The discipline of spinal surgery has slowly caught up to other surgical specialties in the area of minimally invasive techniques. Patients have benefited from technological advancements which allow surgeons to perform surgery with less invasive approaches. The basic tenet of minimally invasive or least invasive spine surgery is to effectively treat patients with the most reliable technique while minimizing tissue trauma. Least invasive spine surgery has become more available over the past 10 years, paralleling the remarkable advancements in surgical visualization technologies coupled with the emergence of the internet as a patient-driven education tool. Patients are seeking smaller incision options and the surgical industry is responding. This article will offer a brief review of the evolution of spinal surgery with a focus on minimally invasive techniques. While most spine surgery is still performed using traditional (open) surgical approaches, smaller incision and less invasive options are utilized more commonly each year. The most important benefactor of this evolution is the patient.

Keywords: Minimally Invasive Surgery, Spine, TLIF, Spinal Implants

In the early 1990’s surgeons developed endoscopic or tubular retractor access options for the spine. By utilizing sequentially larger tubes a surgeon can expand his working channel without cutting muscle fibers. The microendoscopic discectomy (MED™) was pioneered by Foley and Smith in 1997 but the technical delivery of spinal surgery through small tubes proved to be very challenging for all but the most advanced surgeons (Figure 1). Soon after, the METRx System™ (Medtronic, Inc.) was introduced and it allowed for more expansive, and presumably safer, access to the spine. Up to this point, most of the spine surgeries performed through the tubular retractors were simple spinal decompressions (laminotomy or foraminotomy cases). Surgeons, however, saw significant potential for performing more complex surgeries, such as fusions, by utilizing less invasive procedures. The learning curve for tubular access surgery remained high with many surgeons unable to achieve reliable visualization.
The lateral transpsoas approach to the spine was reported by Mayer in 1997 and refined by McAfee and Pimenta in 1998. The pioneering systems which emerged as a result of these efforts combined the benefits of reduced tissue trauma of tubular dilators with the need for direct visualization of the spine. The MaXcess™ (NuVasive, Inc.) retractor system was released in 2003 and utilizes a 3-blade retractor which slides down over dilator tubes gently spreading apart the tissue (Figure 2). This directly exposes the surgical area allowing surgeons better visualization and resulting in a more widespread adoption of small-incision spine surgery for more complex cases.

Small-Incision Spine Surgery: Risks and Rewards

Logic dictates that the smaller the incision, the less tissue trauma inflicted on the patient. This should lead to more rapid recovery times, especially in the early stages of post-surgical healing. Less invasive surgical approaches, however, may limit the surgeon’s ability to directly visualize the critical structures such as the dura and nerve roots. Reduced visibility may be associated with more complications which could offset the gains realized by making a smaller incision. This issue of reduced visibility has been one of the greatest barriers to the widespread adoption of minimally invasive spine surgery.

Surgeons in other disciplines have more readily adopted small-incision surgeries such as arthroscopy (“scope”) for the knee or shoulder and laparoscopy for abdominal or gynecological cases. These surgeries are performed by expanding a potential space inside the joint or abdomen cavity and then introducing the “scope” or camera to more easily visualize the area. The spine does not have a cavity or joint space to be inflated and therefore these types of “scopes” are not used routinely.

Visualization for minimally invasive spine surgery can be achieved in many ways. Indirect visualization using cameras or endoscopes is used by a few surgeons but most prefer direct visualization. Microscopes can often be utilized and offer several advantages such as direct, 3-dimensional visualization of the surgical field with magnification. Microscopic assistance is practical for simple spinal decompression surgery such as laminotomy, discectomy, or foraminotomy, but can be challenging to work around efficiently for more extensive surgeries such as fusions.

Intra-operative fluoroscopy (C-arm) has dramatically improved the delivery of complex, less-invasive spine surgeries. Surgeons can accurately assess the trajectory of spinal implants and retractor systems by visualizing the spine with x-ray guidance during surgery. Nerve monitoring during these surgeries also enhances the safety profile and provides real-time feedback to surgeons as they operate in smaller spaces with reduced visualization.

Internet advertising suggests that there is a significant amount of spinal surgery that is amenable to laser techniques. This is incorrect and misleading. There are no prospective controlled studies that support the role of lasers in spine surgery as compared to proven techniques such as lumbar microdiscectomy or minimally invasive procedures. The vast majority of spine surgeons, including those with advanced skills and training in minimally invasive techniques, do not use lasers in surgery. CMS (Centers for Medicare/Medicaid Services) and the major insurance companies do not reimburse for laser spine surgery as it has not been shown to be safe and effective. A recent review by Stern reported that “laser discectomy may be more effective in attracting patients than in treating them.”

The potential benefits for patients who undergo least invasive spine surgery include shortened hospital stays, reduced tissue damage, and more rapid recovery.
times. A few reports, however, have noted more complications with certain “minimally invasive” procedures, compared to more traditional “open” surgical approaches, such as increased rates of spinal fluid leaks, dural tears, recurrent disc herniations and prolonged operative times. As the technologies and surgeon training improves over time, the outcomes are likely to continue to improve as well.27

**Essential Elements for Success**

**Retractor Systems**

Surgeons performing more traditional (open) spine surgery use large retractors to hold the skin and muscle open for visualization. Less invasive spine surgeons use smaller retractor systems to access the spine with less tissue trauma. Most of these systems have tubular dilators which are first inserted to gently separate rather than cut the muscles. As the dilators increase in size the opening for access increases and once the surgeon has reached the appropriate size he selects the retractor to insert over the dilator. The current retractors allow for direct visualization of the spine but do so with a much smaller footprint (Figure 3). Surgeons can then use a microscope, image guidance, or loupe magnification to visualize the spine and perform the needed procedures.

**Image Guidance/ Intra-Operative X-Ray (Fluoroscopy)**

Least invasive spinal surgery demands precision and accuracy. The smaller incisions reduce tissue trauma but also reduces the ability of the surgeon to directly visualize the spine. Therefore, most surgeons using minimally invasive techniques must rely on specialized x-ray equipment (image guidance) in surgery.25 Radiographic imaging for these surgeries can be achieved with a C-arm machine, which is a mobile x-ray machine shaped like a large letter ‘C’. This open ring allows the surgeon a 360 degree view of the spine and can be coupled with more advanced imaging software packages. Intra-operative, portable CT scanning, now available in selected centers, can also assist surgeons in performing more complex surgeries with small incisions.28

**Bone Graft Substitutes: Osteobiologics**

Advances in surgical equipment and technologies have been essential components for the continued success and evolution of minimally invasive spine surgeries. In addition to the retractor systems discussed above, significant improvements in bone-graft alternatives have emerged. Prior to the advent of biological alternatives, patients who underwent spinal fusions had bone graft harvested from their pelvis. At least 30% of patients reported permanent pain and disability related to the bone graft procedure.29

A recent, important development in the evolution of minimally invasive spine surgery has been the commercialization of rhBMP-2 (recombinant human Bone Morphogenetic Protein-2/ InFuse™ Medtronic Minneapolis, MN).29, 30, 31 This protein is soaked on a small sponge and placed inside a titanium fusion cage. The rhBMP-2 stimulates the body to form bone fusion, effectively eliminating the need for bone graft from the iliac crest (pelvis). There are now several other bone graft substitutes which may have the capacity to biologically stimulate bone inside the fusion. Achieving a fusion without making a separate incision to harvest bone graft, is essential to providing patients a successful and minimally invasive option for spinal fusion surgery.

**Implants**

For spinal fusion surgery to be successful, the surgeon must often implant a fusion cage to achieve bone growth across the disc space and pedicle screws.
to stabilize the vertebrae. Originally, most of these implants were intended to be inserted using larger incisions. With the evolution of minimally invasive surgical approaches these implants had to be re-designed to be inserted under much smaller incisions. Common materials used as fusion cages include bone, PEEK Rod (medical grade plastic), carbon fiber, and titanium. Percutaneous (small incision) pedicle screw systems are available to be placed with minimal tissue trauma to the surrounding back muscles. These systems, combined with specialized interbody fusion spacers, are utilized by surgeons to perform spinal fusions with minimally invasive techniques.

**Surgeon Training**

Not all spine surgeons have the advanced training or experience to become proficient in minimally invasive techniques. Operating through smaller incisions is technically more challenging for most surgeons. Therefore, one must first master the essential skills necessary to perform spinal surgery using traditional open approaches and then gradually move toward the minimally invasive or least invasive procedures. A one year fellowship training program in spine surgery is the most common way to gain exposure to these advanced surgical techniques, while continuing medical education training courses are essential for improving surgeon skills.

**Case Examples**

The following are a few examples of minimally invasive surgeries frequently performed by trained spine surgeons. While there are many other exciting techniques, due to the limited scope of this short review article only a few cases could be described here.

**Lumbar Microdiscectomy**

Patients with lumbar disc herniations usually complain of radicular symptoms (sciatica) into the leg. Physical examination typically yields findings of neurological irritation (positive nerve root tension signs, dermatomal sensory disturbances) and MRI scanning will demonstrate nerve compression. If a patient fails to improve with non-operative treatment such as physical therapy or epidural spinal injections then surgical decompression has been shown to be more effective than ongoing non-surgical care. The most common surgery to treat a herniated lumbar disc is a microscopically assisted laminotomy with discectomy. Surgeons trained in minimally invasive spine procedures will usually perform the surgery as an outpatient, allowing the patient to go home the same day as surgery.

**Lumbar Arthodesis (Fusion)**

Fusion surgery is indicated for patients with axial (back > leg) low back pain that has been refractory to greater than 6 months of non-operative treatments. Usually the disc itself has been torn and becomes painful, causing symptoms of severe low back pain. The discs are located in the front (anterior) column of the spine. Therefore, spinal fusion surgery can be performed from either the anterior (front) or posterior (back) approach, depending on the specific situation and surgeon preference. If the surgeon determines that screws are needed to stabilize the spine then he can use a minimally invasive percutaneous system.

**Mini-open ALIF (Anterior Lumbar Interbody Fusion)**

The most accessible disc level for a small incision anterior spinal fusion is the L5-S1 segment. In many cases a surgeon can do the complete fusion from the
Minimally Invasive TLIF (Transforaminal Lumbar Interbody Fusion)

The transforaminal (access to the disc space through the neural foramen) interbody fusion is frequently performed now by surgeons with advanced training in minimally invasive techniques. Holley and colleagues made significant improvements in the technology and techniques which allowed surgeons to utilize small incisions and safely perform the TLIF fusion. There are three critical elements to this surgery: 1) Transforaminal nerve decompression with removal of the facet joint 2) Interbody fusion with implant placement 3) Pedicle screw and rod insertion. Image guidance is essential during the surgery and most surgeons use intra-operative fluoroscopy and nerve monitoring. Surgeons trained in minimally invasive TLIF surgery can perform these fusions using 2 small incisions on the sides of the spine. The images show several intra-operative x-ray images of the surgery (Figures 5a, 5b).

Vertebral Compression Fracture (VCF) Stabilization with Kyphoplasty/Vertebroplasty

The leading cause of VCF’s is osteoporosis. Fractures occur in women six-times more frequently than men. Spinal compression fractures can be very painful and may require treatment with narcotic medications, bed rest, or sometimes hospitalization for pain control. Surgical stabilization of the fracture can be helpful for those patients who cannot tolerate the pain or have side effects from the pain medications. Two methods for surgical treatment include vertebroplasty and kyphoplasty and both rely on an injection of bone cement into the fracture to stabilize the break. Most surgeons prefer kyphoplasty as data suggests that there is usually less cement extravasation (leakage) compared to the other technique. Both procedures are done using a percutaneous (small hole through the skin) approach and patients can be discharged soon after the surgery is complete.

Conclusion

Technological advances have fueled the evolution of minimally invasive spinal surgery. Significant improvements in intra-operative microscopes, fluoroscopy, and nerve monitoring...
combined with advancements in surgeon training programs have resulted in many new options for patients suffering from back and neck pain. Least invasive spine surgery is emerging as a safe and effective alternative for an increasing number of patients to consider when consulting with their surgeons.

References


