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Comparison between Conventional Open Surgery, Percutaneous Fixation and Intermuscular Fixation.

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ABSTRACT

Background: Degenerative lumbar spine disorders are common causes of low back pain, radiculopathy, neurogenic claudication, and functional limitation. Surgical management may be required when conservative treatment fails or when instability, stenosis, or neurological compromise is present. Objective: This review compares conventional open surgery, percutaneous fixation, and intermuscular/muscle-sparing fixation concepts in degenerative lumbar spine surgery, focusing on tissue disruption, decompression and fusion principles, perioperative morbidity, recovery, technology support, complications, and cost. Conclusion: Conventional open surgery provides direct exposure and remains suitable for complex or multilevel pathology, but is associated with greater soft-tissue disruption. Minimally invasive and percutaneous approaches aim to reduce muscle injury, blood loss, and hospital stay while maintaining comparable clinical objectives. Intermuscular and muscle-sparing principles are relevant because preservation of paraspinal muscles is central to reducing approach-related morbidity.

Keywords: Degenerative lumbar spine, open surgery, percutaneous fixation, intermuscular fixation, minimally invasive spine surgery...

INTRODUCTION

Degenerative lumbar spine surgery has evolved from conventional open exposure toward less invasive approaches designed to preserve posterior soft tissues while achieving decompression and stabilization. The comparison between conventional open surgery, percutaneous fixation, and intermuscular fixation is therefore mainly centered on the balance between adequate surgical access and minimization of approach-related injury.

Degenerative Lumbar Spine Disease:

Erected vertically, the spine is the mast of our body and has three major functions: to provide structural support, enable trunk movement and protect the neural elements. From a biomechanical point of view, the spine is a multiarticular structure comprising numerous segments or units, enabling multidirectional motions and the absorption of large complex loads. Two adjacent vertebrae, the intervertebral disc, spinal ligaments and facet joints between them constitute a functional spinal unit (Fig. 1). [1].

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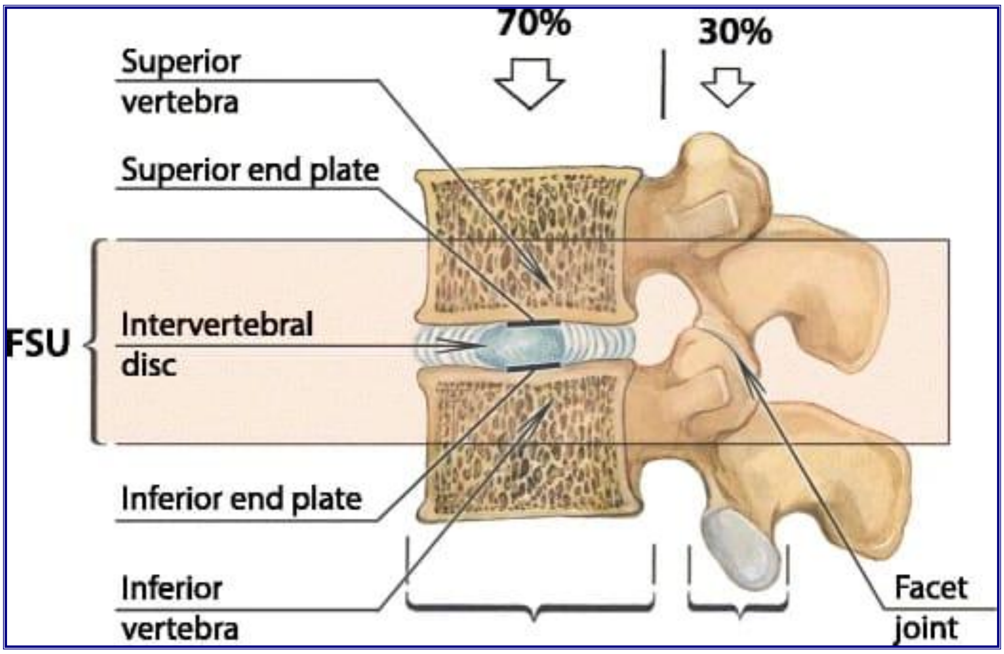

Figure (1): Functional spinal unit (FSU). The FSU represents the smallest motion segment of the spine and exhibits biomechanical characteristics similar to those of the entire spine. Approximately 70% of applied axial compression is transmitted by the vertebral body and the intervertebral discs, with the remaining 30% of the load being distributed through the facet joints. [2]

Degenerative change is considered a response to insults, such as mechanical or metabolic injury, rather than a disease. The aetiology of the degenerative changes may be mechanical micro-insults or damage secondary to macro-insults, such as spinal fractures, spinal surgery not related to degenerative disc disease or significant metabolic processes, such as ochondrosis or mucoplysaccharidoses. All elements of the spine, including the intervertebral discs, joints, ligaments and bony structures, may undergo morphological changes that can be classified as degenerative. [3]

Etiology

The etiology of lumbar degenerative disease (LDD) is multifactorial. These factors are normal aging, genetic tendency (probably one of the most important factors), congenital malformations (i.e., congenital canal stenosis, midline closure defects, pars interarticularis defects), trauma, and acute disc herniation, among others. External factors may worsen or exacerbate symptoms, such as heavy work (weightlifting, twisting and bending activities, vibration activities, etc.), obesity, smoking, sedentary lifestyle, social and economic factors, job satisfaction, depression and other mood disorders, etc. [4]

Epidemiology

Low back pain is one of the most common causes of work absence and seeking emergency care in the world. The cause for complaints is generally non-specific and mainly attributed to sustained muscle spasm or non-specific degenerative changes. It is estimated that about 13 million physician visits are due to chronic low back pain each year. [5]

Symptomatic lumbar disc herniation occurs in about 1–3% of the population, having a higher prevalence among people aged 30–50 years, with a male/female ratio of 2 (Jordon et al). In the vast majority of the cases it affects the L4-L5 or L5-S1 levels (approximately 95% of the cases); on the other hand, herniations in the upper lumbar levels are more common in elderly patients. In 90% of the cases, symptoms disappear in up to 6 weeks and only a minority of the patients will require surgical treatment. [6]

In older patients, lumbar stenosis is more common than an isolated disc herniation. Of note, lumbar stenosis is the most common cause of spinal surgery in patients in their 60s. Lumbar stenosis is associated with ligamentous and facet joint hypertrophy; in some cases, spondylolisthesis, loss of lumbar lordosis, and scoliosis can also be seen. [7]

Treatment / Management

Fortunately, the majority of patients will improve without surgical treatment. A course of at least 6 weeks of physical therapy with an emphasis on core strengthening and stretching should be attempted. Non-surgical intervention includes cognitive therapy, lifestyle modification and modification of the activity that may exacerbate the pain, non-steroidal anti-inflammatory medications (NSAIDs), and epidural injections. Epidural injections may provide moderate, short-term relief of pain due to disc herniations, but the literature regarding the usefulness of injections for chronic non-radiating back pain is less certain. Certainly, the literate does not advocate against injections as a non-operative treatment option [8].

Unfortunately, many patients do not respond to conservative treatment. With a failed conservative course, the patient has three options: (1) continued pain, (2) complete avoidance of activities that elicit pain, or (3) surgical intervention. Again, the surgical options for disc herniations, as well as degenerative spinal stenosis, should be reserved for those with either neurologic deficits, degenerative spondylolisthesis, or pain limiting daily functions [8].

Operative intervention includes:

Lumbar discectomy with fusion: The Swedish Lumbar Spine Study Group has reported systematic evidence on the superiority of outcomes of fusion for degenerative lumbar disc disease when compared with nonsurgical treatment. Fusion has been considered for a long time as the gold standard for the management of lumbar degenerative disc disease [9].

One of the most cited guides on the outcomes of surgical versus conservative management for lumbar disc herniations comes from the Spine Patient Outcomes Research Trial (SPORT). In their report, patients electing for surgery had better outcomes at 3 months, years, and 4 years compared to patients who did not elect surgery. The literature regarding the optimal surgical procedure, approach, and roles for decompression/instrumentation continues to expand. Literature shows that a traditional open surgery compared to a microdiscectomy is broadly similar in outcomes and effectiveness. In regard to the amount of disc removed during a discectomy, while a "limited" discectomy provides better pain relief and patient satisfaction compared to a subtotal discectomy, they have a higher risk of repeat herniations. Patient outcomes and satisfaction are similar in repeat/revision micro discectomies as compared to their initial discectomy. The operation, at times, requires overnight hospitalization; but frequently, these surgeries are designed to be outpatient procedures [10].

The patient needs to understand that while surgical intervention has favorable outcomes for relieving radicular pains, the results are less predictable for non-radiating lower back pain [11].

Muscle Preservation Rationale:

The erector spinae is a large and superficial muscle that lies just deep to the lumbodorsal fascia and arises from an aponeurosis on the sacrum, iliac crest, and thoracolumbar spinous processes. The muscle mass is poorly differentiated, but divides into three sections in the upper lumbar area: (1) The iliocostalis is most lateral and inserts into the angles of the rib; (2) the longissimus, the intermediate column, inserts into the tips of the spinous processes of thoracic and cervical vertebrae; (3) the spinalis is most medial and inserts into spinous processes of the cervical and thoracic vertebrae. The innervation of all the lumbar paraspinal muscles is from the dorsal rami of the nerve root as it exits at the most approximate level and overlaps proximally and distally along the muscle length [12].

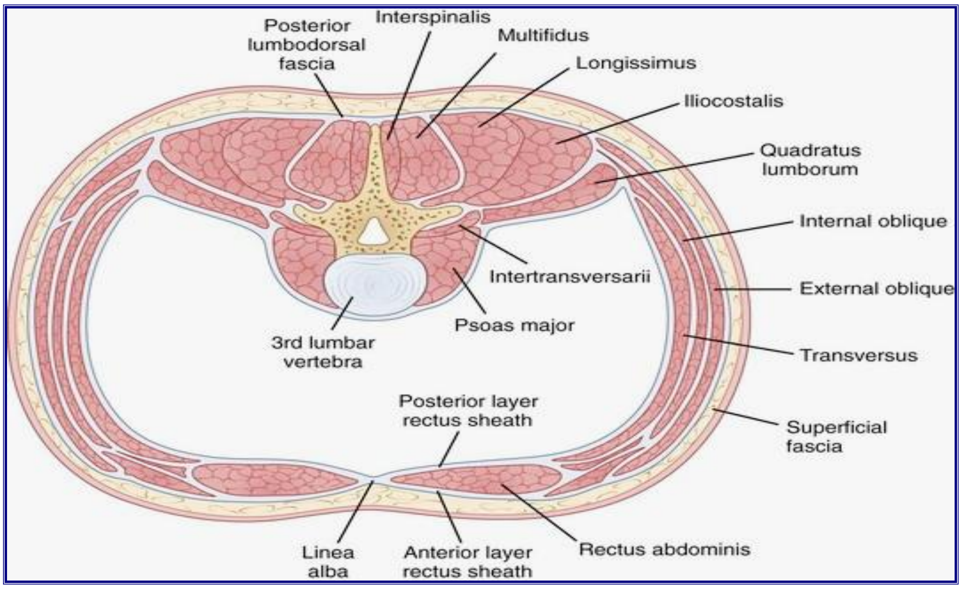

Figure (2): Cross section of body musculature and fascia through L3 showing intrinsic spinal musculature. Abdominal muscles also function in containing viscera and respiration [13].

The importance of the lumbar musculature is inferred by the intricate redundancy of the paraspinal innervation. Each area of these long muscles has overlapping innervation that may include up to two segments craniad and two segments caudal of coinnervation. This redundancy allows maintenance of function even if a particular level is affected by injury to its respective neural structure [14].

Multifidi:

Multifidi are a series of small muscles, best developed in the lumbar spine, that originate on the mammillary processes of the superior facets and run upward and medially for two to four segments, inserting on the spinous processes. This orientation produces greater capacity for rotation and abduction, in addition to extension. They also share a multilevel innervation (similar to the erector spinae bundle or group) where function is maintained even with injury to the proximate dorsal rami [15].

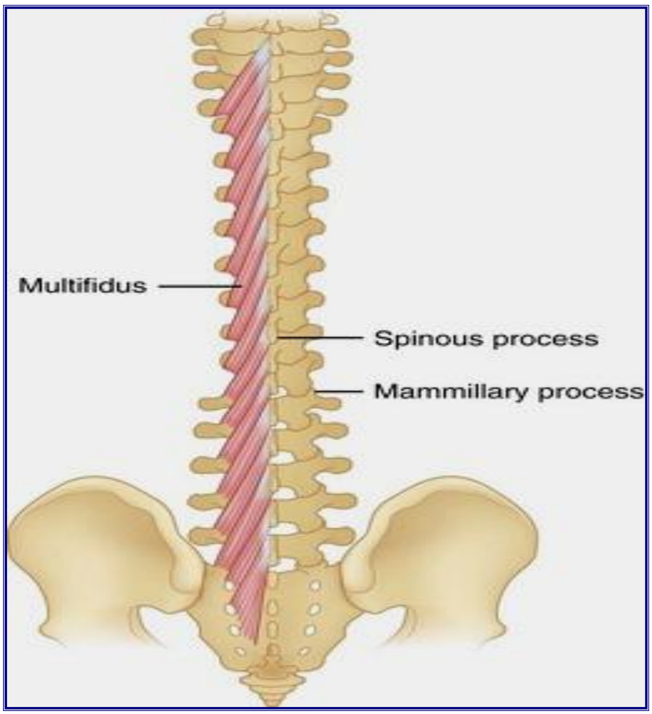

Figure (3): Multifidi consist of numerous small muscle slips that arise from small bony prominences on the articular facet.[16]

Conventional Open Surgery in Degenerative Lumbar Spine Surgeries

Conventional open surgery for degenerative lumbar spine conditions has been a mainstay in spinal surgery for decades. It involves making a larger incision along the lower back to directly access the spine, allowing the surgeon to visualize and treat structural abnormalities such as disc herniation, spinal stenosis, spondylolisthesis, and degenerative disc disease [10].

Common Indications [17]:

Lumbar Disc Herniation – When conservative management fails.

Lumbar Spinal Stenosis – To relieve pressure on neural elements.

Degenerative Spondylolisthesis – Often with instability requiring fusion.

Degenerative Disc Disease – In cases of severe, debilitating pain with radiographic confirmation.

Failed Conservative Management – When symptoms persist beyond 6–12 weeks.

Surgical Techniques [17]:

Laminectomy:

Purpose: Decompression of the spinal cord and nerves by removing the lamina.

Indication: Primarily for spinal stenosis.

Discectomy:

Purpose: Removal of herniated disc material compressing nerve roots.

Indication: Lumbar disc herniation with radiculopathy.

Spinal Fusion:

Purpose: Stabilization of the spine using bone grafts and instrumentation.

Indication: Instability due to spondylolisthesis or degenerative changes.

Instrumentation:

Pedicle screws and rods are commonly used to maintain stability during fusion.

Advantages of Conventional Open Surgery:

Direct visualization of anatomical structures.

Familiar approach for most spine surgeons.

Suitable for complex or multi-level pathologies.

Better manipulation and correction of spinal alignment.

Disadvantages:

Greater Tissue Disruption: Muscle dissection and retraction can cause significant trauma.

Higher Blood Loss: Compared to minimally invasive techniques.

Longer Recovery Time: Due to more extensive soft tissue damage.

Increased Risk of Infection and Postoperative Pain.

Longer Hospital Stay.

Outcomes:

Effectiveness: Generally good outcomes for pain relief and functional improvement, especially in appropriately selected patients.

Fusion Rates: High when instrumentation is used.

Complication Rate: Varies by patient health, surgeon experience, and surgical complexity (5–20%).

Minimally Invasive Spine Surgery

In the field of spine surgery, minimally invasive spine surgery (MISS) has advanced significantly in recent years. It has clinical and radiological outcomes comparable to open spine surgery, can reduce approach-related harm (a drawback of open surgery), and preserves normal anatomy. Thus, postoperative recovery and return to regular life is quick. The benefits of MISS include less bleeding during the procedure, quicker recovery period, and fewer postoperative complications [18].

Percutaneous Fixation within Minimally Invasive Lumbar Fusion

1. Lumbar posterior decompression

Decompression or discectomy using the posterior route is necessary when conservative measures fail to relieve lumbar spinal stenosis, lumbar disk herniation, burst fracture, or spine metastasis [19].

Surgery can be performed using the traditional open surgical approach, although minimally invasive procedures have been increasingly gaining popularity. The use of either an endoscope or a microscope is based on the discretion of the operator. Despite the variations among different approaches, scars or fibrosis can be avoided postoperatively by avoiding damage to healthy tissues; the epidural blood supply can be maintained by safeguarding the epidural vessels via a minimally invasive approach compared with open surgery [20].

Several studies have demonstrated excellent clinical outcomes in surgeries employing a transforaminal approach or an interlaminar approach using a microscope and an endoscope. MISS is a viable option for treating lumbar disk herniation, lumbar spinal stenosis, and infectious spondylitis. [21]

In case of a massive herniated disk, it may be that severe fibrotic adhesion occurs from the previous surgery, or the bony structure deviates significantly from normal structure due to severe arthritic alterations; it may be challenging to perform MISSs. Therefore, to achieve an accurate patient evaluation, surgical indications for MISS should be considered before the surgery. [22]

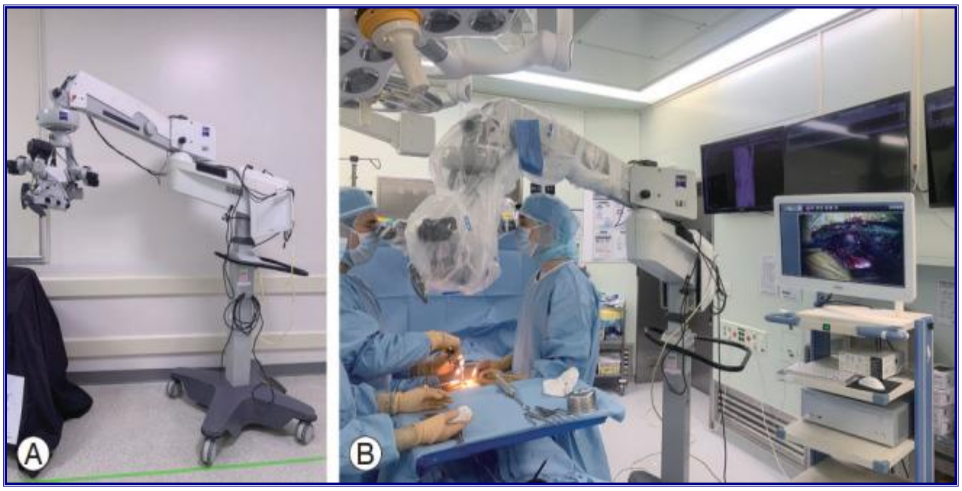

Figure (4): (A, B) Surgical field for minimally invasive spinal surgery using a microscope. [23]

Compared with open lumbar surgery, the minimally invasive lumbar posterior decompression surgery has the following disadvantages: steep learning curve, limited field of view, and narrow surgical field. Therefore, it is necessary to be completely familiar with the orientation of bony anatomy visually and to be able to feel the anatomical structures through tactile perception.

While it is not easy to perform MISSs well right from the beginning, the learning curve of surgeons practicing this may be improved, and with a larger field of view, good clinical results can be obtained through sufficient decompression and control of bleeding and normal tissue. With proper training, the advantages of MISS can be maximized while minimizing its disadvantages. [24]

2. Lumbar interbody fusion

If the patient's condition cannot be resolved with a relatively straightforward lumbar posterior decompression surgery, lumbar fusion surgery may be necessary. For example, decompression and fusion are required in case of segmental instability, a significant bone spur, severe arthritic alterations in the facet joints, or both spinal and foraminal stenosis. Sufficient decompression and fusion are possible with conventional posterolateral fusion (PLF) and posterior lumbar interbody fusion (PLIF). However, PLF has a risk of postoperative complications due to tissue injury and failure to remove the disk material; in PLIF, a reasonably large cage cannot be inserted. We present a minimally invasive lumbar interbody fusion technique that can compensate for this deficiency. [23]

The transforaminal lumbar interbody fusion (TLIF) approach can directly decompress the neural foramen by removing the facet joint through direct approach to unilateral facet joint. In addition, access to disk space is possible through this route, allowing discectomy and interbody cage insertion. Since the angle of insertion of the interbody cage is relatively gentle compared to the coronal orientation of human body, this technique allows insertion of a larger cage. TLIF can be performed through a minimally invasive approach using a microscope with a tubular retractor or an endoscope.

Compared with PLIF, minimally invasive TLIF can minimize damage to structures that contribute to posterior stability such as interspinous ligaments, contralateral facet joints, and paravertebral muscles. [25]

3. Posterior approach: transforaminal lumbar interbody fusion

In the microscopic TLIF (MI-TLIF) approach, the first step is to check the spinal level for surgery by fluoroscopy, as well as the coronal position of the pedicle for the intended approach site. Then, a skin incision of approximately 1 cm is made on the lateral side of the pedicle and secured by gradually expanding the surgical field using a tubular retractor. In the endoscopic TLIF (E-TLIF) approach, the spinal level for surgery is confirmed by fluoroscopy and 1-cm incisions are made at disk levels cranial and caudal to the level intended for fusion.[26]

These serve as a viewing portal and a working portal. After bringing the camera and shaver tip together, tactile sense is used to recognize the approximate bony anatomy, and paravertebral muscle debridement is performed to an appropriate extent. When the target facet and lamina are exposed, the desired range of surgical field is secured through an appropriate approach for both MI-TLIF and E-TLIF. Facetectomy, ligamentum flavectomy, discectomy, and body endplate preparation are sequentially performed, similar to the sequence followed for open TLIF. Subsequently, a cage of appropriate size and a percutaneous bilateral pedicle screw are inserted. [27]

Several studies have compared the surgical and clinical outcomes of traditional open TLIF, MI-TLIF, and E-TLIF. MI-TLIF and E-TLIF have reported similar fusion rates compared to open TLIF. Very few surgery-related complications include greater operation time, higher blood loss, delayed return to daily life, and longer hospital stay.

However, MI-TLIF has a high rate of rehospitalization and reoperation. Considering the steep learning curve for MI-TLIF, the advantage of this technique is not significant. Therefore, long-term studies are required to corroborate these findings. [28]

Technology Supporting Percutaneous and Minimally Invasive Fixation

1. Endoscopy

MISS aims to minimize damage to normal tissues. Compared with conventional open surgery, a small incision is initially made using a microscope, a narrow surgical field is secured using a tubular retractor or a Taylor retractor, and decompression or fusion surgery is performed using specialized instruments to obtain the desired result. In addition to the classic posterior approach, approaches involving a different direction such as LLIF and DLIF have been developed. [29]

The use of endoscope has been introduced in spine surgery, which is considered the most innovative development in the field. Due to many pioneering efforts to treat various spine diseases using an endoscope, the current endoscope-based technique has become a universal surgical method in spine surgery. [30]

By endoscopy using a high-magnification camera, normal and pathological structures can be clearly distinguished through an enlarged field of view. In addition, unlike a microscope, various viewing angles such as 0°, 30°, and 70° can be applied. Thus, structures that cannot be visualized with conventional approaches can be clearly observed. For example, if the camera is positioned toward the disk space and in the lateral recess, foraminal, and far lateral, the degree of endplate preparation can be checked in real time **(Fig. 5).** [31]

Figure (5): (A, B) Surgical field for minimally invasive spinal surgery using an endoscope. [23]

Despite the steep learning curve for endoscopy, surgeons can overcome this with the development of systematic education methods. With advances in technology and consequent expansion in the indications for this technique, the clinical and surgical outcomes are expected to improve. [32]

2. Navigation

Damage to important structures such as nerves and blood vessels can result in serious consequences for patients. A navigation system that uses real-time images is a technological advancement that improves surgical accuracy and stability. Using the O-arm system, a high-quality computed tomography (CT) scan can be performed after the patient under general anesthesia was placed in the operative position (Medtronic Sofamor Danek, Memphis, TN, USA) [33].

Surgeons can perform intraoperative three-dimensional (3D) spine anatomical mapping in real time by integrating it with a real-time anatomical tracking tool. Spine surgeons initially use navigation systems for percutaneous pedicle screw fixation. In many MISSs, intraoperative fluoroscopy is performed to achieve percutaneous pedicle screw fixation. However, despite its excellent accuracy, both the surgeons and patients are exposed to radiation. By contrast, CT-based navigation systems can significantly improve precision for pedicle screw fixation and may lower the risk of radiation exposure to surgeons and patients by more than 90% [34].

Due to the excellent reliability and safety of navigation systems, percutaneous pedicle screw fixation is frequently used in MISSs, particularly in MI-TLIF and MI-LLIF. The reliability of current CT-based navigation systems has been confirmed by several studies, and these may be used with the majority of MISSs to reduce surgery-associated complications including reoperation rates. However, the use of navigation systems is expensive, which should be addressed with increasing utilization rates of these systems [35].

Figure (6): (A, B) The O-arm system (Medtronic Sofamor Danek, Memphis, TN, USA). The O-arm is used to recreate the intended surgical anatomy during the surgery according to the patient's posture [23].

3. Robotics

Robotic spinal systems are increasingly used in spine surgery owing to their ability to execute precise, dependable, and efficient procedures. Robotic technologies provide a greater precision in pedicle screw fixation and less soft tissue abrasion than other modalities when used with navigation systems, for example, the fixation of pedicle screws [36].

Although there is a lack of clinical data addressing the use of robotics in spine surgery, some studies have observed that the precision of pedicle screw fixation achieved by robotic systems is better than that achieved through free-hand (FH) approach or C-arm fluoroscopy-guided pedicle screw fixation. Robotic spine surgery can help avoid physical and mental exhaustion of the surgeons, which could lead to better surgical, radiologic, and clinical outcomes. Nevertheless, robotic systems are rarely used, since they are expensive. However, the use of robotics in spine surgery may increase when the associated costs are reduced [37].

4. Augmented reality-assisted spine surgery

Compared with traditional FH surgical approaches, AR-assisted spine surgery has been demonstrated to increase the accuracy of pedicle screw placement and thus gaining popularity. Despite the established benefits of An assisted spine surgery, its deployment in spine surgery has lagged behind similar cranial applications, partly because the setup for spine surgeries is more time-consuming and intricate [38].

To validate anatomical and surgical landmarks using a virtual 3D reconstruction, surgeons using traditional navigation must gaze away from the operating field toward a dedicated navigation screen [39].

Studies on AR navigation are still in their early stages. Some have produced the first published work on an AR application that was later used in clinical studies. This method uses a monitor to display an A enhanced video stream in the operating room as well as in other subsequent preclinical and clinical investigations. Recent studies focused on placing AR systems directly in the surgeon's field of view using head-mounted displays rather than monitors. For spine surgery, AR results in significant improvements compared with FH surgery and conventional navigation techniques. The surgical field is improved using radiological guidance to maintain the surgeon's focus. Between AR and FH or traditional navigation approaches, AR systems have superior workflow and accuracy and result in lower radiation exposure for the surgeons and patients [40].

Figure (7): (A, B) Augmented reality assisted spine surgery [23].

Minimally Invasive versus Open Surgery for Degenerative Lumbar Lesions

Several treatment options are available to treat degenerative spinal diseases, such as laminectomies, posterior fusions, and interbody fusions, depending on their locations, correction necessities, and surgeon philosophy. Traditionally those techniques were made in an open fashion, which allowed a great visualization of the surgical field; however, it comes with a more morbid and tissue-damaging procedure [41].

Therefore, with the advance in technology and surgical knowledge, minimally invasive techniques (MIS) arose as a solution to reduce surgical morbidity, while maintaining the same benefits of the traditionally/open surgeries, in this way allowing older and weakened patients could have access to the benefits of those surgeries with a reduced risk of complications [42].

Several studies investigated the possible advantages of MIS techniques against the traditional open procedures. Showing that the MIS procedures were usually associated with reduced blood loss, and length of hospital stay, were usually like open surgeries regarding the clinical benefits and surgical duration, and with incremental cost–benefit varying according to the techniques included in the studies. However, those articles are usually focused only on one technique or on one pathology, which might raise questions about whether the observed effects are exclusively related to a specific condition or technique or if they might be true in a more general aspect [43].

Minimally invasive techniques were and still are one of the greatest revolutions in spinal surgery, as those techniques allowed surgeons to treat patients that usually require but were too weakened to receive an open procedure and to face its complications. However, the MIS techniques are not without pitfalls such as pricy materials and steep learning curves [44].

Complications and length of stay

One of the key points of minimally invasive surgery is its theoretical ability to reduce the intra and postoperative complications involving lumbar surgery. Goldstein et al., 2016 showed in a meta-analysis that using MIS PLIF or TLIF could lead to reduced medical complications compared to the open version of the same procedures. Similarly, Hu et al., 2016 showed that using MIS TLIF significantly reduced the complications rate when compared with the open TLIF procedure [45].

Interestingly studies investigating specifically the use of MIS technology to treat spondylolisthesis showed a significant reduction in length of stay, but not in the complication rates [46].

Surgical duration and blood loss

In a recent study comparing MIS versus open TLIFs Hockley et al., it showed that patients who underwent MIS procedures had significantly lower surgical time and blood loss. Further, Lu et al., showed that using MIS techniques to treat spondylolisthesis could lead to a significant reduction in surgical time and blood loss [47].

Similar to when comparing open with MIS decompressions for extraforaminal diskectomy, Akinduro et al., 2017 showed that MIS techniques showed lower blood loss and surgical time.

Also, when studying the effects of MIS decompression against open decompressions, Evaniew et al., 2021 showed that patients receiving MIS decompressions had lower blood loss and surgical time [48].

Finally, Qin et al., 2018, also showed the advantages of MIS-TLIFs over open TLIFs in blood loos, however, differently than the previous study, the authors reported higher operative in the MIS-TLIF group, in consonance with the findings of the prospective subgroup of Lu et al., 2017 study that showed an increased operative time in MIS surgeries, also similar to the findings presented by Miller et al., 2020, who reported no differences in surgical time between patients receiving MIS-TLIF or open TLIF for single-level degenerative pathologies [48].

Quality of life

Finally, Miller et al., [49] showed that pain severity between MIS and open patients was similar, however, the ODI at the last follow-up slightly favored MIS techniques results consistent with the presented by Qin et al., [46] that reported better ODI outcomes for patients receiving MIS TLIFs to treat spondylolisthesis.

Surgical costs

One of the most controversial aspects of the MIS-open corundum is the cost-effectiveness of the minimally invasive techniques, on whether the reduction in blood loss and hospitalization times compensates for the costlier materials needed to perform MIS surgeries [50].

In a study published, Goldstein and collaborators reported a cost-saving from MIS procedures ranging from 2.5 to 49% [51]. Further Vertuani et al. [50], in a simulation of costs and cost-effectiveness based on the United Kingdom and Italy surgical prices for both MIS and open surgeries, showed that in both countries the MIS techniques were presented with increased cost-effectiveness compared to open procedures.

Conclusion

The reviewed literature supports that conventional open surgery remains an important option in degenerative lumbar spine disease because it allows wide exposure, direct decompression, and instrumented stabilization, particularly in complex or multilevel pathology. However, open posterior approaches are more likely to involve muscle dissection, blood loss, postoperative pain, and longer recovery.

Minimally invasive and percutaneous fixation approaches were developed to reduce approach-related morbidity while preserving the core goals of decompression and fusion. Percutaneous pedicle screw fixation is strongly linked to fluoroscopic or navigation-based technologies, which can improve screw-placement accuracy and may reduce tissue disruption, although equipment cost, radiation considerations, and learning curve remain important limitations.

Intermuscular and muscle-sparing concepts are important in this comparison because the preservation of the paraspinal and multifidus musculature is central to reducing iatrogenic muscle injury. Overall, the choice between open, percutaneous, and intermuscular fixation should be individualized according to pathology, required exposure, surgeon experience, available technology, expected soft-tissue injury, and cost.

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