently performed, improving patient prognosis in the process.

There are a number of emerging techniques for use of MIS in treatment of patients with thoracic spine tumors. The exact procedure performed depends on its anatomical location, its size, and the site of the primary tumor (Figure 2). Smith et al[12] discussed the advances in treatment of thoracic spine tumors to include percutaneous techniques like vertebroplasty and kyphoplasty, spinal radiosurgery, and MIS spinal decompression. Each of these MIS techniques has the potential to improve clinical outcomes by decreasing surgical morbidity and increasing safety and efficiency of treatment pathways. By developing new MIS techniques, surgical treatment is now available to patients who were previously excluded because of morbidities associated with their metastases.

Patients requiring a corpectomy often present with significant comorbidities that can increase the risk of complications. Indications of the procedures are often the result of metastases or trauma. The evolution of MIS has been imperative to the treatment of these cases, as conventional treatments often pose too large of a risk to these patients. Kim et al[13] documented the use of expandable 22-mm diameter tubular retractor paramedian incisions to access the vertebral bodies extrapleurally during posterolateral thoracic corpectomies. These complete corpectomies were accomplished for 2 T6 burst fractures, a T4-T5 plasmacytoma, and a T12 colon cancer metastasis using intraprocedural fluoroscopy. This MIS technique was successful in all 4 clinical cases, as assessed by CT measurement of the degree of decompression. MIS decreased the tissue disruption associated with open thoracotomy and showed promising signs of decreasing associated complication rates.

As the viability of new MIS spinal tumor resection techniques is developed, evidence shows that they significantly decrease the associated morbidities of conventional open procedures. Namely, Uribe et al[14] found that a mini-open lateral approach for thoracic tumor removal decreased frequency of complications and recovery time when compared with conventional surgical treatments. Although this procedure was found effective for many thoracic spinal tumors, this mini-open lateral approach requires direct-visualization MIS retractors and proper training in MIS techniques. As discussed, the need for specialized equipment and training has led to resistance of incorporation of MIS nationally.

Nonetheless, integration of MIS into clinical practice is still favored, as the benefits far outweigh the limitations of certain procedures. Decreasing blood loss, hospitalization time, and disruption of local tissue are paramount in the treatment of thoracic spinal tumors. All of these clinical outcomes can be achieved through MIS techniques—even in complex cases of intradural-extramedullary neoplasms.[15] Spinal tumors can cause immense pain from neural compression, making their resection or removal immensely beneficial for patient quality of life.

One common and often dangerous complication of spinal metastases is epidural spinal cord compression. There are a number of ways to approach resolving this complication. Taghva et al[16] treated a 36-year-old man with metastatic adenocarcinoma of the lung with spinal cord compression at T4 and T5. Using MIS techniques, a vertebrectomy with expandable cage placement was performed and T1-T8 pedicle screw fixation and fusion. At 9-month follow-up, the patient remained neurologically intact and pain free with no hardware failure. This is one of many case reports citing MIS decompression as a viable treatment for a patient with metastatic epidural spinal cord compression. MIS has been demonstrated to decrease pain and neurologic deficit from thoracic spinal tumors while decreasing blood loss, operative time, and complication rates compared with conventional surgical treatment.[17]

MIS for the thoracic spine has enabled surgical treatment of thoracic spinal metastases that were previously deemed inoperable. By decreasing exposure, blood loss, and operative times, clinical outcomes have improved for these patients. As the documented efficacy of these procedures continues to grow, clinical research has channeled the development of more efficient and applicable techniques. As these techniques are refined, many of the initial obstacles of MIS, such as specialized equipment and training, are being overcome.

IMAGING AND COMPUTER-ASSISTED NAVIGATION

One of the main challenges with MIS techniques for pedicle screw fixation is retaining adequate visualization of the target site and accurate placement of spinal instrumentation, all while trying to minimize skin incision length. This is of particular importance in the thoracic spine, where pedicle dimensions are substantially narrower than in the lumbar spine, and screw misplacement rates have been reported as high as 51%.[18] Several image-guided and navigation techniques have been developed to minimize screw misplacement despite limited direct visualization. One such technique for accomplishing this task is through fluoroscopy, which has proven effective for use in countless other invasive procedures—including catheter insertion, stent placement, and so on—and, of course, is an essential component of modern-day pedicle screw placement in the spine. Fluoroscopy offers enhanced visualization of underlying bone and surgical instrument positions, decreasing the need for direct visualization of the tissue. However, conventional fluoroscopic techniques require imaging in the anterior-posterior and lateral views for each screw to confirm 3-dimensional orientation, subjecting patients and surgeons to harmful doses of radiation. Additionally, with this technique, overall accuracy of screw placement is only reported to be 68%.[19] Even among experienced surgeons, pedicle screws are still misplaced medially in up to 5% of cases, increasing risk of iatrogenic neural element injury, and inferolaterally in 15% of cases with traditional fluoroscopy.[20]

In an effort to increase screw placement accuracy and further reduce risk of complication, multiple computer-assisted navigation techniques have been explored. CT-based navigation was the first form of computer-assisted surgical navigation to be developed and explored in spinal surgery. This method has been shown to significantly increase the accuracy of pedicle screw placement, but never gained popularity, due to a number of drawbacks.[21] First, it relies upon preoperative CT imaging for anatomical reference, which, while high-quality, is subject to potential error if patient position changes during the procedure. Second, it requires a preprocedural registration process that increases operative time and poses a substantial learning curve for the surgeon to accurately complete.[21]

To overcome the disadvantages of CT navigation, 2-dimensional and 3-dimensional fluoroscopic navigation techniques have been developed, which have been shown to increase accuracy of screw placement to 84% and 96%, respectively.[19] Two-dimensional fluoroscopic guidance systems, commercially available since 2000, use images obtained from a conventional fluoroscope to map the patient's spinal anatomy. Infrared light is then used to track the position of surgical instrumentation during the procedure, allowing the surgeon to visualize the instrument's orientation in reference to the stored anatomical images. This technique reduces the total radiation exposure and potentially reduces operative time, while increasing accuracy.[6]

Three-dimensional fluoroscopic navigation requires the use of a specially designed fluoroscope to create multiplanar reconstructions of spinal anatomy, similar to traditional CT imaging. This technique has been shown to provide excellent visualization of 3-dimensional relationships, albeit of lower quality than CT imaging, with significantly increased accuracy over 2D fluoroscopy and decreased radiation exposure.[22] Although the use of this modality comes at substantial direct cost, economic studies have demonstrated that the reduced need of perioperative imaging and postoperative complications result in this being the most cost-effective strategy.[23]

Through modification of established imaging techniques that have been used in medicine for decades, fluoroscopy and CT have been adapted to safely and effectively provide visualization of the spine during MIS procedures. Adapting these modalities for the thoracic spine will greatly improve patient outcomes by decreasing radiation exposure and increasing procedural accuracy.

ROBOTIC-ASSISTED SURGERY

Although still a relatively new technology, robotic systems for spinal surgery have been available for over 10 years. Two robotic systems are currently FDA-approved that can assist with placement of spinal instrumentation, the Mazor and ROSA systems. Use of these robotic systems allows for MIS approaches, but like free-hand placement requires imaging for guidance. The Mazor system requires a preoperative CT along with intraoperative fluoroscopy to guide screw trajectory. The ROSA system, however, uses instrument tracking through a mounted navigation camera and only requires intraoperative imaging, either CT or fluoroscopy. The Mazor robot is a miniature system that mounts to bone, whereas the ROSA consists of 2 mobile units that rest on the floor. Both systems use robotic arms with 6 degrees of freedom.

There is a significant learning curve with use of either of these systems, with current studies suggesting a minimum of 25 to 30 cases before surgical and fluoroscopy time begin to decrease and accuracy increase. Evidence is mixed regarding the impact these systems have on total radiation exposure, with some showing a significant benefit over both open robotic and free-hand placement, whereas others show fluoroscopy time to be greatest with the use of robotic placement in MIS approaches. All studies assessing accuracy of screw placement have demonstrated high accuracy rates with these systems and many show a significant benefit over free-hand placement.[24] Although these systems greatly increase the direct cost of the procedure, a recent analysis suggest that when considering potential savings in reduced length of stay, infections, operative time, and need for revision surgery, robotically assisted MIS may be a cost-effective strategy in the treatment of spinal diseases.[25] As this technology continues to develop, its clinical applications and benefits will likely expand and use of robotic systems may become more widely integrated into the practice of spinal surgeons.

COMPLICATIONS

There is a benefit to MIS when compared with conventional open procedures; however, its acceptance into practice has been hampered by a few constraints. Sufficient tissue visualization was an initial concern. In the process of overcoming this obstacle, most concerns stem from the complexity of the techniques, surgical instruments, and imaging modalities. Surgeons must perfect their understanding of 3-dimensional procedures through 2-dimensional video images. They must also cope with limited tactile feedback and small working channels to their target site. Although this does not hold true for all MIS for the thoracic spine, a large number do have a steep learning curve. Procedures, such as the widely popular mini-open lateral approach to the thoracolumbar spine for corpectomy/fusion, have been deemed technically demanding and require immense specialized training in procedural techniques and in equipment use.[26] When preformed properly, this technique offers many advantages over conventional open procedures; however, the complexity of the procedure has prevented its acceptance as the standard of care.

These complexities are continuously modified in an effort to create simplified alternatives. Oftentimes these simplifications enable the procedure to be performed using standard equipment. For instance, percutaneous internal pedicle screw fixation can be done using standard instruments for posterior stabilization of the thoracic spine.[16] This provides the benefits of MIS without the customized instruments and navigational support. In addition, there are surgical technique alternations that have allowed surgeons to use microscopes and loupes to make MIS techniques more accessible to a wider range of surgeons.[7]

The complexities of the techniques and equipment associated with MIS are warranted reasons for their incomplete integration into national practice. However, the once-novel complication profiles of MIS are now better understood and the benefits of MIS are well documented and vast. As MIS techniques are refined and simplified, more alternatives will be discovered, and use of MIS will increase.

ECONOMICS

Back pain is one of the most prevalent and expensive health conditions in the developed world. Accordingly, it is one of the most common presentations among patients and the third most common cause of surgical procedures in the United States. Although the lumbar spine takes most of the recognition for back procedures, degeneration of the thoracic spine is prevalent and painful. Its firm attachment to the ribcage can lead to wear and tear over time in an age-related manor. Herniated discs, bone spurs, and pinched nerves in the thoracic spine can all contribute to upper back pain. These disorders are extremely common and can be very costly to the patient financially, physically, and emotionally. The rate and price of treatments for these spinal conditions have increased extremely rapidly. The importance of lower costs and improving quality are not mutually exclusive, both rather extremely dependent on each other. Together, these 2 factors form the value of spine care. The cost and clinical outcome of a surgery must be measured during an adequate amount of time to gauge overall value of the surgery.[27] This value-based spine care will give patients a better indication of whether spine surgery is right for them.

As clinical outcomes improve, economic burdens decrease. MIS spinal procedures result in less blood loss, shorter hospital stays, lower complication rates, and lower numbers of residual events. All of these factors contribute to decreased hospital operating costs compared with those seen with conventional open procedures.[28] Additionally, rates of surgical site infections are far lower in patients who receive MIS as compared with conventional open surgery.[7] Surgical site infections lead to longer and costlier hospitalizations. Patients with surgical site infections are twice as likely to die and 5 times more likely to be readmitted.[29] The economic burden for the patient and the hospital is greatly decreased by MIS when compared with open procedures.

CONCLUSION

The advent of MIS revolutionized the way that spinal surgery is approached. Initially, most of the research and procedures focused on the lumbar spine; however, during the past decade these MIS techniques have expanded to use in the thoracic spine. These techniques have enabled surgical treatment of previously inoperable situations, namely, presentations with substantial comorbidities.

MIS for the thoracic spine provides better clinical outcomes by decreasing intraoperative blood loss, shortening hospital stays, decreasing infection rates and operative time, and minimizing damage to surrounding tissue. There is extensive research supporting MIS techniques for corpectomies, metastases, and spinal stabilizations. Novel technologies, such computer-assisted navigation and robotic surgery, have allowed traditionally open procedures to be safely performed with minimal incisions and soft tissue dissection. However, the steep learning curve of these procedures and specialized equipment has presented opposition to its complete acceptance into practice. Overall, the value of spinal surgery, economically and clinically, has greatly increased from the introduction of MIS.

After reading this article, readers should be able to evaluate when MIS for the thoracic spine is appropriate, appreciate the benefits of MIS for the thoracic spine, and understand how to incorporate MIS for the thoracic spine into their practice.

REFERENCES

1. Smith ZA, Fessler RG. Paradigm changes in spine surgery: evolution of minimally invasive techniques. *Nat Rev Neurol*. 2012;8(8):443450. doi:10.1038/nrneurol.2012.110.
2. Mayer HM. Minimally invasive spine surgery. In: *Minimally Invasive Spine Surgery: A Surgical Manual*. 2nd ed. Berlin, Germany: Springer; 2006. doi:10.1007/3-540-29490-2_1.
3. Heary RF. Minimally invasive transmuscular pedicle screw fixation of the thoracic and lumbar spine—commentary. *Neurosurgery*. 2006;59 (4, suppl 2):361-367. doi:10.1227/01.NEU.0000223505.07815.74.
4. Palmisani M, Gasbarrini A, Brodano GB, et al. Minimally invasive percutaneous fixation in the treatment of thoracic and lumbar spine fractures. *Eur Spine J*. 2009;18(suppl 1):71-74. doi:10.1007/s00586-009-0989-6.
5. Ishii K, Shiono Y, Funao H, et al. A novel groove-entry technique for inserting thoracic percutaneous pedicle screws. *Clin Spine Surg*. 2017;30(2):57-64. doi:10.1097/BSD.0000000000000461.
6. Mobbs RJ, Sivabalan P, Li J. Technique, challenges and indications for percutaneous pedicle screw fixation. *J Clin Neurosci*. 2011;18(6):741-749. doi:10.1016/j.jocn.2010.09.019.
7. Smith JS, Ogden AT, Fessler RG. Minimally invasive posterior thoracic fusion. *Neurosurg Focus*. 2008;25(2):E9. doi:10.3171/FOC/2008/25/8/E9.
8. Abbasi H, Abbasi A. Minimally invasive direct thoracic interbody fusion (MIS-DTIF): technical notes of a single surgeon study. *Cureus*. 2016; 8(7):e699. doi:10.7759/cureus.699.
9. Smith WD, Dakwar E, Le TV, et al. Minimally invasive surgery for traumatic spinal pathologies: A mini-open, lateral approach in the thoracic and lumbar spine. *Spine (Phila Pa 1976)*. 2010;35(26 suppl):S338-S346. doi:10.1097/BRS.0b013e3182023113.

10. McAfee PC, Regan JJ, Peter Geis W, et al. Minimally invasive anterior retroperitoneal approach to the lumbar spine. Emphasis on the lateral BAK. *Spine (Phila Pa 1976)*. 1998;23(13):1476-1484. doi:10.1097/00007632-199807010-00009.
11. Ogden AT, Eichholz K, O'Toole J, et al. Cadaveric evaluation of minimally invasive posterolateral thoracic corpectomy: a comparison of 3 approaches. *J Spinal Disord Tech*. 2009;22(7):524-529. doi:10.1097/BSD.0b013e31818e5488.
12. Smith ZA, Yang I, Gorgulho A, et al. Emerging techniques in the minimally invasive treatment and management of thoracic spine tumors. *J Neurooncol*. 2012;107(3):443-455. doi:10.1007/s11060-011-0755-6.
13. Kim DH, O'Toole JE, Ogden AT, et al. Minimally invasive posterolateral thoracic corpectomy: cadaveric feasibility study and report of four clinical cases. *Neurosurgery*. 2009;64(4):746-753. doi:10.1227/01.NEU.0000340783.83964.27.
14. Uribe JS, Dakwar E, Le TV, et al. Minimally invasive surgery treatment for thoracic spine tumor removal: a mini-open, lateral approach. *Spine (Phila Pa 1976)*. 2010;35(26 suppl):S347-S354. doi:10.1097/BRS.0b013e3182022d0f.
15. Fessler RG. Minimally invasive resection of intradural-extramedullary spinal neoplasms. *Neurosurgery*. 2006;59(5):1181. doi:10.1227/01.NEU.0000252890.39001.D5.
16. Taghva A, Li KW, Liu JC, et al. Minimally invasive circumferential spinal decompression and stabilization for symptomatic metastatic spine tumor: technical case report. *Neurosurgery*. 2010;66(3):E620-E622. doi:10.1227/01.NEU.0000365270.23815.B1.
17. Molina CA, Gokaslan ZL, Sciubba DM. A systematic review of the current role of minimally invasive spine surgery in the management of metastatic spine disease. *Int J Surg Oncol*. 2011;2011:598148. doi:10.1155/2011/598148.
18. Upendra BN, Meena D, Chowdhury B, et al. Outcome-based classification for assessment of thoracic pedicular screw placement. *Spine (Phila Pa 1976)*. 2008;33(4):384-390. doi:10.1097/BRS.0b013e3181646ba1.
19. Mason A, Paulsen R, Babuska JM, et al. The accuracy of pedicle screw placement using intraoperative image guidance systems. *J Neurosurg Spine*. 2014;20(2):196-203. doi:10.3171/2013.11.SPINE13413.
20. Mirza SK, Wiggins GC, Kuntz C, et al. Accuracy of thoracic vertebral body screw placement using standard fluoroscopy, fluoroscopic image guidance, and computed tomographic image guidance: a cadaver study. *Spine (Phila Pa 1976)*. 2003;28(4):402-413. doi:10.1097/01.BRS.0000048461.51308.CD.
21. Du JP, Fan Y, Wu QN, et al. Accuracy of pedicle screw insertion among 3 image-guided navigation systems: systematic review and meta-analysis. *World Neurosurg*. 2018;109:24-30. doi:10.1016/j.wneu.2017.07.154.
22. Villavicencio AT, Burneikiene S, Bulsara KR, et al. Utility of computerized isocentric fluoroscopy for minimally invasive spinal surgical techniques. *J Spinal Disord Tech*. 2005;18(4):369-375. doi:10.1097/01.bsd.0000168511.67189.64.
23. Sanborn MR, Thawani JP, Whitmore RG, et al. Cost-effectiveness of confirmatory techniques for the placement of lumbar pedicle screws. *Neurosurg Focus*. 2012;33(1):E12. doi:10.3171/2012.2.FOCUS121.
24. Joseph JR, Smith BW, Liu X, et al. Current applications of robotics in spine surgery: a systematic review of the literature. *Neurosurg Focus*. 2017;42(4):E2. doi:10.3171/2017.2.FOCUS16544.
25. Menger RP, Savardekar AR, Farokhi F, et al. A cost-effectiveness analysis of the integration of robotic spine technology in spine surgery. *Neurospine*. 2018;15(3):216-224. doi:10.14245/ns.1836082.041.
26. Baaj AA, Dakwar E, Le TV, et al. Complications of the mini-open anterolateral approach to the thoracolumbar spine. *J Clin Neurosci*. 2012;19(9):1265-1267. doi:10.1016/j.jocn.2012.01.026.
27. Rihn JA, Currier BL, Phillips FM, et al. Defining the value of spine care. *J Am Acad Orthop Surg*. 2013;21(7):419-426. doi:10.5435/JAAOS-21-07-419.
28. Lucio JC, van Conia RB, de Luzio KJ, et al. Economics of less invasive spinal surgery: an analysis of hospital cost differences between open and minimally invasive instrumented spinal fusion procedures during the perioperative period. *Risk Manag Healthc Policy*. 2012;5:65-74. doi:10.2147/RMHP.S30974.
29. Kirkland KB, Briggs JP, Trivette SL, et al. The impact of surgical-site infections in the 1990s: attributable mortality, excess length of hospitalization, and extra costs. *Infect Control Hosp Epidemiol*. 1999;20(11):725-730. doi:10.1086/501572.

CME Quiz

To earn CME credit, you must read the CME article and complete the quiz and evaluation assessment survey on the enclosed form, answering at least 70% of the quiz questions correctly. **Select the best answer and use a blue or black pen to completely fill in the corresponding box on the enclosed answer form.** Please indicate any name and address changes directly on the answer form. If your name and address do not appear on the answer form, please print that information in the blank space at the top left of the page. Make a photocopy of the completed answer form for your own files and mail the original answer form to Wolters Kluwer Health, Continuing Education Department, P.O. Box 1543, Hagerstown, MD 21741-9914 by **February 28, 2022.** Only two entries will be considered for credit. For more information, call (800) 638-3030.

Online quiz instructions: To take the quiz online, **log on to your account at www.cssnewsletter.com**, and click on the "CME" tab at the top of the page. Then click on "Access the CME activity for this newsletter," which will take you to the log-in page for **http://cme.lww.com**. Enter your ***username*** and ***password.*** Follow the instructions on the site. You may print your official certificate ***immediately***. Please note: Lippincott CME Institute, Inc., ***will not*** mail certificates to online participants. **Online quizzes expire on the due date.**

The American Association of Neurological Surgeons (AANS) manually tracks *AMA PRA Category 1 Credits*™ earned from neurosurgery activities not sponsored or joint-sponsored by the AANS. As a service to AANS members, Lippincott CME Institute will continue to provide the AANS a monthly listing of their participants and the CME credits they earned so that AANS members do not have to send their individual certificates to the AANS for tracking.

Credits related to activities on orthopaedics may be applied to American Board of Orthopaedic Surgery Maintenance of Certification. Please confirm credit for specific activity with the Board at www.abos.org.

1. Which one of the following is a *disadvantage* of MIS in the thoracic spine?
A. More expensive
B. Greater blood loss
C. Technically challenging
D. Long hospital stays
E. Longer procedures

2. Which one of the following is an example of MIS for vertebral fracture?
A. Kyphoplasty
B. Vertebroplasty
C. Circumferential spinal decompression
D. Percutaneous transpedicular fixation
E. Thoracotomy

3. Which one of the following is an approach to morbidity associated with conventional thoracic spinal tumor removal?
A. Decreased blood loss
B. High infection rate
C. Decreased operative time
D. Spinal cord compression
E. Decreased complications

4. Which one of the following approaches is *best* for MIS in the anterior thoracic spine?
A. 6 cm off the midline
B. 3 cm off the midline
C. Midaxillary
D. Midclavicular
E. Through the thorax

5. Which one of the following was the initial indication for MIS?
A. Tumor resection
B. Microendoscopic decompression
C. Thoracolumbar corpectomy
D. Intradural-extramedullary neoplasms
E. Transmuscular pedicle screw fixation

6. Use of two-dimensional fluoroscopic guidance systems reduces total radiation exposure.
A. True
B. False

7. Which one of the following describes value-based spine care?
A. Price per operation
B. Financial burden for the hospital
C. Number of operations performed
D. Cost and clinical outcome
E. Duration of hospital stay

8. Fluoroscopy is used in all of the following procedures, *except*
A. catheter insertion
B. stent placement
C. angiography
D. chemotherapy
E. MIS

9. Which of the following procedures can be performed using MIS?
A. Corpectomy
B. Tumor resection
C. Spinal fusion
D. Spinal fixation
E. All the above

10. Most back pain originates from which one of the following parts of the spine?
A. Cervical
B. Lumbar
C. Thoracic
D. Sacral
E. Pelvic