

Evolution of Minimally Invasive Transforaminal Lumbar Interbody Fusion: Improving Patient Safety and Outcomes

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Lumbar degenerative disc disease is a leading cause of emergency department visits and missed work days in the United States. There are many surgical techniques that treat the neural compression and instability responsible for the symptoms of low back pain and leg pain caused by lumbar degenerative disc disease. As with other areas of spine surgery, an intensive effort has evolved to develop minimally invasive surgical (MIS) approaches to the spine to decrease the morbidity associated with these procedures. One of the greatest success stories of minimally invasive surgery for lumbar degenerative disc disease is MIS transforaminal lumbar interbody fusion (TLIF). This surgical technique has led to decreased blood loss, shorter operative times and hospital stays, and improved overall patient outcomes. One of the previous drawbacks to the MIS TLIF has been the large amount of radiation required to safely and successfully perform these surgeries. However, a low-dose radiation protocol has recently been developed at Barrow Neurological Institute that significantly reduces the amount of ionizing radiation to which both the patient and the surgical team are exposed during an MIS TLIF operation. As these and other surgical and diagnostic advances are made, patient outcomes will undoubtedly continue to improve.

Key Words: fluoroscopy, lumbar spine, minimally invasive surgery, radiation exposure, radiation safety, spine surgery, transforaminal lumbar interbody fusion

Abbreviations Used: MIS, minimally invasive surgery; TLIF, transforaminal lumbar interbody fusion

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Spinal instability, spondylolisthesis, and degenerative disc disease have long been recognized as surgically treatable causes of lower back and radicular leg pain.^{7,18} Since Cloward introduced the posterior lumbar interbody fusion in 1952, minimally invasive alternatives to lumbar spine fusion have been sought in hopes of offering a less invasive alternative that achieves comparable outcomes to open surgery with reduced blood loss, lower risk of infection, and lower risk of postoperative complications.¹² In 1982, two major advances toward achieving these goals were realized when Magerl⁹ published the first report of a percutaneous screw placement technique, and Harms and Rolinger⁶ published the first description of the open transforaminal lumbar interbody fusion (TLIF). The open TLIF was noted to have several advantages over posterior approaches, including a reduced need for retraction of the thecal sac and nerve root, preservation of the contralateral anatomy, and reduced risk associated with revision surgery secondary to the avoidance of epidural fibrosis.^{6,9,13} The primary drawback to the open TLIF approach is that it requires significant paraspinous muscle dissection and retraction, resulting in substantial postoperative pain and short-term disability. Throughout the 1990s, surgeons continued to refine and modify techniques to make lumbar fusions less invasive. These efforts culminated in the development of a minimally invasive surgery (MIS) TLIF approach in 2002.⁴

In the decade since Foley⁴ first described the MIS TLIF, dozens of stud-

ies have compared the respective outcomes, advantages, and disadvantages of open versus MIS TLIF. These studies cover multiple patient populations and varying surgical indications and, collectively, they show that MIS TLIF offers reduced patient morbidity and improved overall outcomes.⁵ Critics of this approach cite longer operative times, limited access to the midline, and increased radiation exposure for patients and surgeons. However, a recent report demonstrated no significant difference in operative time between open and MIS TLIF surgery.¹⁰ Furthermore, at our institute, we have developed low-dose radiation protocols that dramatically reduce radiation dose without compromising image quality, accuracy of pedicle screw placement, or procedure efficiency.² Although MIS TLIF is a relatively new procedure, the first decade of clinical outcomes research and experience with this procedure support its increased use among surgeons treating lumbar degenerative spine disease.

MIS TLIF Technique

The MIS TLIF technique represents a major advance in the evolution of lumbar spinal decompression, fixation, and fusion. Through the implementation of minimally invasive principles,

MIS TLIF achieves clinical outcomes similar to those of open TLIF while minimizing perioperative patient morbidity. An important drawback to MIS TLIF is that the surgeon's perspective is much different from that in traditional open TLIF. Large surgical openings that allow for anatomical landmarks to direct the surgeon's operative steps are eschewed in MIS TLIF in an effort to minimize the size of the incision and thereby decrease postoperative pain and improve wound healing. In order to compensate for this loss of landmarks, MIS spine surgeons must rely on other diagnostic modalities, such as radiography and neuromonitoring, in order to provide their patients with optimal surgical outcomes. Moreover, the information from each of these individual modalities must be continuously interpreted and integrated by the surgeon during the case. For MIS TLIF surgical technique, meticulous preoperative planning and judicious use of intraoperative ionizing radiation (i.e., fluoroscopic images) are important. The use of these diagnostic tools, along with the use of MIS retractors and instruments, ensure the success of an MIS TLIF procedure.

Before surgery, magnetic resonance imaging (MRI) studies of the lumbar spine are analyzed so that the proper pedicle screw diameters, lengths, and

entry points can be selected. The side of access for placing the TLIF (left vs. right) is also determined preoperatively, based on which leg is more symptomatic for the patient. For instance, if the right leg is more symptomatic and the MRI shows neural compression on the right side, then the TLIF is planned for the right side. Next, the neurophysiology technician sets up somatosensory evoked potential (SSEP) and electromyography monitoring. These studies will give the surgeon important information during the case regarding changes in neural compression caused by the surgical maneuvers. The patient is then positioned prone on a Jackson table and the correct surgical level is identified by using fluoroscopy to image a spinal needle over the index levels.

When the proper entry point has been identified, two 28-mm incisions are planned approximately 3 to 3.5 cm lateral to the midline, centered between the pedicles of the two surgical vertebral bodies (Fig. 1). Incisions are made bilaterally and an MIS expandable retractor is placed within each incision (Fig. 2). The retractors are positioned using a Wiltse approach, which separates the fibers of the muscle, instead of the method used in traditional open surgery, which is to strip the muscles from their bony attachments to the

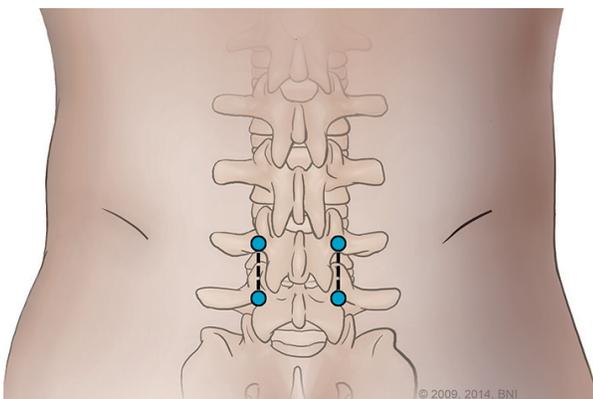


Figure 1. For surgical access for the MIS TLIF, two 28-mm incisions are made approximately 3.0 to 3.5 cm lateral to the midline, centered between the pedicles of the two surgical vertebral bodies.

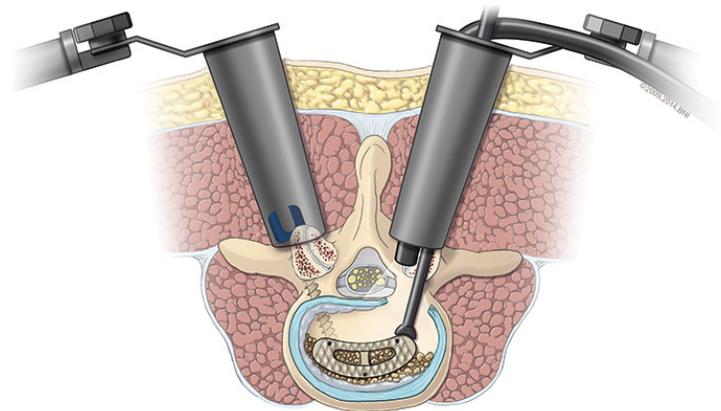


Figure 2. Expandable retractors are placed bilaterally using the Wiltse muscle-splitting technique. After all four pedicle screws are placed through the corridors provided by the expandable retractors, a discectomy is performed, and morcellized autograft and a structural TLIF cage are placed in the intervertebral body disc space.

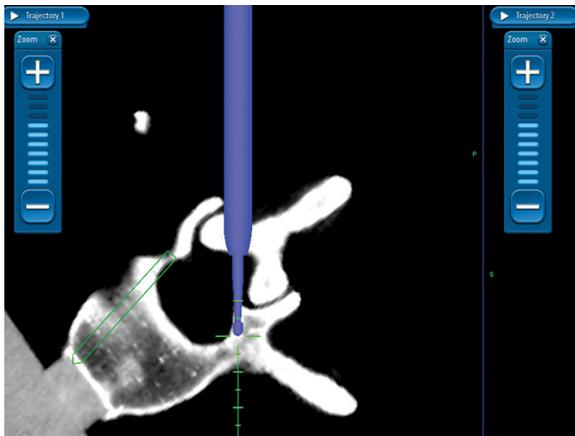


Figure 3. The image from this intraoperative navigational screen illustrates the surgeon’s ability to identify and decompress the exiting nerve roots on both sides from a unilateral approach.

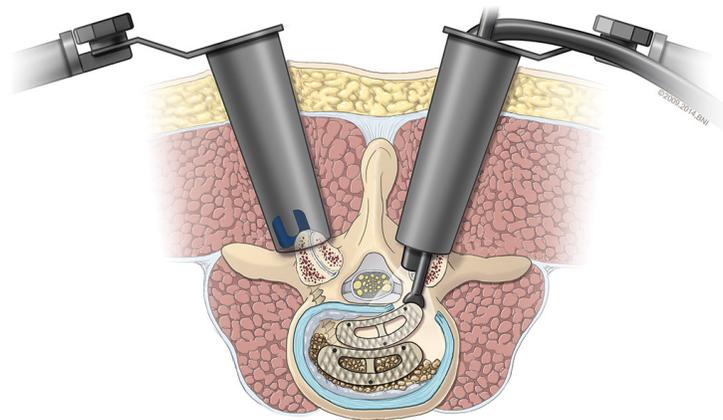


Figure 4. After the pedicle screws have been placed, decompression has been achieved, and a TLIF cage has been placed, the surgeon can determine whether there is enough space to allow placement of a second, shorter TLIF interbody spacer posterior to the first one. The placement of a second TLIF interbody spacer provides increased surface area for fusion and maximum stability.

spine. The Wiltse muscle-splitting approach is one of the MIS techniques believed to play a significant role in decreasing postoperative pain in patients undergoing MIS TLIF. It is important that the retractors be placed to allow the surgeon complete visualization of the pars interarticularis, transverse process, and facet joints at both vertebral levels. This view, in conjunction with fluoroscopic images, allows the surgeon to confirm the entry points for the pedicle screws.

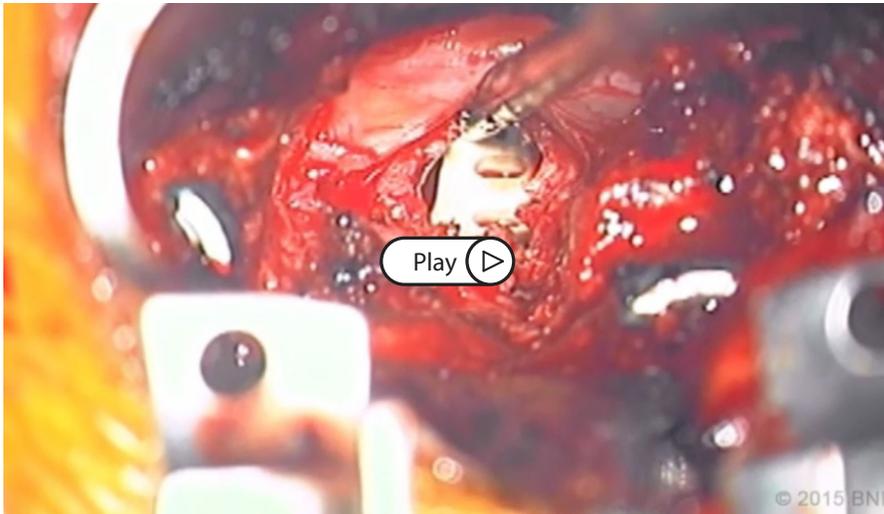
Proper placement of the pedicle screws is of utmost importance in the MIS TLIF, as they will be the cornerstones that allow for distraction during the operation and stable fixation for the months afterward while the bony fusion develops. As mentioned earlier, one aspect of MIS that makes it difficult for some surgeons to adopt it is the limited bony anatomy that is visible in the operative field. Although all of the landmarks necessary for a safe and effective surgery are available through an MIS exposure, less of the spine’s surface area can be directly visualized and palpated by the surgeon via an MIS exposure than in an open procedure. Because of the limited exposure available in the MIS approach, it can be more difficult for surgeons new to this technique to extrapolate the orientation of all the

spinal elements. Moreover, the surgeon must integrate the information from a number of different diagnostic modalities in order to achieve the surgical goal. First, the surgeon must integrate the information from the limited visual surgical field and the intraoperative fluoroscopy. It is important to note that the entry points are identified based on the same anatomical landmarks used in open cases. The junction of the pars interarticularis, facet, and transverse process reliably leads to the pedicle. A fluoroscopy image can then confirm the pedicle screw entry point and set the trajectory into the pedicle. A Lenke probe is then placed into the pedicle and with tactile guidance is passed through the cancellous portion of the pedicle. Encountering resistance is indicative of cortical bone. Additional fluoroscopic images may guide the surgeon’s hands in a rostral-caudal manner. It is vital to continuously integrate the tactile feedback from the Lenke probe and pedicle probe, as well as the fluoroscopic images, to ensure a proper avenue through the pedicle into the vertebral body without breaching the cortex of the bone.

Next, the pedicle screw landmarks identified from the preoperative MRIs must be reconciled with the depths measured intraoperatively with the pedicle probe as it palpates the pedicle

and vertebral body. At each step, neurophysiological monitoring information must also be interpreted by the surgeon in the form of changes in SSEP monitoring and in positive stimulation of a pedicle screw, which would indicate that the screw had breached the bony cortex and is either in close proximity to or causing compression of the neural elements. All this must be done without the traditional feedback available to surgeons during an open procedure, which includes palpation of the outer cortex of the pedicles from within the spinal canal, as well as complete visualization of the thecal sac and exiting nerve roots after laminectomies have been performed.

After the pedicle screws are successfully placed, the operative microscope is brought into the surgical field and the decompression begins. The laminectomies and facetectomies are completed utilizing a high speed drill. The bony shavings that result from the drilling are collected and used as autograft during the arthrodesis portion of the case. From the unilateral MIS approach, the exiting nerve roots on both sides can be identified and decompressed (Fig. 3). After the stenosis has been addressed and the thecal sac and disc space have been visualized, the discectomy is completed in the usual fashion. Meticulous prepara-



Video 1. The angling of the microscope allows the unilateral MIS TLIF approach to be used to decompress both the ipsilateral and contralateral neural foramina. <https://www.barrowneuro.org/TLIF1>

tion of the endplate, with removal of the cartilaginous end plate is imperative. Next, the TLIF interbody spacer is appropriately sized and fusion material is placed within it. The TLIF interbody spacer is placed across the midline within the intervertebral body defect. If room allows, a second shorter TLIF interbody spacer is placed posterior to the first one in order to increase the fusion surface area and provide maximum stability (Fig. 4).¹¹ After the TLIF spacer has been placed, the neural elements can be inspected to ensure that there is no residual stenosis (Video 1). At the summation of the surgery, the retractors are removed and the incision is closed in layers, leaving only 2 small incisional scars (Fig. 5).

Illustrative Case

Preoperative evaluation

A 71-year-old woman presented with axial back pain and right radicular leg pain. The patient had been diagnosed with spondylolisthesis 8 years earlier. She presented to our clinic because her symptoms had become intolerable despite conservative management techniques. She described her pain as beginning in her right lower back and then traveling down through the right glu-

teal region and into her right knee. She had become incapacitated by the pain and could no longer engage in various activities that were meaningful to her.

MRI of the lumbar spine demonstrated a grade 1 spondylolisthesis at L4-5 with bilateral foraminal narrowing caused by almost total L4-5 disc collapse (Fig. 6). She was otherwise in good health and had never smoked. Her neurological examination demonstrated full strength throughout, except for 4/5 strength in right ankle dorsiflexion, plantar flexion, and inversion. The patient was informed of the goals of the surgery, which were to realign the vertebral bodies and relieve the compression on the neural elements both directly via bony decompression and indirectly via restoration of disc height through the insertion of an interbody spacer. Because we felt that these goals could be achieved through an MIS approach, we recommended an L4-5 MIS TLIF.

Surgical procedure

The patient was taken to the operating room and the procedure was completed using the steps outlined in the paragraphs above. These steps included initial fluoroscopic localization and progressive dilation of the incision for placement of the MIS re-



Figure 5. Photograph of patient's postoperative scars from a single-level minimally invasive transforaminal lumbar interbody fusion (MIS TLIF). This patient had previously undergone a right-sided microdiscectomy that had been unsuccessful. Note the patient's well-healed previous microdiscectomy scar just medial to his right-sided MIS TLIF scar.

tractor (Fig. 7A). After the expandable MIS retractors were placed, the pedicle screws were placed bilaterally in the L4 and L5 pedicles (Fig. 7B). The pedicle screws were then used to capture the distraction created during the discectomy (Fig. 7C) and allow eventual placement of a 9-mm interbody spacer in the disc defect (Fig. 7D). Distracting across the pedicle screws made it possible to properly size the interbody space, which allowed the patient's normal disc height to be restored (Fig. 7E). After the interbody spacer was believed to be properly placed based on lateral fluoroscopy, anteroposterior fluoroscopy was used to confirm that it had been placed in the midline (Fig. 7F). For this patient, a single 30-mm by 9-mm polyetheretherketone interbody crescent spacer (Medtronic, Minneapolis, MN) was packed with both autograft and 1.05 mg of bone morphogenetic protein. The nestled crescent technique was not feasible in this patient because of the relatively small size of her vertebral bodies; however, the single interbody device



Figure 6. Imaging of 71-year-old woman who presented with axial back pain and right radicular leg pain demonstrating evidence of (A) grade 1 spondylolisthesis and disc degeneration on sagittal magnetic resonance imaging (MRI), (B) bilateral foraminal stenosis on axial MRI, and (C) severe loss of disc height on lateral radiography.

provided her with excellent restoration of disc height (Fig. 8). Estimated blood loss for the surgery was 20 mL. The patient was discharged home after a short hospital stay.

Postoperative course

At 3 weeks postoperatively, the patient reported complete resolution of her lower extremity symptoms. She was no longer using narcotic pain medications, and she had no sensory deficits. Her only complaint was some incisional discomfort, which was improving daily. Her strength had improved to 5/5 in all muscle groups, and her preoperative right leg weakness had resolved.

Benefits

The growth of MIS procedures has been driven by many factors. The most important is that patients are able to realize a number of tangible defined benefits when they undergo an MIS TLIF. In the recent article by Seng et al., clinical and radiological outcomes of 40 patients treated with MIS TLIF were compared with those of 40 patients treated with open TLIF at 6-month and 5-year follow-ups.¹⁰ The patients in these two groups underwent matched-pair analysis with prospectively collected data. The study demonstrated that patients undergoing MIS TLIF required less morphine, had less blood loss, were able to ambulate earlier

postoperatively, and had shorter hospitalizations than those who underwent open fusion. Importantly, both groups demonstrated excellent fusion rates and significant improvements in a number of functional outcome scores, including Oswestry Disability Index and SF-36 scores at 6 months through 5 years. These data indicate that the MIS TLIF group had improved short-term outcomes as compared to the open TLIF group. Moreover, the long-term outcomes were similar between patients treated with both types of approaches. In fact, the only metric in which open TLIF was superior was a shorter fluoroscopic time per case (16.4 seconds vs. 55.2 seconds).¹⁰

Our experience at Barrow Neurological Institute echoes the excellent outcomes reported by other groups for patients undergoing either single-level or 2-level MIS TLIF. In our series of 206 patients, the mean estimated blood loss was 54.6 mL and the mean length of hospitalization was 1.6 days. Importantly, no deep-seated infections occurred, and only 2 superficial infections required a return to the operating room for incision and drainage. The safety and utility of the MIS technique for placing hardware is reflected in the fact that no unplanned return trips to the operating room were required for explantation, repositioning of screws, or any other cause. Taking all these factors into account, the MIS TLIF approach appears to have the potential to help most patients achieve a lower rate of perioperative morbidity and an earlier return to function than traditional open TLIF surgery, while still achieving equivalent long-term outcomes.

Challenges

Intraoperative radiation exposure continues to be a concern for the MIS spine surgeon. Although an extra minute of radiation exposure for a patient during a solitary spine procedure most likely has minimal effects on the patient's long-term health, the cumulative long-term

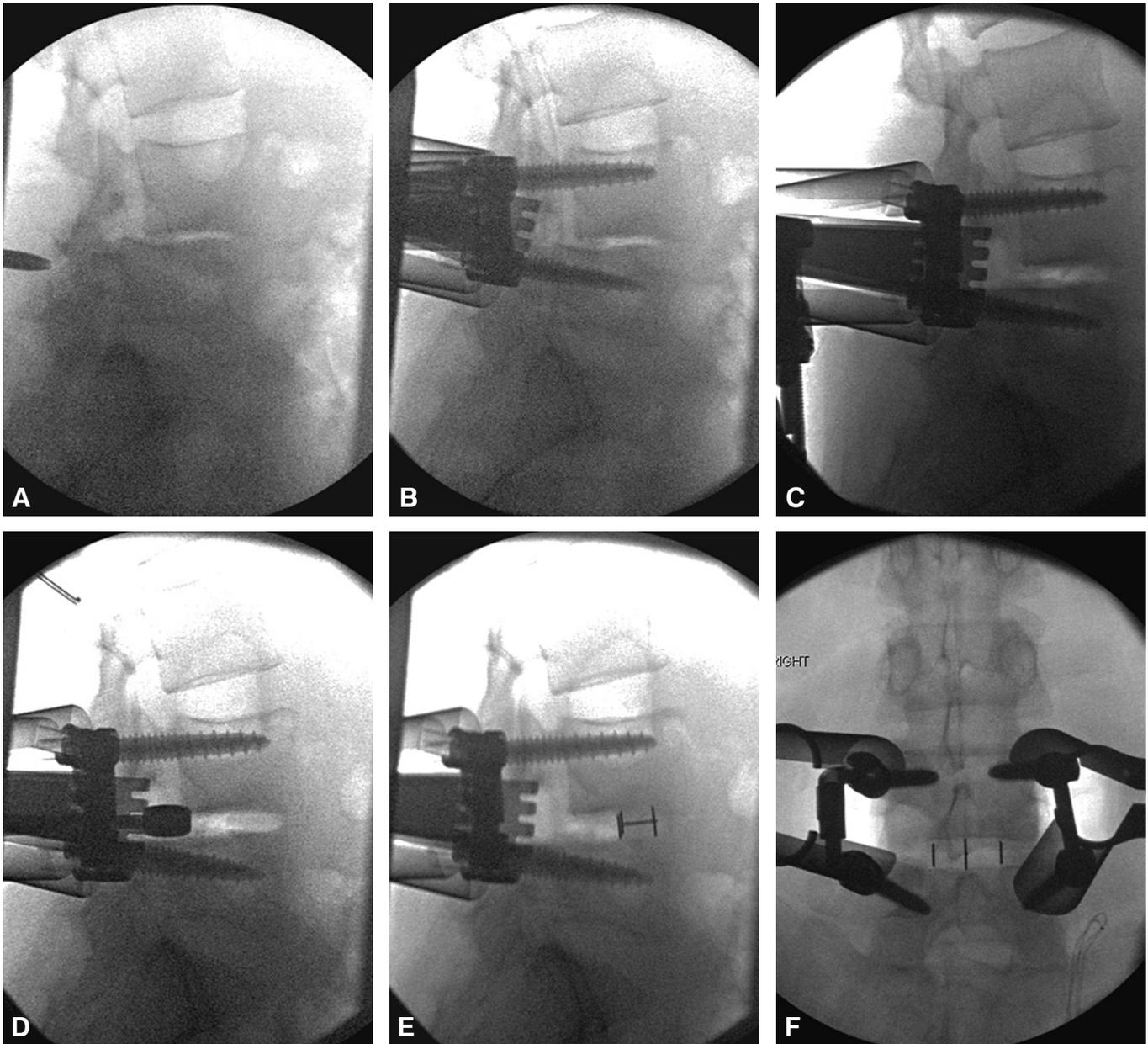


Figure 7. The steps performed for the minimally invasive transforaminal lumbar interbody fusion. (A) Initial fluoroscopic localization and progressive dilation of the incision for placement of the MIS retractor. (B) Bilateral placement of pedicle screws in the L4 and L5 pedicles. (C) The pedicle screws are used to capture the distraction created during the discectomy, which allows for (D) eventual placement of a 9-mm interbody spacer in the disc defect and (E) restoration of the patient's normal disc height. (F) Anteroposterior fluoroscopy is used at the end of the procedure to confirm that the interbody spacer has been placed in the midline.

effects that ionizing radiation has on the MIS spine surgeon and the surgical staff after hundreds of cases remain largely unknown. The practice guidelines of the National Council on Radiation Protection and Measurements state that radiation exposure for personnel working with radiation should be limited annually to 5 rem to

the body and 50 rem to an extremity. These numbers are unlikely to represent a threshold for injury. We know this because the harmful effects of radiation occur across a continuum; therefore, it is our opinion that every effort should be made to keep annual radiation exposure of health care professionals to the absolute minimum.

Reducing Ionizing Radiation Exposure

Across the country, health care professionals are becoming more aware of the levels of radiation that they and their patients are exposed to during diagnostic imaging studies. As stated above, fluoroscopic imaging is an essential tool in MIS spine surgery; how-

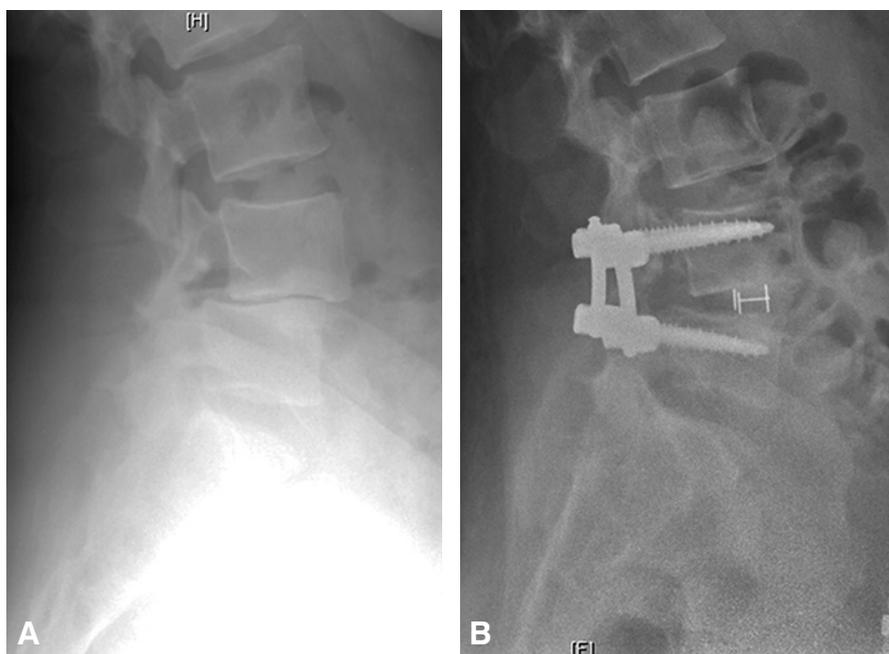


Figure 8. Lateral radiography demonstrating (A) the patient’s preoperative disc height loss, which (B) was restored using MIS TLIF.

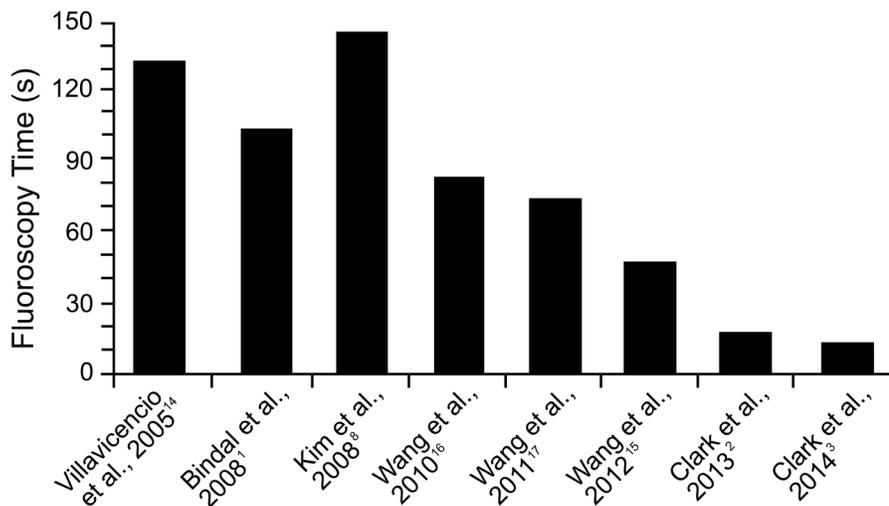


Figure 9. Intraoperative fluoroscopy times from previous studies of single-level MIS TLIF cases. Studies are arranged in chronological order.

ever, its effects on MIS spine surgeons, surgical staff, and patients are unknown. In order to effectively deal with the harmful effects of diagnostic ionizing radiation, MIS spine surgeons will need to approach the problem in two ways. The first is to develop tools and techniques that will allow ionizing radiation to be minimized during surgical cases. The second is to raise awareness among

neurosurgeons regarding the amount of ionizing radiation that they are exposed to during the course of their training as residents. Here at Barrow Neurological Institute, we are actively engaged in dealing with these two problems. Our minimally invasive spine team has developed a low-dose protocol that minimizes ionizing radiation use within the operating room during MIS proce-

dures.² This protocol allows equivalent images to be obtained fluoroscopically using only a fraction of the radiation used in traditional fluoroscopic techniques. Through the implementation of this protocol, our MIS spine team has been able to reduce the amount of ionizing radiation that their patients and operating room team are exposed to during the course of an MIS case from more than 1 minute of fluoroscopy time to an average of less than 15 seconds.^{2,3} Figure 9 shows the radiation exposure times from several recent MIS studies.^{1-3,8,14-17}

On a national level, the Barrow Neurological Institute MIS spine team has raised awareness of the unnecessary levels of ionizing radiation that neurosurgeons are exposed to daily. Recently, the senior author (L.M.T.) coauthored a resolution that was passed by the Council of State Neurosurgical Societies (CSNS), a nationally recognized neurosurgical organization.¹⁹ The goal of this resolution was to, “establish guidelines on monitoring radiation exposure to neurosurgery residents in training and develop criteria for monitoring radiation exposure during residency.” With the successful passage of this resolution, the CSNS has validated the importance of this topic and demonstrated the organization’s resolve to improve the safety of the working conditions of neurosurgeons across the United States. Neurosurgeons at Barrow Neurological Institute are currently prospectively studying radiation exposure to residents and continue to make efforts to refine the low-dose radiation protocol for all spine procedures.

Conclusion

The MIS TLIF is the product of an untiring effort by spine surgeons around the world to make surgery safer and more effective for patients. As clinical outcomes data continue to be reported on the excellent results achieved with MIS TLIF, the popularity of this technique will continue to rise. There is no doubt that as long as the spirit of

innovation continues to be fostered within the minds of surgeons, we will one day move past the MIS TLIF to the next advances in lumbar spinal decompression, fixation, and fusion. Until that time, it is imperative that all surgeons adequately train themselves in MIS TLIF techniques, so that they can offer this highly effective surgical procedure to their patients.

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