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# Minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) in treatment of degenerative diseases of lumbosacral spine compared to modified open TLIF: a prospective randomised controlled study

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## ABSTRACT

**Introduction.** The aim of this study was to determine the clinical and radiological outcomes of minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) compared to modified open TLIF via the Wiltse approach for treatment of degenerative diseases of the lumbosacral region. The results were evaluated over a post-operative period of 48 months.

**Material and methods.** Radiological data and medical records of patients who underwent MIS TLIF and modified open TLIF between May 2017 and May 2021 were reviewed. Parameters monitored to evaluate the surgical results were: clinical status, operation time, blood loss, radiation dose to patient, day of discharge, analgesic consumption, fusion, and complications rate. For functional assessment, the Visual Analogue Scale for back pain (VAS-BP), VAS for leg pain (VAS-LP), Oswestry Disability Index (ODI), Patient Satisfaction Rate (PSR), and the complication rate were used.

**Results.** This study included 57 patients randomly divided into two groups: 30 operated on using the MIS TLIF technique, and 27 operated on using the modified open TLIF technique via the Wiltse approach. 48-month follow-up rates were similar for the two cohorts. Patients did not differ significantly at baseline in terms of ODI, VAS-BP, or VAS-LP. Perioperatively, MIS TLIF was associated with significantly less blood loss (167.3 ± 80.0 vs. 297.9 ± 81.5 ml, p = 1.1E-05), slightly longer procedures (185.7 ± 45.2 vs. 183.1 ± 66.4 minutes, p = 0.76), a lower radiation dose (MIS 16.9 ± 7.1 vs. 22.0 ± 9.7 mGy OPEN p = 0.012), and shorter hospitalisations (MIS 5.9 ± 1.8 vs. 7.7 ± 1.6 days OPEN). The most common complication was radiculitis, which accounted for 33% and 37% in the MIS and the TLIF groups, respectively. The second most common complication was malposition of the fixation material, which accounted for 18.5% in the TLIF group and 20% in the MIS group. The level of fusion achieved was 92.6% in the MIS group versus 92.3% in the TLIF group. There was lower consumption of analgesics in MIS. Patient Satisfaction Rate (PSR) was 90%.

**Conclusions.** Clinical and radiological outcomes after MIS TLIF in patients with degenerative disease of the lumbosacral region are generally favourable. MIS TLIF was associated with decreased blood loss perioperatively, a lower radiation dose and an earlier discharge, but there was no difference between MIS TLIF and modified open TLIF in 48-month outcomes in terms of disability, back pain, leg pain, quality of life, or patient satisfaction rate or complication rate. Although the differences taper off over time, MIS TLIF has undeniable advantages in the perioperative and early postoperative periods.

**Keywords:** MIS TLIF, degenerative disc disease, stenosis, discogenic instability

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## Introduction

Transforaminal lumbar interbody fusion (TLIF) has become a commonly used surgical option for treating various kinds of degenerative lumbar spinal pathologies that require fusion [1–4]. In recent years, TLIF using minimally invasive techniques (known as MIS TLIF, minimally invasive transforaminal lumbar interbody fusion) has gained popularity with the emergence of minimally invasive spinal techniques and instruments e.g. tubular retractors and percutaneous pedicle screw fixation [5–8]. Proponents of MIS TLIF have suggested in several stiudies that this approach decreases muscle injury and pain, minimises blood loss, allows for rapid postoperative recovery, and is associated with improved clinical outcomes [9–12]. The risk of complications is low and comparable to conventional open methods of surgery [13–18]. There have been multiple studies comparing MIS TLIF to traditional open TLIF in cohorts of heterogeneous degenerative diagnoses [19–22, 38, 39, 45]. However, studies focused on MIS TLIF and comparing it to modified open TLIF via the Wiltse approach are very limited, and the impact of MIS TLIF on long-term patient-reported outcomes is unclear.

Mini-invasive techniques generally aim to achieve the same surgical outcome, i.e. fusion, in a gentler and less invasive manner.

In addition to all this, the use of peri-operative imaging aids has increased exponentially, with the aim of maximising the accuracy of the introduction of the fixation material. Nowadays, the use of spinal navigation, implantation via O-arm, CT navigated systems is slowly becoming standard, where the accuracy is supported by a number of studies compared to implantation under 2D fluoroscopy [17, 23, 24]. At the same time, emphasis is being placed on reducing the radiation dose to the patient and the medical staff, which can be a limiting factor and has been cited as one of the drawbacks of the MIS technique [23–26]. However, 2D fluoroscopy remains the most commonly used imaging technique.

Where fusion surgery is indicated, the MIS TLIF technique is one of the possible surgical alternatives.

The primary objective of this study was to show whether MIS TLIF is superior to open modified TLIF in terms of the most monitored parameters, and show the usefulness of this technique for surgeons and patients. There is still much debate surrounding MIS techniques, but the results of this prospective randomised controlled study, comparing MIS TLIF to a modified open TLIF technique, show that nowadays MIS TLIF can fully replace open TLIF, when indicated.

### Terminology

The term TLIF (transforaminal lumbar interbody fusion) was first used in 1982 when Harms and Rolinger presented the use of a bone graft in a titanium mesh that was inserted transforaminally into the disc space [18]. The term minimally invasive surgery (MIS) reflects a procedure that is less invasive than the open technique, achieving the same goal. The term was coined by Wickham in 1987 to refer to procedures that cause minimal damage to biological tissue at the site of instrumentation entry [27]. The MIS TLIF technique was first presented by Foley and Lefkowitz in 2002 [19].

In general, the MIS TLIF technique can be defined as a unilateral approach with complete or partial removal of the facet joint on the pathology or access side respectively, using a special dilatator for a minimally invasive technique through the paraspinal space (the Wiltse approach), various specula, tubes, scapular expanders, endoscope, nowadays especially the non-dilatable 22 mm diameter tube, disc replacement graft/spacer/cage inserted from one side obliquely, this part of the operation under a microscope or with glasses and percutaneously inserted screws bilaterally through Kirschner wires (K-wires), most often under skiascopic control [3, 5, 8, 29–32]. The resulting condition after such a surgical procedure is shown in Figure 1. Figure 2 shows the fundamental difference between open TLIF and minimally invasive TLIF. Figure 3 shows the aforementioned plane between the muscles. There also exists UNILIF (unilateral lumbar interbody fusion), which can be considered as an even more modern and improved form of MIS TLIF, when the screws are inserted only from one side [10, 33, 34, 49]. MIS TLIF is indicated in patients with low back pain (LBP) with or without root irritation, where conservative therapy has failed. Conditions leading to the clinic are internal disc disruption (IDD), degenerative disc disease (DDD), disc herniation due to disc degeneration, recurrent symptomatic disc herniation, canal stenosis especially foraminal, lateral, central stenosis except Schizas D, and segmental instability, also iatrogenic DI (discogenic instability), and isthmic and degenerative spondylolisthesis I and II according to the Mayerding classification [4–9, 14, 35, 36].


**Figure 1.** Scars as a result of surgical procedure. Source: author's archive

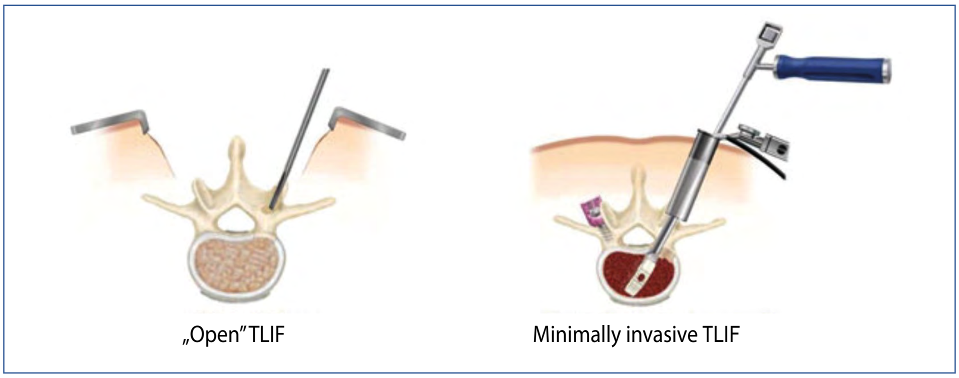


**Figure 2.** Difference between open and minimally invasive approaches. Source: spinecenteratlanta.com/conditions

**Figure 3.** Wiltse approach. Source: How to perform the Wiltse posterolateral spinal approach: technical note. Surgicalneurologyint.com/surgicalint-articles

## Material and methods

Between May 2017 and May 2021, 30 patients were operated on using the MIS TLIF technique, and 27 patients were operated on using a modified open TLIF via a Wiltse approach. Patients were randomly assigned after meeting indications for operation. Inclusion criteria for the study were patient aged 18 years or over with degenerative disability in the lumbosacral region indicated for surgery. Exclusion criteria were patients under 18, cancer patients, patients with learning disabilities or difficulties, patients with scoliosis or severe central Schizas D stenosis. Data collected consisted of age, sex, symptoms, fusion levels, operative time, assessment of fusion performed, perioperative blood loss, perioperative radiation dose, day of discharge, consumption of analgesics, complications, and clinical and radiological postoperative outcomes. Preoperative radiological evaluation consisted in all patients of standing anteroposterior and lateral radiographs, dynamic lateral radiographs, magnetic resonance imaging (MRI), and computer tomography (CT) of the lumbar spine.

We assumed that in the MIS group there would be a longer operating time, higher radiation dose, less blood loss, faster discharge, and less consumption of analgesics [4–8, 10–14, 22, 24–27, 40–43]. The reasoning behind this was: longer operating time because the technique is new, through a narrow corridor, and without known anatomical landmarks; higher radiation dose because of the need for more frequent X-ray inspection when working with K-wires and minimally invasive towers; less blood loss for reasons that are clear and due to the minimally invasive nature of the technique itself; faster discharge because decreased muscle damage allows earlier mobilisation and rehabilitation; and related to that point, in using the MIS technique, we assume less postoperative pain and consequently lower consumption of analgesics.

In the postoperative (follow-up) period, patients were checked six weeks, six months, one year and two years after surgery. The Visual Analogue Scale (VAS) was evaluated separately for back pain (VAS BP) and for leg pain (VAS LP). The Oswestry Disability Index (ODI) was assessed to determine a patient's functional disability in connection with spinal pain. The last two parameters evaluated were a Patient Satisfaction Rate (PSR) and a complications rate expressed in percentage: for the PSR we used a 5-point scale, where 1 = poor, 2 = unsatisfied, 3 = satisfied, 4 = very satisfied and 5 = outstanding, with grades 3, 4 and 5 considered as denoting satisfaction. We evaluated the clinical examination with any neurological deficit. We used CT to assess screw position, using a scale wherein

**Table 1.** Bridwell's criteria for interbody fusion [54]

| Bridwell interbody fusion system |
|---|
| Signs of fusion, bone remodelling, trabeculae |
| Graft intact, not fully remodelled and incorporated, no lucent zones |
| Graft intact, lucent zones present on upper and lower edge of graft |
| No fusion, collapse/resorption of graft |

Grade 0 is the correct position, Grade 1 is overlying the pedicle border < 2 mm, Grade 2 < 4 mm, and Grade 3 > 4 mm. Alternatively, fluoroscopic radiographs were performed six weeks, six months, one year and two years after surgery, the same intervals as in the follow-up period monitoring.

In addition to the above, we also assessed the position of the fixation material, cage position, and the spinal geometry and fusion on X-ray or CT [10, 12–15, 22, 26, 32, 50]. Overgrowth/fusion was assessed using the Bridwell criteria (Bridwell interbody fusion system, Table 1), wherein grades 1 and 2 of the scale were considered as denoting fusion.

In order to statistically evaluate the results of the work, the following methodologies were used for smaller datasets: Student's T test (comparing two sets, two-sided distribution); and two-sample with unequal variances, at a significance level α = 0.05).

## Results

Patients were divided randomly into either the Open or the MIS group. Regarding the indications for surgery, specifically in our TLIF set, we had four patients with ventrolisthesis, these were degenerative or isthmic spondylolisthesis Grades I and II, 14 patients with disc chondrosis with foraminostenosis, and nine patients with lateral disc herniation and recurrent lateral disc herniation. Clinically, all patients had low back pain and 24/27 patients (88%) also had radicular syndrome. Motor deficit was present in the TLIF group in 10 patients (37%) preoperatively: seven with moderate fibular weakness, two with femoral weakness, and one with tibial weakness. Modified open TLIF was carried out via the Wiltse approach, using a straight bullet-shaped cage from one side. A banana-shaped cage was used only three times. Screws were inserted under fluoroscopy. In the MIS TLIF group, there were 14 patients with degenerative or isthmic ventrolisthesis Gr I, II, nine with chondrosis, and seven with lateral disc herniation (Suppl. Graph 1). Clinically, all had low back pain, 25/30 had radiculopathy (83%), of whom 11 (40%) had motor deficits preoperatively, including seven with moderate or mild fibular weakness, two with femoral weakness and two with tibial weakness. We have made MIS TLIF with tubular retractor and percutaneous screws. All cages were straight, bullet shaped, and inserted under microscopic guidance from one side.

**Table 2.** Characteristics of dataset

| Group | Open TLIF | MIS TLIF |
|---|---|---|
| Total number, n | 27 | 30 |
| Gender, n (%) | | |
| Male | 12 (44.4) | 14 (46.7) |
| Female | 15 (55.6) | 16 (53.3) |
| Age (years), mean | 56.6 | 57.5 |
| Segment, n (%) | | |
| L1/2 | 1 (3.2) | 1 (2.9) |
| L2/3 | 2 (6.4) | 1 (2.9) |
| L3/4 | 3 (9.7) | 3 (8.6) |
| L4/5 | 15 (48.4) | 23 (65.7) |
| L5/S1 | 10 (32.3) | 7 (20.0) |
| Number of segments, n | | |
| 1 | 23 | 26 |
| ≥ 2 | 4 | 4 |
| Total segment number, n | 31 | 35 |
| ODI preoperatively, % | 60.0 | 62.7 |
| VAS, n | | |
| VAS leg pain | 7.4 | 7.5 |
| VAS back pain | 7.8 | 7.7 |

**Table 3.** Operated segments

| Segment, n (%) | TLIF | MIS TLIF |
|---|---|---|
| L1/2 | 1 (3.2) | 1 (2.9) |
| L2/3 | 2 (6.4) | 1 (2.9) |
| L3/4 | 3 (9.7) | 3 (8.6) |
| L4/5 | 15 (48.4) | 23 (65.7) |
| L5/S1 | 10 (32.3) | 7 (20.0) |

The characteristics are set out in Table 2. Supplemental Graph 2 and Table 3 illustrate the frequency of each segment operated on.

The analysed population was predominantly female, with a mean age of 57.5 and 56.6 years in the MIS and open TLIF groups, respectively. Preoperatively, there were no significant differences in the parameters studied. Mean operating time was (MIS 185.7 ± 45.2 vs. 183.1 ± 66.4 minutes OPEN, p = 0.76), from skin incision to final wound closure (Tab. 4, Suppl. Graph 3). Mean blood loss was (MIS 167.3 ± 80.0 vs. 297.9 ± 81.5 mL OPEN p = 1.1E-05), a predictable result due to the very nature of the MIS approach, this being one of its most advantageous features (Tab. 5, Suppl. Graph 4). The significant difference was in radiation dose, but paradoxically with the patient receiving a lower dose in the minimally invasive procedure, (mean radiation dose MIS 16.9 ± 7.1 vs. 22.0 ± 9.7 mGy OPEN, p = 0.012) (Tab. 6, Suppl. Graph 5). This is a very encouraging result that did not correlate with our hypothesis, where we assumed more frequent X-ray inspection when working with K-wires and minimally invasive towers. Under fluoroscopic control, it is necessary to monitor the position of the K-wires more often and to be careful not to immerse the K-wire when implanting the screw, which also leads to more frequent fluoroscopy [10, 14, 27, 35]. We routinely used the MIS technique and checked the position of the K-wire only once, and after penetrating the screw beyond the pedicle boundary into the vertebra, we extracted the K-wire. This led to less fluoroscopic control.

Clinical improvement ocurred in 25/27 TLIF patients (92.6%), and paresis improved or corrected in 12/14 patients (85%). In the MIS group, improvement occurred in 28/30 patients (93.3%), and paresis improved or corrected in 10/11 patients (90.1%). Properly indicated surgery had a positive effect on the preoperative neurological deficit. Patients where there was no improvement in the paretic component had a long duration of debilitation of more than six months.

**Table 4.** Statistical comparison between times required for procedures

| Property | Open TLIF | MIS TLIF |
|---|---|---|
| Time (min), median | 151 | 177.5 |
| Time (min), mean ± SD | 183.1 ± 66.4 | 185.7 ± 45.2 |
| Observations, n | 27 | 30 |
| P-value | 0.76 | |

**Table 5.** Statistical comparison between blood loss in different procedures

| Property | Open TLIF | MIS TLIF |
|---|---|---|
| Blood loss (mL), median | 286 | 142 |
| Blood loss (mL), mean ± SD | 297.9 ± 81.5 | 167.3 ± 80.0 |
| Observations, n | 27 | 30 |
| P-value | 1.1E-05 | |

**Table 6.** Statistical comparison of radiation dose administered

| Property | Open TLIF | MIS TLIF |
|---|---|---|
| Dose (mGy), median | 18.7 | 13.5 |
| Dose (mGy), mean ± SD | 22.0 ± 9.7 | 16.9 ± 7.1 |
| Observations, n | 27 | 30 |
| P-value | 0.012 | |

Regarding complications, in our set there were a total of 10 radiculitis in the MIS group, accounting for 33%, and 10 in the TLIF group as well, accounting for 37%. The second most common complication in our study was malposition of the fixation material, which accounted for five patients (18.51%) in the TLIF group and six (20%) in the MIS group. Screw revision was required four times in the open TLIF group and five times in the MIS group. In all cases this was grade 3 screw malposition. No dural sac damage was observed in any of the cases. In two patients in the TLIF group, superficial infection was noted, with no need for reoperation. There was no complication in terms of epidural haematoma, which is related to the use of the Redon drain that we inserted on the insertion side of the disc replacement.

We have completed 2-year follow-up in 27 patients from the MIS group and 26 from the TLIF group. The fusion rate achieved was 92.6% in the MIS and 92.3% in the TLIF group. Mean postoperative day of discharge was MIS 5.9 ± 1.8 vs. 7.7 ± 1.6 days OPEN. In the MIS group, faster mobilisation and initiation of rehabilitation were possible and at the same time there was less pain, which resulted in faster discharge and less analgesic consumption during hospitalisation. The immediate effect of surgery had a rapid onset in the MIS group, while in the longer term the differences blurred. Surgery had a definite effect when well indicated. The postoperative follow-up at two years was practically identical, and the Patient Satisfaction Rate (PSR) with the procedure at 2-year follow-up was 90%. See postoperative ODI ann VAS for back and leg pain in Tables 7–8 and Supplemental Graphs 6–7.

## Discussion

In this paper, one technique is discussed in detail and presented in our own dataset, where there is also a comparison

**Table 7.** Postoperative monitoring ODI

| ODI | Open TLIF | MIS TLIF |
|---|---|---|
| Time period, % | | |
| Preoperative | 60.0 | 62.7 |
| 1 month | 54.2 | 45.3 |
| 6 months | 38.6 | 34.2 |
| 1 year | 30.4 | 29.1 |
| 2 years | 26.0 | 26.2 |

**Table 8.** Postoperative monitoring VAS

| VAS | Leg pain TLIF | Back pain TLIF | Leg pain MIS TLIF | Back pain MIS TLIF |
|---|---|---|---|---|
| Time period, n | | | | |
| Preoperative | 7.4 | 7.8 | 7.5 | 7.7 |
| 1 month | 6.2 | 5.7 | 5.0 | 4.8 |
| 6 months | 5.1 | 4.8 | 4.4 | 4.4 |
| 1 year | 4.3 | 4.1 | 4.0 | 3.7 |
| 2 years | 3.8 | 3.6 | 3.6 | 3.5 |

between the MIS TLIF technique and the modified open TLIF technique. There are many variations of this technique, and even in the literature there is no clear definition of it. Currently, the MIS TLIF technique is defined as an operation where the most basic factor is the use of a tubular non-expandable dilator, the second factor is the paramedian incision, and the medial incision does not fulfill the MIS TLIF criteria [27, 48, 51, 52]. The next criterion is the use of a microscope or surgical loupes as an image magnification technique (in future perhaps an endoscope), and the last criterion meeting the definition is percutaneous insertion of screws and rods.

As for the hypotheses, the undisputed advantage with MIS techniques is lower blood loss, which follows from the definition of the technique itself and was confirmed in our set. The non-invasive nature of the procedure should also, in theory, lead to the lower consumption of analgesics and swifter discharge. The unexpected result was the statistically significant lower radiation dose for the MIS group. Although we started using minimally invasive techniques only in 2017, we today use them routinely in other surgical procedures such as spinal tumours and infections. Consequently, we have acquired certain skills and habits, which results in less X-ray control in this procedure. There is only one check of the position of K-wires, and extraction of K-wires when the screw is just under the dorsal border of pedicle, which leads to less frequent fluoroscopy control. At the same time, this challenges the narrative of higher radiation dose in minimally invasive procedures. The growing number of operations using this technique is crucial, but also the surgeon's experience [32]. Both of these things can reduce the radiation dose for patients and medical staff and also the time of operation, although the times in our study waere almost identical.

Complications of MIS techniques are a topic for a separate discussion. For MIS TLIF, a review of the literature reports a risk of complications of 0–33.3% [28, 29, 44, 47]. Wang et al. wrote that a distinction should be made between complications that are not directly related to the surgical technique and the operation and complications that are directly related to the procedure; furthermore, complications should be divided into permanent and transient complications [27]. One recent review of the literature addressing complications associated with MIS TLIF procedures reported 89 described complications, with radiculitis (2.8–57.1%) the most common symptom [28, 29]. Fortunately, this is mostly a transient complication that subsides and does not require special treatment. It results from the technique and approach itself, and is a consequence of newly arising sensations and pain in the innervation zone of the spinal root, post-operatively. If radiculitis is caused by the approach or by manipulation of the spinal root, it will resolve within 30 days. Here it is necessary to differentiate root symptomatology from other causes and to exclude a complication such as a haematoma or root compression by another pathology that would require an active surgical approach.

Radiculitis occurs naturally also with the open technique, which results from the very nature of the technique and approach. The second most common complication is malposition of screws (0.3–12.7%) [28, 29, 44, 47], which was confirmed in our study, although there was a higher percentage of malposition. We suggest that the fact that we performed all operations under fluoroscopic control and/or the larger number of more obese patients with poorer visualisation of the necessary osseous structures, contributed to this. However, this assertion cannot be confirmed, as the BMI value was not obtained from the dataset and is only an author‘s hypothesis based on his personal experience during the surgeries. In patients who are not yet included in the study, this has been addressed and the BMI of the patients is noted down, as this can serve as an important indicator for evaluating this particular hypothesis [37]. Another explanation as to why there was such a high percentage of malposition could be the delayed start with MIS techniques in our department. This technique was new to us, and took some time getting used to, which could easily have resulted in increased malposition. Nowadays, in patients not included in the present study, there is more than 96% accuracy of screw positioning. The third most frequent complication is reported to be incidental dura damage (0.3–8.6%) [28, 29], which has not yet been observed in our study. These complications also occur in the open technique but, for example, epidural haematoma, postoperative seroma in the wound, reported earlier in open techniques, were not observed in our study. In two cases in the TLIF group, superficial infection occurred, without the need for reoperation. There are also unique complications associated with the MIS technique that do not occur elsewhere. These include fracture of the Kirschner guide wires, which, although rare, has a reported incidence of 1.2% [28, 29, 44]. There is a potential risk of wire migration and associated problems [28, 29]. This complication is likely to be underestimated, with many not even considering it as a complication. In our series, we had a Kirschner wire fracture in one patient; this was a fracture on both sides, with the broken pieces remaining in the vertebra, with no migration. Wang et al. published a clinical study from a single facility, centred around complications in 204 patients who underwent MIS TLIF [29]. The overall incidence perioperatively was 36.76% (75/204 patients). Of all complications, seven (9.33%) were classified as permanent and 68 (90.67%) as transient. A complication that resolved within 30 days of surgery was considered transient. The complications in our series did not differ significantly from the literature-reported data, except for a higher percentage of malposition of the fixation material. Any postoperative radiculitis in our series was transient, with resolution within 30 days. Root irritation due to malposition of fixation material in our series was present in all cases for patients, who also had irritation or radiculopathy preoperatively. Thus, we did not record it as new, but rather as persistent. In no case with malposition was there a worsening of the motor deficit. We indicated reoperation on the basis of postoperative CT scan.

Of course, MIS techniques have their disadvantages. However, the advantages appear to outweigh the negatives, and many of the disadvantages cited can be considered relative. In the literature, longer operating times are often reported [8, 9, 13, 14, 24, 33, 37, 40]. The MIS TLIF technique is relatively new, requiring practice, coupled with the fact that the operator is working in a narrow working corridor, where the orientation is not so clear. However, this is not a completely unfamiliar situation. Microscopic approaches for other diagnoses are commonplace, as is the use of specula or tubes in the treatment of other conditions, which significantly reduces the time of surgery with the MIS technique. Of course, the time will also be reduced as the number of procedures increases. In our series, the mean operative time was (MIS 185.7 ± 45.2 vs. 183.1 ± 66.4 minutes OPEN, p = 0.76) which is practically identical.

Another disadvantage cited is the longer exposure time and the greater radiation dose on the patient and the attending medical staff [3–6, 9, 14, 15 ,17, 35]. In contrast, in our cohort we had a statistically significantly lower radiation dose to the patient with the MIS technique (MIS 16.9 ± 7.1 vs. 22.0 ± 9.7 mGy OPEN p = 0.012). In addition to the above, the other explanation for this is by less fluoroscopic control of the screw trajectory, as we have Kirschner wires in place. We emphasise not to plunge the Kirschner wires, hence we extracted them before the screw suddenly crossed into the vertebral body. Another relative disadvantage is a relatively long learning curve and the difficulty of navigating the procedure through a narrow corridor, which can be eliminated by gradually expanding the indications and implementing the MIS technique [41, 46, 53]. In mentioning the disadvantages, we must not forget the possibility of a specific type of complications, but from the overall picture, it is clear that this technique currently has an irreplaceable place in the treatment of degenerative spinal diseases.

For the last three years, we have been going even further and using the UNILIF technique, where the screws are only on one side, from which we also insert a disc replacement [10, 33, 34, 49].

## Limitations of study

The dataset in this study is relatively moderate (n ≤ 60) with randomised assignment into one of two groups. Although the definition of MIS is provided within the context of this study, there may be variations in how the surgical procedure itself is performed. There might also be limitations associated with a 48-month follow-up period, and longer monitoring might be required. Lastly, some important parameters (such as BMI or cage type) were not taken into account, which could have made some of the observed results easier to explain.

Despite that, the discussion describes the observed outcomes in a clean and conscise manner, with the author providing some of his insights to assist with drawing conclusions, where there is insufficient data to support it.

## Conclusion

In a 48-month post-operative comparison, of the 57 patients who underwent MIS (30) and open modified TLIF (27) for degerative diseases, no significant differences in terms of disability, back pain, leg pain, quality of life, patient satisfaction rate, or complication rate have been observed. Both procedures were associated with mean improvements in each of the measured parameters compared to baseline.

Therefore, there is no compelling evidence supporting the use of one technique over the other, regarding the eventual long term result. However, the results indicate that there are significant differences during the procedure itself, namely lower blood loss and lower radiation dose administered to the patient. The data shows that the MIS technique, when suitable, has demonstrable advantages over the modified open TLIF, during the surgery itself. However, it is very important to consider the experience of the surgeon, who should perform the new technique more than once to fully familiarise himself with the new aspects of the technique. This can initially result in an increased rate of complications or higher radiation dosing due to the increased need for fluoroscopic control. Minimally invasive techniques generally have an acceptable risk of complications, comparable to open techniques [28, 29, 38, 45]. The most common complication is radiculitis, but fortunately this is transient in most cases (indeed transient for all patients in this dataset).

This study demonstrates that many of the perceived disadvantages of the MIS techniques (longer operating time, higher radiation dose) can be mitigated, or even completely eliminated, once the surgeon has acquired sufficient experience with the method.

Not every patient is suitable for surgery with the MIS technique, but strictly indicated target patients clearly benefit from it. In future, we will see the gradual replacement of open methods of surgery with minimally invasive ones. Nowadays, practically every open technique has its minimally invasive equivalent.

## Article information

**Ethical permissions:** *This study was approved by the local ethics committee of the F.D. Roosevelt Hospital in Banská Bystrica (12.04.2022, No. 14/2022).*

**Conflicts of interest:** *The author declares that he has no conflict of interest in relation to the subject of the study.*
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## References

1. Epstein NE. Foraminal and far lateral lumbar disc herniations: surgical alternatives and outcome measures. Spinal Cord. 2002; 40(10): 491–500, doi: 10.1038/sj.sc.3101319, indexed in Pubmed: 12235530.
2. Kunogi J, Hasue M. Diagnosis and operative treatment of intraforaminal and extraforaminal nerve root compression. Spine (Phila Pa 1976). 1991; 16(11): 1312–1320, doi: 10.1097/00007632-199111000-00012, indexed in Pubmed: 1750006.
3. Sheehan J, Shaffrey C, Jane J. Degenerative lumbar stenosis. clinical orthopaedics and related research. 2001; 384: 61–74, doi: 10.1097/00003086-200103000-00009.
4. Holly LT, Schwender JD, Rouben DP, et al. Minimally invasive transforaminal lumbar interbody fusion: indications, technique, and complications. Neurosurg Focus. 2006; 20(3): E6, doi: 10.3171/foc.2006.20.3.7, indexed in Pubmed: 16599422.
5. Kim JS, Choi WG, Lee SH. Minimally invasive anterior lumbar interbody fusion followed by percutaneous pedicle screw fixation for isthmic spondylolisthesis: minimum 5-year follow-up. Spine J. 2010; 10(5): 404–409, doi: 10.1016/j.spinee.2010.02.022, indexed in Pubmed: 20421075.
6. Scheufler KM, Dohmen H, Vougioukas VI. Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. Neurosurgery. 2007; 60(4 Suppl 2): 203–12; discussion 212, doi: 10.1227/01.NEU.0000255388.03088.B7, indexed in Pubmed: 17415155.
7. Schwender JD, Holly LT, Rouben DP, et al. Minimally invasive transforaminal lumbar interbody fusion (TLIF): technical feasibility and initial results. J Spinal Disord Tech. 2005; 18 Suppl: S1–S6, doi: 10.1097/01.bsd.0000132291.50455.d0, indexed in Pubmed: 15699793.
8. Rudinský B, Koleják K. Degeneratívne ochorenie driekovej chrbtice--možnosti chirurgickej liečby. Neurol prax. 2008; 3: 135.
9. Hari A, Krishna M, Rajagandhi S, et al. Minimally invasive transforaminal lumbar interbody fusion-indications and clinical experience. Neurol India. 2016; 64(3): 444–454, doi: 10.4103/0028-3886.181536, indexed in Pubmed: 27147152.
10. Wang L, Wang Y, Li Z, et al. Unilateral versus bilateral pedicle screw fixation of minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF): a meta-analysis of randomized controlled trials. BMC Surg. 2014; 14: 87, doi: 10.1186/1471-2482-14-87, indexed in Pubmed: 25378083.
11. McCulloch JA, Young PH. Essentials of spinal microsurgery. Lippincott--Raven, Philadelphia 1998.
12. Clark J, Bohl C, Tumialán L, et al. Evolution of minimally invasive transforaminal lumbar interbody fusion : Improving patient safety and outcomes. Barrow Quarterly. 2016; 26(1): 26–33.
13. Qin R, Liu B, Zhou P, et al. Minimally invasive versus traditional open transforaminal lumbar interbody fusion for the treatment of single--level spondylolisthesis grades 1 and 2: a systematic review and meta--analysis. World Neurosurg. 2019; 122: 180–189, doi: 10.1016/j.wneu.2018.10.202, indexed in Pubmed: 30414524.
14. Nayar G, Blizzard DJ, Wang TY, et al. Pedicle screw placement accuracy using ultra-low radiation imaging with image enhancement versus conventional fluoroscopy in minimally invasive transforaminal lumbar interbody fusion: an internally randomized controlled trial. J Neurosurg Spine. 2018; 28(2): 186–193, doi: 10.3171/2017.5.SPINE17123, indexed in Pubmed: 29192879.
15. Weiss H, Garcia RM, Hopkins B, et al. A systematic review of complications following minimally invasive spine surgery including transforaminal lumbar interbody fusion. Curr Rev Musculoskelet Med. 2019 [Epub ahead of print]; 12(3): 328–339, doi: 10.1007/s12178-019-09574-2, indexed in Pubmed: 31302861.
16. Anand N, Kong C. Can Minimally invasive transforaminal lumbar interbody fusion create lordosis from a posterior approach? Neurosurg Clin N Am. 2018; 29(3): 453–459, doi: 10.1016/j.nec.2018.03.010, indexed in Pubmed: 29933812.
17. Yang Y, Liu ZY, Zhang LM, et al. Microendoscopy-assisted minimally invasive versus open transforaminal lumbar interbody fusion for lumbar degenerative diseases: 5-year outcomes. World Neurosurg. 2018; 116: e602–e610, doi: 10.1016/j.wneu.2018.05.049, indexed in Pubmed: 29778600.
18. Harms J, Rolinger H. [A one-stager procedure in operative treatment of spondylolistheses: dorsal traction-reposition and anterior fusion (author's transl)]. Z Orthop Ihre Grenzgeb. 1982; 120(3): 343–347, doi: 10.1055/s-2008-1051624, indexed in Pubmed: 7113376.
19. Foley KT, Lefkowitz MA. Advances in minimally invasive spine surgery. Clin Neurosurg. 2002; 49: 499–517, indexed in Pubmed: 12506566.
20. Magerl F. External skeletal fixation of the lower thoracic and the lumbar spine. Current concepts of external fixation of fractures. 1982: 353–366, doi: 10.1007/978-3-642-68448-7_40.
21. Qin R, Liu B, Zhou P, et al. Minimally invasive versus traditional open transforaminal lumbar interbody fusion for the treatment of single--level spondylolisthesis grades 1 and 2: A Systematic review and meta--analysis. World Neurosurg. 2019; 122: 180–189, doi: 10.1016/j.wneu.2018.10.202, indexed in Pubmed: 30414524.
22. Nayar G, Blizzard DJ, Wang TY, et al. Pedicle screw placement accuracy using ultra-low radiation imaging with image enhancement versus conventional fluoroscopy in minimally invasive transforaminal lumbar interbody fusion: an internally randomized controlled trial. J Neurosurg Spine. 2018; 28(2): 186–193, doi: 10.3171/2017.5.SPINE17123, indexed in Pubmed: 29192879.
23. Chen K, Chen H, Zhang K, et al. O-arm Navigation Combined With Microscope-assisted MIS-TLIF in the Treatment of Lumbar Degenerative Disease. Clin Spine Surg. 2019; 32(5): E235–E240, doi: 10.1097/BSD.0000000000000804, indexed in Pubmed: 30762835.
24. Peng CW, Yue WM, Poh SY, et al. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. Spine (Phila Pa 1976). 2009; 34(13): 1385–1389, doi: 10.1097/BRS.0b013e3181a4e3be, indexed in Pubmed: 19478658.
25. Shunwu F, Xing Z, Fengdong Z, et al. Minimally invasive transforaminal lumbar interbody fusion for the treatment of degenerative lumbar diseases. Spine (Phila Pa 1976). 2010; 35(17): 1615––1620, doi: 10.1097/BRS.0b013e3181c70fe3, indexed in Pubmed: 20479702.
26. Anand N, Kong C. Can Minimally Invasive Transforaminal Lumbar Interbody Fusion Create Lordosis from a Posterior Approach? Neurosurg Clin N Am. 2018; 29(3): 453–459, doi: 10.1016/j.nec.2018.03.010, indexed in Pubmed: 29933812.
27. Ahn J, Tabaraee E, Singh K. Minimally Invasive Transforaminal Lumbar Interbody Fusion. J Spinal Disord Tech. 2015; 28(6): 222–225, doi: 10.1097/BSD.0000000000000289, indexed in Pubmed: 26079840.
28. Weiss H, Garcia RM, Hopkins B, et al. A Systematic Review of Complications Following Minimally Invasive Spine Surgery Including Transfo-

raminal Lumbar Interbody Fusion. Curr Rev Musculoskelet Med. 2019 [Epub ahead of print]; 12(3): 328–339, doi: 10.1007/s12178-019-09574-2, indexed in Pubmed: 31302861.
29. Wang J, Zhou Y. Perioperative complications related to minimally invasive transforaminal lumbar fusion: evaluation of 204 operations on lumbar instability at single center. The Spine Journal. 2014; 14(9): 2078–2084, doi: 10.1016/j.spinee.2013.12.016.
30. Zhang D, Mao K, Qiang X. Comparing minimally invasive transforaminal lumbar interbody fusion and posterior lumbar interbody fusion for spondylolisthesis: A STROBE-compliant observational study. Medicine (Baltimore). 2017; 96(37): e8011, doi: 10.1097/MD.0000000000008011, indexed in Pubmed: 28906383.
31. Choi WS, Kim JS, Hur JW, et al. Minimally Invasive Transforaminal Lumbar Interbody Fusion Using Banana-Shaped and Straight Cages: Radiological and Clinical Results from a Prospective Randomized Clinical Trial. Neurosurgery. 2018; 82(3): 289–298, doi: 10.1093/neuros/nyx212, indexed in Pubmed: 28499016.
32. Parajón A, Alimi M, Navarro-Ramirez R, et al. Minimally Invasive Transforaminal Lumbar Interbody Fusion: Meta-analysis of the Fusion Rates. What is the Optimal Graft Material? Neurosurgery. 2017; 81(6): 958–971, doi: 10.1093/neuros/nyx141, indexed in Pubmed: 28419312.
33. Wang L, Wang Y, Li Z, et al. Unilateral versus bilateral pedicle screw fixation of minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF): a meta-analysis of randomized controlled trials. BMC Surg. 2014; 14: 87, doi: 10.1186/1471-2482-14-87, indexed in Pubmed: 25378083.
34. Than KD, Mummaneni PV. Unilateral approach for bilateral decompression with MIS TLIF. World Neurosurg. 2014; 82(5): 646–647, doi: 10.1016/j.wneu.2014.08.024, indexed in Pubmed: 25153294.
35. Alvi M, Kurian S, Wahood W, et al. Assessing the Difference in Clinical and Radiologic Outcomes Between Expandable Cage and Nonexpandable Cage Among Patients Undergoing Minimally Invasive Transforaminal Interbody Fusion: A Systematic Review and Meta-Analysis. World Neurosurgery. 2019; 127: 596–606.e1, doi: 10.1016/j.wneu.2019.03.284.
36. White IK, Tuohy M, Archer J, et al. The Use of Bone Morphogenetic Protein in the Intervertebral Disk Space in Minimally Invasive Transforaminal Lumbar Interbody Fusion: 10-year Experience in 688 Patients. Clin Spine Surg. 2019; 32(6): E272–E276, doi: 10.1097/BSD.0000000000000800, indexed in Pubmed: 30839419.
37. Krüger MT, Naseri Y, Hohenhaus M, et al. Impact of morbid obesity (BMI > 40 kg/m) on complication rate and outcome following minimally invasive transforaminal lumbar interbody fusion (MIS TLIF). Clin Neurol Neurosurg. 2019; 178: 82–85, doi: 10.1016/j.clineuro.2019.02.004, indexed in Pubmed: 30739072.
38. Zhao J, Zhang S, Li X, et al. Comparison of Minimally Invasive and Open Transforaminal Lumbar Interbody Fusion for Lumbar Disc Herniation: A Retrospective Cohort Study. Med Sci Monit. 2018; 24: 8693–8698, doi: 10.12659/MSM.912808, indexed in Pubmed: 30504756.
39. Haws BE, Khechen B, Patel DV, et al. Impact of local steroid application in a minimally invasive transforaminal lumbar interbody fusion: results of a prospective, randomized, single-blind trial. J Neurosurg Spine. 2018; 30(2): 222–227, doi: 10.3171/2018.7.SPINE18584, indexed in Pubmed: 30497132.
40. Enami A, Faloon M, Sahai N, et al. Risk factors for pseudoarthrosis in MIs TLIF. . Oct;():-838. Asian spine J 2018 Oct;12(5):830-838 doi:10 31616/asj 2018 12 5 830 Epub. 2018; 12(5): 830–838, doi: 10.31616/asj.2018.12.5.830., indexed in Pubmed: 30213165.
41. Sharif S, Afsar A. Learning Curve and Minimally Invasive Spine Surgery. World Neurosurg. 2018; 119: 472–478, doi: 10.1016/j.wneu.2018.06.094, indexed in Pubmed: 29935319.
42. Chandra Vemula VR, Prasad BC, Jagadeesh MA, et al. Minimally invasive transforaminal lumbar interbody fusion using bone cement--augmented pedicle screws for lumbar spondylolisthesis in patients with osteoporosis. Case series and review of literature. Neurol India. 2018; 66(1): 118–125, doi: 10.4103/0028-3886.222826, indexed in Pubmed: 29322970.
43. Hawasli AH, Khalifeh JM, Chatrath A, et al. Minimally invasive transforaminal lumbar interbody fusion with expandable versus static interbody devices: radiographic assessment of sagittal segmental and pelvic parameters. Neurosurg Focus. 2017; 43(2): E10, doi: 10.3171/2017.5.FOCUS17197, indexed in Pubmed: 28760032.
44. Yang Y, Zhang L, Liu B, et al. Hidden and overall haemorrhage following minimally invasive and open transforaminal lumbar interbody fusion. J Orthop Traumatol. 2017; 18(4): 395–400, doi: 10.1007/s10195-017-0464-9, indexed in Pubmed: 28741030.
45. Xie L, Wu WJ, Liang Yu. Comparison between Minimally Invasive Transforaminal Lumbar Interbody Fusion and Conventional Open Transforaminal Lumbar Interbody Fusion. Chinese Medical Journal. 2016; 129(16): 1969–1986, doi: 10.4103/0366-6999.187847.
46. Wang J, Zhou Y, Zhang ZF, et al. Disc herniation in the thoracolumbar junction treated by minimally invasive transforaminal interbody fusion surgery. J Clin Neurosci. 2014; 21(3): 431–435, doi: 10.1016/j.jocn.2013.04.029, indexed in Pubmed: 24225365.
47. Wu WJ, Liang Yu, Zhang XK, et al. Complications and clinical outcomes of minimally invasive transforaminal lumbar interbody fusion for the treatment of one- or two-level degenerative disc diseases of the lumbar spine in patients older than 65 years. Chin Med J (Engl). 2012; 125(14): 2505–2510, indexed in Pubmed: 22882930.
48. Kai-Hong Chan A, Choy W, Miller CA, et al. A novel technique for awake, minimally invasive transforaminal lumbar interbody fusion: technical note. Neurosurg Focus. 2019; 46(4): E16, doi: 10.3171/2019.1.FOCUS18510, indexed in Pubmed: 30933917.
49. Alshal E. Spinal Interbody Fusion with Unilateral Pedicle Screw Fixation. Orthopedics and Rheumatology Open Access Journal. 2019; 14(5), doi: 10.19080/oroaj.2019.14.555897.
50. Closkey RF, Parsons JR, Lee CK, et al. Mechanics of interbody spinal fusion. Analysis of critical bone graft area. Spine (Phila Pa 1976). 1993; 18(8): 1011–1015, doi: 10.1097/00007632-199306150-00010, indexed in Pubmed: 8367768.
51. Li XC, Huang CM, Zhong CF, et al. Minimally invasive procedure reduces adjacent segment degeneration and disease: New benefit-based global meta-analysis. PLOS ONE. 2017; 12(2): e0171546, doi: 10.1371/journal.pone.0171546, indexed in Pubmed: 28207762.
52. Wang HL, LU FZ, Jiang JY, et al. Minimally invasive lumbar interbody fusion via MAST Quadrant retractor versus open surgery: a prospective randomized clinical trial.Chin Med J (Engl). 2011 Dec. ; 124(23): 3868–3674, indexed in Pubmed: 22340311.
53. Scheufler KM, Dohmen H, Vougioukas VI. Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. Neurosurgery. 2007; 60(4 Suppl 2): 203–212; discussion 212, doi: 10.1227/01.NEU.0000255388.03088.B7, indexed in Pubmed: 17415155.
54. https://www.researchgate.net/figure/Bridwell-interbody-fusion--grading-system_tbl1_47809535 (10.10.2023).