Review Article

Minimally Invasive Transforaminal Lumbar Interbody Fusion: A Perspective on Current Evidence and Clinical Knowledge

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This paper reviews the current published data regarding open transforaminal lumbar interbody fusion (TLIF) in relation to minimally invasive transforaminal lumbar interbody fusion (MI-TLIF). Introduction. MI-TLIF, a modern method for lumbar interbody arthrodesis, has allowed for a minimally invasive method to treat degenerative spinal pathologies. Currently, there is limited literature that compares TLIF directly to MI-TLIF. Thus, we seek to discuss the current literature on these techniques.

Methods. Using a PubMed search, we reviewed recent publications of open and MI-TLIF, dating from 2002 to 2012. We discussed these studies and their findings in this paper, focusing on patient-reported outcomes as well as complications.

Results. Data found in 14 articles of the literature was analyzed. Using these reports, we found mean follow-up was 20 months. The mean patient study size was 52. Seven of the articles directly compared outcomes of open TLIF with MI-TLIF, such as mean duration of surgery, length of post-operative stay, blood loss, and complications. Conclusion. Although high-class data comparing these two techniques is lacking, the current evidence supports MI-TLIF with outcomes comparable to that of the traditional, open technique. Further prospective, randomized studies will help to further our understanding of this minimally invasive technique.

1. Introduction

The advent of minimally invasive surgery has provided surgeons new techniques for treating clinical disease. Within the field of spinal surgery, techniques in lumbar interbody arthrodesis have shown a continued evolution of procedural approach and instrumentation. Minimally invasive spine surgery aims to reduce approach-related morbidity, while producing clinical outcomes comparable to its open predecessors. One important example of this is the development of minimally invasive techniques for lumbar interbody fusion, including transforaminal lumbar interbody fusion (TLIF) [1].

The MI-TLIF technique, has displayed comparable outcomes to open TLIF, while adding the benefits of less approach-related morbidity, decreased intraoperative blood loss, and shorter hospital stays [2]. However, critics of the technique have noted that the MI-TLIF has longer operative times and exposes patients to increased fluoroscopic radiation. Over the past decade MI-TLIF has been shown to have a number of benefits, especially with regard to perioperative outcomes. However, it may have its own unique challenges and potential morbidity. Ultimately, comparing the known literature of a traditional, open TLIF approach to published reports on MI-TLIF will identify the unique risks and benefits associated with each. This understanding may help guide improved clinical decision making for patients presenting with lumbar degenerative disk disease.

In this paper, we evaluate the literature to examine the efficacy of MI-TLIF compared to its open counterpart. In addition, key studies discussing the risks and benefits of MI-TLIF were included to more thoroughly explore the nature of the technique and its application.

2. Materials and Methods

In this paper, the authors have used the PubMed/MEDLINE search engines to search for relevant reports addressing the topic of transforaminal lumbar interbody fusion. This was primarily done from January 2000 to January 2012. However, a few historical reports have been added for completeness. Included in this search was the following key phrases: “Minimally invasive,” “transforaminal,” “interbody fusion,”
3. MI-TLIF Technique

After failed conservative management for a minimum of 6 months, surgery becomes the next therapeutic option for patients presenting with degenerative disc disease (DDD), radiculopathy with spinal instability, and/or grade 1 spondylolisthesis. Initially patients are assessed through radiological investigations including X-ray (AP, lateral, flexion, and extension), and noncontrast lumbosacral MRI. Length of hospitalization is determined by postoperative pain control and functional dependence, with patients of advanced age or medical comorbidities often requiring longer postoperative recovery. However, a majority of patients are admitted the day of surgery and discharged within 24–72 hours after operation.

Under general anesthesia, patients are fixed in a Wilson frame in a prone position. The patient is prepped and draped in standard fashion, and a fluoroscopic C-arm is positioned in the sterile field. Under fluoroscopic guidance the appropriate level is marked and a 3 cm incision is made 4.5 cm off midline. A k-wire is targeted to the bony complex at the superior level is marked and a 3 cm incision is made 4.5 cm of o.

In the MI-TLIF literature reviewed, many authors discussed the challenging learning curve associated with MI-TLIF, which makes certain complications, particularly those related to instrumentation more likely [5]. Endoscopic
| Author (year)                | Study design | Follow-up           | Number of patients | Significant results                                                                 |
|-----------------------------|--------------|---------------------|--------------------|-------------------------------------------------------------------------------------|
| Scheufler et al. (2007) [10] | Retrospective | 8 months, 16 months | 53                 | OR time equivalent between pTLIF and mini-open TLIF                                 |
|                             |              |                     |                    | Blood loss and postoperative pain reduced in pTLIF                                   |
| Villavicencio et al. (2010) [8] | Retrospective | 37.5 months        | 63 and 76 patients | Mean blood loss lower in MI-TLIF                                                     |
|                             |              |                     |                    | Mean duration of hospital stay shorter in MI-TLIF                                     |
|                             |              |                     |                    | Rate of neurological deficit was greater in the MI-TLIF group                         |
| Schizas et al. (2009) [5]   | Prospective  | 22 months (MI)      | 36 patients        | MI-TLIF: decreased blood loss, shorter hospital stay and decreased pain               |
|                             |              | 24 months (O)       | (O = 18, MI = 18)  | Steeper learning curve in MI-TLIF                                                    |
| Dhall et al. (2008) [4]     | Retrospective | 24 months (MI)      | 21 (MI)            | MI-TLIF: less blood loss, shorter LOS                                                |
|                             |              | 34 months (O)       | 21 (O)             |                                                                                     |
| Jang and Lee (2005) [13]    | Pilot        | 30 months           | 100 consecutive patients | Significant reduction in pain, ODI, and TIS                                         |
|                             |              |                     |                    | Improvement in lordosis from 2° to 9°, anterior disc height 6 to 14 mm, and posterior disc height from 4 to 8 mm |
| Peng et al. (2009) [3]      | Prospective  | 6 months, 2 years   | 29 (MI), 29 (O)    | MI-TLIF: fluoroscopic time increased, longer operative times, less blood loss, decreased morphine use, and decreased LOS |
| Beringer and Mobasser (2006) [15] | Prospective | 6 months           | 8                  | All had solid bone fusions                                                           |
| Park and Foley (2008) [16]  | Retrospective | Minimum 24 months, Mean 35 months | 40                 | Mean ODI 55 → 16 post-op                                                            |
|                             |              |                     |                    | Mean leg and back pain VAS 65 and 52, improving to 8 and 15                           |
|                             |              |                     |                    | Reduction of spondylolisthesis was achieved in all cases, with a mean decrease in forward translation of 76% |
| Deutsch and Musacchio (2006) [11] | Prospective | 6–12 months        | 20                 | 85% had >20 point reduction in ODI                                                  |
|                             |              |                     |                    | ODI 57 → 25                                                                        |
|                             |              |                     |                    | VAS 8.3 → 1.4                                                                      |
| Jang and Lee (2005) [13]    | Prospective  | 19 months           | 23                 | NRS back pain 7.5 → 2.3                                                             |
|                             |              |                     |                    | NRS leg pain 7.4 → 0.7                                                              |
|                             |              |                     |                    | Mean ODI 33.1 → 7.6                                                                |
| Author (year)         | Study design       | Follow-up               | Number of patients | Significant results                                                                                     |
|----------------------|--------------------|-------------------------|--------------------|---------------------------------------------------------------------------------------------------------|
| Isaacs et al. (2005) | Retrospective      | n/a                     | 20                 | METLIF: less blood loss, less postoperative wound drainage, no dural violation, less pain medication, and shorter LOS |
| Shunwu et al. (2010) | Prospective cohort study | 24–42 months            | 32 (MI), 30 (O)    | MI: reduced blood loss, less postoperative back pain, lower serum creatine kinase, shorter time to ambulation, and shorter LOS |
| Wang et al. (2010)   | Prospective        | Minimum 13-month follow-up | MI = 42, O = 43 | ME reduced blood loss, less postoperative back pain, shorter LOS, greater radiation time |
| Foley et al. (2003)  | Retrospective      | 12–20 months, mean 22 months | 39 patients       | Twenty-six had excellent outcomes and 12 had good ones, as determined by the modified MacNab criteria |
| Schwender et al. (2005) | Retrospective       | 22.6 mean follow-up     | 49 patients        | Estimated blood loss of 140 mL, mean length of hospital stay 1.9 days, and all 45 patients presenting with preoperative radiculopathy had resolution of symptoms |
| Dong et al. (2008)   | Retrospective      | 38.6 mean follow-up     | 27 patients        | Solid fusion in 77.8% of patients, clinical success achieved in 88.9% of cases |
| Anand et al. (2006)  | Prospective        | 30                      | 100                | Improvement in VAS, ODI, TIS, and NRS for back, 99% fusion |
visualization of the spinal structure limits the field of view for the surgeon, making identification of already unfamiliar landmarks even more difficult. Though visualization techniques have improved over time, percutaneous fixation systems do not have the ability to reposition three dimensionally [10]. Tubular dilator retractors can result in poor decompression while resulting in higher rates of neurological injuries [4]. Of all complications presented in the MI-TLIF comparative literature, approximately 1 in 5 were related to neurological complications (Table 4). Schizas et al. wrote of possible inexperience leading to inappropriate placement of transpedicular screws, and inadequate preparation of intervertebral cage and fusion site which can lead to further instrumentation related complications.

The operative surgeon additionally must be familiar with 3D lumbar anatomy and be able to carefully interpret 2D radiographic images to make a mental reconstruction. This is a unique skill and one that is not as critical with a traditional, open approach. The surgeon must be able to read anterior-posterior and lateral imaging in order to accurately insert percutaneous pedicle screws, thereby allowing for possible misinterpretation leading to complications [14]. Screw misplacement and cage migration or subsidence accounted for 44.8% of complications reported in MI-TLIF comparative studies.

Radiation exposure is another area of interest. MI-TLIF itself presents with increased risk to the surgeon related to increased radiation exposure due to lengthened intraoperative fluoroscopy times. Though many may claim that a surgeon’s experience level with minimally invasive procedures will dictate their fluoroscopy times, some studies found no significant difference as experience increased [7]. Very few studies reported the duration and radiation exposure resulting from X-ray and fluoroscopy. Authors who did...
Table 2: Comparative studies basic data.

| Author       | MIS Mean duration of surgery | Open Mean duration of surgery | MIS Blood loss | Open Blood loss | Length of stay MIS | Length of stay Open |
|--------------|-------------------------------|-------------------------------|----------------|-----------------|---------------------|---------------------|
| Villavicencio et al. | 222.5                       | 214.9                        | 163 mL         | 366.8           | 3                   | 4.2                 |
| Shunwu et al. | 159.2                        | 142.8                        | 399.8          | 517             | 9.3                 | 12.5                |
| Wang et al.  | 156 (X-ray 84)               | 145 (37)                     | 264            | 673             | 10.6                | 14.6                |
| Peng et al.  | 216.4 (fluoro 105.5 s)       | 170 (35.2)                   | 150            | 681             | 4                   | 6.7                 |
| Schizas et al. | 348 (X-ray 2.7 cGy/cm²)     | 312 (1.8)                    | 456            | 961             | 6.1                 | 8.2                 |
| Dhall et al. | 199                          | 237                          | 194            | 505             | 3                   | 5.5                 |
| Isaacs et al. | 300                          | 276                          | 226            | 1147            | 3.4                 | 5.1                 |

Table 3: Complications found in studies comparing open TLIF to MI-TLIF.

| Author       | Year | Open Complication type | MI Complication type | Complication rate |
|--------------|------|------------------------|----------------------|-------------------|
| Peng et al. [3] | 2009 | Atelectasis-(1)       | Infection-(1)        | 13.5% 6.9%        |
|              |      | UTI-(2)                |                      |                   |
|              |      | Infection-(1)         |                      |                   |
| Dhall et al. [4] | 2008 | Radiculitis (1)       | Transient L-5 sensory loss (2) | 2% 5% |
|              |      | Misplaced screw-(1)   | Misplaced screw (1)  |                   |
|              |      |                        | Cage migration (1)   |                   |
| Schizas et al. [5] | 2009 | Infection              | NR                  | Increased pseudarthrosis | 2% 6% |
|              |      | Fluid shift/blood transfusion complications |                      |
|              |      | Positioning-related neuropraxia of the upper extremity |                      |
| Isaacs et al. [6] | 2005 | Infection              | Transient leukopenia (1) | 6% 0% |
|              |      | Fluid shift/blood transfusion complications |                      |
|              |      | Positioning-related neuropraxia of the upper extremity |                      |
| Wang et al. [7] | 2010 | Pedicle screw malposition (1) | Radiculopathy (2) | 4% 5% |
|              |      | Dural tears (2)        | Small dural tear (1) |                   |
| Villavicencio et al. [8] | 2010 | CSF leak               | Neurological deficit > 3 mos | 31.7% 31.6% |
|              |      |                        | Pedicle screw malposition with reoperation |                   |
| Shunwu et al. [9] | 2010 | Superficial wound infection (1) | Screw malposition (2) | 5% 6% |
|              |      | Deep wound infection (1)| Superficial wound infection (1) |                   |
|              |      | Deep venous thrombosis (1)| Ileus (1) |                   |

Table 4: Complication rate by TLIF approach.

| Complications                  | MI | Open |
|-------------------------------|----|------|
| Infection                     | 6.9% | 23.5% |
| UTI                           | 3.4% | 11.8% |
| Neurologic deficits           | 20.7% | 11.8% |
| Screw/Cage complications      | 44.8% | 11.8% |
| CSF leak                      | 10.3% | 5.9% |
| Blood transfusion/coagulation | 3.4% | 11.8% |
| Other                         | 10.5% | 23.4% |

report this data found that MI-TLIF had greater duration of radiation exposure for patients undergoing the procedure [3, 5, 7]. Due to the relative recent adoption of MI-TLIF use, the long-term effects of increased radiation exposure have not been evaluated. The development of 2D computer assisted fluoroscopy systems as well as the O-arm is a modern means to decrease this exposure risk. Further, careful attention to radiation safety in the operating room is critical.

4.2. Studies of Note. Following data collection and the literature review, it is clear that there is a paucity of data comparing MI-TLIF and open TLIF. To our knowledge, there remains no high-class studies that directly compare these two techniques. However, smaller studies, both prospective and retrospective in nature, have shown promise in regards to novel MI techniques for TLIF.

Scheufler et al. compared percutaneous transforaminal lumbar interbody fixation (pTLIF) with mini-open transforaminal lumbar interbody fixation (oTLIF) while utilizing the Wiltse method [10]. They found at 8 month and 16 month follow-up, overall clinical outcome did not differ between the two techniques. However, in terms of pain following the operation, pTLIF resulted in significantly lower...
levels of pain ($P < 0.01$). Though the study showed no decreased advantages due to the percutaneous approach, a longer prospective study would be needed to further discern the success and functionality of each multilevel fusion.

In a study examining 42 patients with mean follow-up time of 29 months, Dhall et al. compared mini-open and open TLIF [4]. The authors found that mean estimated blood loss for mini-open (194 mL) was significantly lower ($P < 0.01$) than the open-group (505 mL). The length of stay was decreased for mini-open patients by on average, 2.5 days ($P < 0.01$). However, there were complications of neurologic nature in 2 patients, while 2 other patients required further revision. All 42 patients displayed fusion, and the authors felt that the mini-open technique was a possible substitute to open TLIF.

Schwender et al. performed one of the earlier studies (2001-2002) on 49 patients who had MI-TLIF. Majority of patients in the study either had degenerative disc disease with herniated nucleus pulposus (HNP) or spondylolisthesis [14]. 45 of 49 cases were completed at the L4-L5 or L5-S1 levels. Mean operative times were approximately 240 minutes, approximate blood loss was 140 mL, and hospital stays averaged 1.9 days. Complications were limited to four patients, two of which required screw repositioning while two others developed radiculopathy following the procedure. VAS changed on average from 7.2 to 2.1 while ODI changed from preoperative assessment to final follow-up. Ultimately, all patients in the study had fusion on follow-up imaging. The author believed that MI-TLIF is at least equivalent if not a marked improvement over its open counterpart.

A variation of the accepted microendoscopic discectomy was completed by Isaacs and colleagues, which was termed METLIF [6]. METLIF was completed on 20 patients who had lumbar spondylolisthesis or mechanical back pain. This unique procedure compared favorably to patients who underwent PLIF at the same institutions. METLIF resulted in less blood loss, shorter hospital stays, and decreased postoperative narcotic administration. There were no associated procedural complications associated with the multicenter study. Ultimately, this new variation showed promise.

Schizas et al. examined their institutional experience executing both MITLIF and open midline transforaminal lumbar interbody fusion [5]. Their 36 patient cohort had isthmic spondylolisthesis or DDD which indicated for TLIF. The study found that length of surgery, postoperative pain, analgesia requirements, and VAS/ODI scores were not significantly different between the MI and open procedures. However, they did find that the MI-TLIF did result in significantly less blood loss and a shorter hospital stay. Complications found in the MI-TLIF group, three pseudarthrosis, may have likely been due to the surgeon's gradual adjustment to the novel instrumentation and visualization techniques associated (Table 5).

## 5. Discussion

Lumbar arthrodesis is an effective method for treating spinal pathology such as spondylolisthesis, DDD, and spinal instability. As minimally invasive spine procedures have emerged, variants such as minimally invasive discectomy and minimally invasive cervical foraminotomies have allowed for reduced complications related to tissue trauma, while reducing blood loss and shortening recovery time [4, 8, 19, 20]. However, no procedure comes without inherent risks. Due to MI-TLIF being a novel procedure for some surgeons, it takes increasingly longer for them to become effective in carrying it out. Villavicencio et al. compared safety and effectiveness of MI-TLIF and open TLIF, showing similar long-term outcomes over the course of the 37.5-month follow-up period [8]. Assigning 63 patients to the open arm and 76 patients to the minimally invasive arm of the study, the authors matched by prior lumbar surgery, diagnosis, and levels at which fusion was performed. They found significant improvement in mean estimated blood loss ($P < .0001$) for MI (163.0 mL) versus the open TLIF (366.8 mL). The study found improvements ($P = 0.02$) in mean duration of
hospitalization in MI-TLIF (3 days) relative to their open counterparts (4.2 days). In addition, rates of neurological deficit were significantly higher ($P = 0.02$) in the minimally invasive arm of the study (10.2%) compared to the open cohort (1.6%). Operative times, mean change in VAS scores, patient satisfaction, all significantly favored the open TLIF procedure. The authors hypothesized that the neurological deficits and other factors in favor of open TLIF could have occurred as a result of the surgical learning curve.

Once the procedure is mastered, its application can positively impact patient care in numerous ways. But, the fundamental advantage of MI-TLIF comes from its decrease in tissue trauma and overall exposure of the patient. This can reduce infection, blood loss, and time to recovery. A prospective cohort study was carried out by Shunwu et al. with 62 patients that had undergone single level TLIF by a single surgeon in a single hospital [9]. One cohort of 32 patients underwent MI-TLIF with the tubular retractor system, while the remaining patients underwent open TLIF. Serum creatine kinase levels, a measure of soft-tissue trauma, was measured on the third postoperative day. Also, time to ambulation and number of transfusions were also measured in the study. Shunwu and colleagues found that MI-TLIF resulted in significantly lower serum creatine kinase levels were found, while patients needed less transfusions and were able to walk earlier than their open counterparts. When comparing the two approaches, this study displayed that MI-TLIF still proposes significant quantifiable benefit in terms of decreased soft tissue trauma.

As a minimally invasive procedure, MI-TLIF can be utilized to treat particular pathologies, while maintaining the same high levels of clinical success as the open TLIF, even with over two years of follow-up. Thus, the long-term results are comparable to that of open TLIF. Park and Foley contributed an article to the literature that described MI-TLIF in 40 consecutive patients who were diagnosed with spondylolisthesis [16]. Their percutaneous approach resulted in reduction of spondylolisthesis in all cases, with an average reduction of spondylolisthesis in all cases, with an average reduction in forward translation was 76%. This was yet another proof of MI-TLIF being a possible replacement to open TLIF in patients with degenerative or isthmic spondylolisthesis. In a prospective study that contrasted clinical and imaging outcomes for MI-TLIF and open TLIF procedures, Peng et al. found that MI-TLIF had equivalent long-term outcomes with open TLIF [3]. The patient cohort had 29 patients in each arm of the study, and 48 of 58 patients were women. The study examined, fluoroscopic times and found that MI-TLIF had significantly ($P < 0.05$) longer (105.5 seconds) compared to open (35.2 seconds). Thus, it is clear that the MI-TLIF cases ran significantly longer overall. Then, the authors discussed the significantly less blood loss, less morphine, and short hospitalization utilized for patients in the MI-TLIF cohort. Yet, open TLIF and MI-TLIF both were very similar in providing significant benefit to patients when rated by ODI, NASS, and VAS, all at follow-ups of six months and two years. In addition, there was no significant difference between open and MI-TLIF in terms of fusion rates, both which were approximately 80%. Peng and colleagues presented data that was supportive of MI-TLIF in terms of pain, hospitalization, and recovery, while at the same time retaining the high-fusion rate associated with open TLIF at two year follow-up.

Aside from particular pathologies that would benefit from MI-TLIF, there are certain populations that could benefit from the decreased tissue disruption and decreased blood loss. In elderly patients, Lee et al. completed a retrospective review of 27 consecutive cases and found a low complication rate and beneficial outcomes for patients over the age of 65 [12]. The average age of patients in the study was approximately 70 years, and each underwent a mini-open TLIF. They were then followed up for three years, displaying fusion rates of nearly 80%, similar to that seen in other studies. However, 44% of patients displayed adjacent segment degeneration, which was statistically significant in terms of its relation to sacral tilt following the procedure ($P = 0.006$). Two patients experienced minor complications in the perioperative period, one being a drug eruption and the other a urinary tract infection. Overall, the authors strongly felt that mini-open TLIF is a low-risk, beneficial option for the elderly.

6. Conclusion

Though the studies presented displayed heterogeneous patient populations with different indications for lumbar arthrodesis, there were many patterns seen across studies. Aside from possible complications such as screw displacement and neurological deficit, which were often related to a steep learning curve, MI-TLIF displayed no significant disadvantages when compared to open TLIF or other standard lumbar fusion techniques. The risks of blood loss, narcotic administration, pseudorthrosis, and infection all are equivalent if not decreased when utilizing MI-TLIF as a possible technique. Various postoperative recovery and pain rating scales often showed consistent improvement across many of the studies presented herein. MI-TLIF and open TLIF are quite similar in absolute indications and often present with similar complications, thus a randomized clinical trial would be beneficial in further elucidating the risks and benefits associated with each. As other variations emerge for MI-TLIF, such as METLIF, there is still need for an overall meta-analysis of all available data, comparing minimally invasive technique to traditional, open procedures.

**Abbreviations**

PLIF: Posterior lumbar interbody fusion  
ALIF: Anterior lumbar interbody fusion  
TLIF: Transforaminal lumbar interbody fusion  
MI-TLIF: Minimally invasive transforaminal lumbar interbody fusion  
DDD: Degenerative disc disease  
LOS: Length of stay  
VAS: Visual analog scale  
ODI: Oswestry Disability Index.
Conflict of Interests

There is no conflict of interests or funding source for this paper or the data contained within it.

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