

## Clinical and radiographic outcomes after minimally invasive transforaminal lumbar interbody fusion

Arnold B. Etame, MD, Anthony C. Wang, MD, Khoi D. Than, MD, Paul Park, MD \*

*Department of Neurosurgery, University of Michigan Health System, Ann Arbor, MI*

### Abstract

**Objective:** To evaluate outcomes after minimally invasive transforaminal lumbar interbody fusion (MI-TLIF).

**Background:** MI-TLIF is a relatively novel technique for treating symptomatic spondylolisthesis and degenerative disc disease of the lumbar spine. It has become a popular option for lumbar arthrodesis largely because of its potential to minimize iatrogenic trauma to the soft tissue, paraspinous muscles as well as to neural elements.

**Methods:** Literature search using PubMed database.

**Results:** Eight retrospective clinical studies and 1 prospective clinical study were identified. No randomized studies were found. The indications for surgery were low-back pain and/or radicular symptoms secondary to spondylolisthesis and/or degenerative disc disease. Analysis of radiographic outcomes demonstrated a fusion rate greater than 90% in the vast majority of patients. Patients also experienced a significant improvement in functional outcome parameters at a mean follow-up of 20 months. Comparison of functional outcomes of MI-TLIF patients to a similar matched cohort of patients who underwent conventional open TLIF did not demonstrate any statistically significant difference between both cohorts.

**Conclusion:** For carefully selected patients, MI-TLIF has a very favorable long term outcome that is comparable to conventional open TLIF, with the added benefit of decreased adjacent tissue injury.

© 2010 SAS - The International Society for the Advancement of Spine Surgery. Published by Elsevier Inc. All rights reserved.

*Keywords:* Minimally invasive spine; Transforaminal lumbar interbody fusion; Outcomes; TLIF

Transforaminal lumbar interbody fusion (TLIF) is relatively novel technique for lumbar interbody fusion. The prototypical posterior lumbar interbody fusion (PLIF) was originally described by Cloward.<sup>1</sup> A limitation of the PLIF procedure was its medialized approach, which required bilateral exposure as well significant retraction of the nerves. PLIF would, therefore, be prohibitive in the upper lumbar segments because of the risks to the conus from increased retraction.<sup>2</sup> It is against this background that TLIF was subsequently introduced by Harms and Rolinger,<sup>3</sup> and has now been widely adopted as a more lateralized unilateral approach relative to PLIF.<sup>3–7</sup>

The potential peri- and postoperative morbidities associated with conventional lumbar fusion surgery served as an impetus for the development of minimally invasive fusion techniques of the lumbar spine. The extensive dissection

and trauma to soft tissue and paraspinous muscles that occurs with conventional lumbar fusion were deemed to be significant confounders to patient outcome.<sup>8–14</sup> Minimally invasive approaches were, therefore, designed to prevent iatrogenic trauma by employing muscle-splitting techniques using specially designed dilators. As a consequence, benefits such as decreased intraoperative blood loss and shorter hospital durations have been reported.<sup>15–17</sup>

Minimally invasive transforaminal lumbar interbody fusion (MI-TLIF) is a relatively novel paramedian muscle-splitting technique for arthrodesis via a unilateral approach in patients with mechanical back secondary to degenerative disc disease (DDD) and spondylolisthesis. The potential benefits are decreased iatrogenic soft tissue and muscle damage. It is hypothesized that such benefits would translate to better clinical outcomes. As MI-TLIF is becoming a very popular method of arthrodesis, stratified long term clinical and radiographic outcome data are necessary. The purpose of this literature review is to determine long term functional and radiographic outcomes in patients who underwent MI-TLIF.

\* Corresponding author: Paul Park, MD, Department of Neurosurgery, University of Michigan Health System, 1500 E. Medical Center Drive, Room 3552 Taubman Center, Ann Arbor, MI 48109-5338.

E-mail address: [ppark@umich.edu](mailto:ppark@umich.edu)

Table 1  
Demographics of patients in clinical series undergoing minimally invasive transforaminal lumbar interbody fusion

Reference	Number of patients in study	Mean age in years (range)	Male/Female	Mean number of follow-up months	Study type
Peng et al, 2009 <sup>18</sup>	29	54 (26-74)	5/24	24	Prospective
Schizas et al, 2009 <sup>26</sup>	18	45.5 (NA)	NA	22	Retrospective
Dhall et al, 2008 <sup>25</sup>	21	53 (NA)	NA	24	Retrospective
Park et al, 2008 <sup>19</sup>	40	56 (38-71)	19/21	35	Retrospective
Scheufler et al, 2007 <sup>20</sup>	53	57 (NA)	24/29	16	Retrospective
Beringer et al, 2006 <sup>24</sup>	8	49 (35-63)	NA	9	Retrospective
Deutsch et al, 2006 <sup>21</sup>	20	49 (33-55)	12/8	6	Retrospective
Jang et al, 2005 <sup>22</sup>	23	60 (48-68)	8/15	19	Retrospective
Schwender et al, 2005 <sup>15</sup>	49	NA (23-80)	19/30	23	Retrospective

Abbreviation: NA, not available.

## Methods

A comprehensive literature search was performed using PubMed for all journal articles published until August of 2009. Keywords employed in the search included “transforaminal lumbar interbody fusion,” “minimally invasive,” and “lumbar fusion,” and were searched individually or in combination. Based on the initial list of publications, we reviewed the bibliography of each article to identify further pertinent studies. The appropriate articles for our study were subsequently selected based on several criteria. Only studies that specifically addressed minimally invasive transforaminal lumbar interbody fusion were selected. Furthermore, articles without patient outcome data and at least 3 months of postoperative follow-up were excluded, as were case reports.

A total of 133 citations including case reports, clinical case series, and technical notes were found using the keyphrase “transforaminal lumbar interbody fusion.” There were no randomized studies found. Of these articles, 38 were associated with the descriptor “minimally invasive.” Pertinent long term patient outcome data were only reported in 9 articles. Given that our primary objective was to evaluate long term outcomes in patients undergoing MI-TLIF, we, therefore, incorporated only those 9 articles in our study.

## Results

### Patient characteristics

The 9 clinical series encompassed a total of 261 patients who were treated by MI-TLIF. The demographic data are illustrated in Table 1. The mean age at the time of operation was provided in all but 1 of the studies.<sup>15</sup> Based on 8 of the 9 studies, the mean age was 53. Gender frequency information, which was reported in 6<sup>15,18–22</sup> of the series, demonstrated a female predominance with 117 females relative to 87 males. The minimum follow-up was 6 months, with a combined mean of approximately 20 months. There were 8 retrospective studies and 1 prospective study.

### Patient selection

Selection criteria for patients undergoing MI-TLIF were quite similar to those undergoing open conventional TLIF with a few exceptions. Traditionally, open conventional TLIF has been used to treat mechanical axial lumbar pain as well as associated radiculopathy secondary to DDD and spondylolisthesis. MI-TLIF was utilized in similar indications except for patients with very high-grade spondylolisthesis, where open conventional TLIF is preferred because of the technical challenges.<sup>23</sup> MI-TLIF was also favored in recurrent disease herniations, as well as selected lumbar revision operations, as the surgical trajectory is lateral to the previous operative scar tissue plane. In terms of imaging, patients were evaluated with a combination of diagnostic modalities such as static and dynamic lumbar plain films, lumbar MRI, and/or CT myelogram.

Patient selection criteria, as well as preoperative assessment, were provided for each of the clinical series. Exclusion criteria were provided for some of the studies.<sup>18,22</sup> Beringer and Mobasser<sup>24</sup> evaluated 8 patients who had a combination of axial lumbar pain and radiculopathy from DDD and recurrent disc herniations. There were no spondylolisthesis patients in this series. With respect to DDD, the patients had to fail 9 months of conservative treatment in conjunction with demonstration of concordant pain on provocative discography in order to be considered surgical candidates. Deutsch and Musacchio<sup>21</sup> applied a similar selection criterion in their series of 20 patients with respect to diagnosis and failure of conservative management; however, discography was never employed as a basis for patient selection. Peng et al<sup>18</sup> selected 29 patients with axial lumbar pain and radiculopathy, secondary to DDD and spondylolisthesis, who had failed conservative management for a minimum of 6 weeks. In addition, they excluded patients who had significantly collapsed disc space, no movement on dynamic lumbar plain films, or those with a significant amount of scarring at the neural foramen. Scheufler et al<sup>20</sup> evaluated 53 patients of whom 19 had DDD and 34 had Grade 1 degenerative spondylolisthesis. MI-TLIF was only offered to patients with symptomatic advanced DDD and

Grade 1 degenerative spondylolisthesis, and who had failed at least 3 months of conservative management. Dhall et al<sup>25</sup> selected 7 patients with DDD and 14 patients with degenerative spondylolisthesis for their MI-TLIF series. Exclusion criteria were not defined. The Schwender et al<sup>15</sup> series of 49 patients included 26 with DDD, 22 with degenerative spondylolisthesis, and 1 with a chance fracture. Jang and Lee<sup>22</sup> focused on 23 patients with unstable Grade 1 degenerative spondylolisthesis, as evident by movement on dynamic lumbar radiographs. Patients with kyphotic deformities, as well as higher-grade spondylolisthesis, were excluded from MI-TLIF. Similarly, degenerative spondylolisthesis was the index diagnosis in 75% of the patients in the Park and Foley<sup>19</sup> series. Ten percent had isthmic spondylolisthesis. Schizas et al,<sup>26</sup> however, performed MI-TLIF predominantly on patients with symptomatic isthmic spondylolisthesis who had failed conservative modalities, which accounted for approximately 83% of the 18 patients in the MI-TLIF group.

### Surgical technique

The hallmark of minimally invasive lumbar fusion techniques is the relative preservation of the posterior paraspinous musculature via a paramedian muscle-splitting approach. The MI-TLIF technique has been well-described in the past.<sup>16,17,27–29</sup> Typically, following induction of general anesthesia, patients are positioned prone on a radiolucent table. Using fluoroscopic guidance, an incision measuring 2.5–3 cm is made 4–5 cm lateral to the midline on the side where the patient's radiculopathy is worst. The incision is centered on the interspace of interest. Muscle splitting can be attained using serial dilators over a guidewire, as was the case for 8 of the series.<sup>15,18–22,24,26</sup> Alternatively, blunt dissection can be carried out in Wiltse's plane, which lies between the longissimus and multifidus muscles, followed by progressive dilation of the dissected plane. The latter has been termed the mini-open approach,<sup>30</sup> and was the method employed by Dhall et al.<sup>25</sup> Tubular retractors are then docked over the facet complex. Using loupe magnification or the operating microscope, a total facetectomy as well as a hemilaminectomy are carried out. The traversing nerve root is protected with its associated ligamentum flavum, while the superior exiting nerve root is protected with a cotton patty. With the disc space now in view, the disc is sharply incised and a discectomy is undertaken. Distraction of the disc is accomplished using sequential interspace distractors. Disc space distraction can be maintained using contralateral pedicle screw and rod constructs. The disc space is then filled with a combination of autograft as well as a structural allograft, with bone morphogenetic protein (BMP) to promote fusion depending on the surgeon's preferences. The ipsilateral minimally invasive pedicle screw-rod construct is then inserted with fluoroscopic guidance.

In general, all reviewed studies reported a similar surgical technique with a few exceptions. While most of the studies<sup>15,18–20,25,26</sup> employed bilateral transpedicular fixa-

Table 2

Postsurgical radiographic outcome data for patients undergoing minimally invasive transforaminal lumbar interbody fusion

Reference	Number of patients in study	Arthrodesis rate	Graft subsidence
Peng et al, 2009 <sup>18</sup>	29	*Grade 1: 80% *Grade 2: 20%	0%
Schizas et al, 2009 <sup>26</sup>	18	83%	5.6%
Dhall et al, 2008 <sup>25</sup>	21	95%	5%
Park et al, 2008 <sup>19</sup>	40	100%	0%
Scheufler et al, 2007 <sup>20</sup>	53	94%	0%
Beringer et al, 2006 <sup>24</sup>	8	100%	0%
Deutsch et al, 2006 <sup>21</sup>	20	65%	0%
Jang et al, 2005 <sup>22</sup>	23	95%	13%
Schwender et al, 2005 <sup>15</sup>	49	100%	0%

\* Bridwell anterior fusion grading system: Grade 1 – evidence of fusion with remodeling and trabeculae present; Grade 2 – evidence of intact graft with incomplete remodeling or incorporation, and without lucency; Grade 3 – evidence of intact graft with lucency both above and below the graft; Grade 4 – evidence of collapsed or resorbed graft and absence of fusion.

tion, unilateral pedicle screws were used in 2 studies.<sup>21,24</sup> Jang and Lee<sup>22</sup> performed ipsilateral pedicle screw as well as a contralateral facet screw.

### Radiographic outcome

The radiographic outcome was ascertained through demonstration of bone formation across the target segment. In situations where surgery was performed for spondylolisthesis, the extent of correction of listhesis was reviewed. Patients were typically evaluated with plain radiographs and/or lumbar CT scans, based on the surgeon's preference. The radiographic outcome data from the selected series are illustrated in Table 2.

Beringer and Mobasser<sup>24</sup> assessed long term radiographic outcome at 6 months in 8 nonspondylolisthesis patients who had undergone MI-TLIF with BMP. Using thin-cut lumbar CT scans, complete fusion was demonstrated in all patients. There were no hardware failures.

Jang and Lee<sup>22</sup> evaluated 23 patients with degenerative spondylolisthesis using static and dynamic plain lumbar radiographs at 1, 3, 6, 12, and 24 months after MI-TLIF. Twenty-two patients underwent a single-level TLIF while 1 patient had a 2-level TLIF, accounting for a total of 24 fusion sites. Incorporation of BMP during the procedure could not be ascertained from their report; however, complete fusion was noted in 22 of 24 fusion sites, accounting for a 95% arthrodesis rate. Subsidence of interbody graft was noted in 3 cases, accounting for 13%, 1 of which was associated with a pedicle screw fracture.

Dhall et al<sup>25</sup> evaluated radiographic outcomes in their series of 21 patients who underwent MI-TLIF using static and dynamic lumbar radiographs as the primary modality, or lumbar CT in cases where the radiograph was equivocal. There was a single incidence of interbody cage migration that eventually required surgical revision. Another patient developed symptomatic pseudoarthrosis for which an ante-

rior lumbar fusion was performed. The patient in question had received local autograft without BMP during surgery. Complete fusion was otherwise realized in the rest of the patients in this series, accounting for a 95% arthrodesis rate.

Peng et al<sup>18</sup> examined 29 patients who underwent MI-TLIF with allograft, autograft, but without BMP at 2 years post-surgery. Fusion was assessed by using the Bridwell anterior fusion grading system. This classification system entails 4 grades: Grade 1 – evidence of fusion with remodeling and trabeculae present; Grade 2 – evidence of intact graft with incomplete remodeling or incorporation, and without lucency; Grade 3 – evidence of intact graft with lucency both above and below the graft; Grade 4 – evidence of collapsed or resorbed graft and absence of fusion. Employing the above scheme, 80% of the patients attained a Grade 1 fusion, while the remaining 20% were Grade 2. There were no Grade 3 or 4 fusions.

Schizas et al<sup>26</sup> evaluated by plain radiographs or CT scan 18 patients' status post-MI-TLIF, most of whom had isthmic spondylolisthesis. There were 3 cases of nonunion initially seen on radiographs and subsequently confirmed by CT, accounting for a 95% arthrodesis rate. Two of the above cases were associated with loosening of pedicle screws at 1 year follow-up, while the other was associated with screw breakage at 3 years post surgery. Only 2 of these patients underwent revision surgery that confirmed the radiographic findings, in addition to a loose interbody cage in one of the patients.

Park and Foley<sup>19</sup> assessed radiographic outcome in 40 patients with spondylolisthesis who underwent MI-TLIF. All patients underwent lumbar CT scans at 2 years post surgery. Fusion, as defined by bone-bridging, was established in all patients. They also reported a 76% mean translation reduction of spondylolisthesis.

Schwender et al<sup>15</sup> evaluated 49 patients whom they had treated with MI-TLIF for evidence of radiographic fusion at minimum follow-up of 18 months. Using the criteria of trabecular bone-bridging, they noted solid fusion in all patients. There was no compromise of hardware.

Deustch and Musacchio<sup>21</sup> evaluated 20 patients at 3 and 6 months post surgery with lumbar CT scans. All patients received local autograft with BMP at the time of fusion. At 6 months, fusion could only be established on 13 patients, accounting for a fusion rate of only 65%.

Scheufler et al<sup>20</sup> performed MI-TLIF on 53 patients, 46 of whom were assessed at 16 months after surgery fusion. Solid fusion as evident by trabecular bone-bridging was observed in 43 patients accounting for a 94% fusion rate. Restoration of segmental lordosis and disc height to at least 10 mm was reported for all cases. They did not observe any evidence of hardware failure in the course of the study.

### *Functional outcome*

Several questionnaire devices have been developed and employed in assessing functional outcome in patients who have undergone lumbar surgery. The most commonly used

devices are the Visual Analogue Scale (VAS) and Oswestry Disability Index (ODI). The VAS assesses pain using a colored gradient and graduated line on a 10-point scale. Lower scores correspond to improved pain. The ODI provides a measure of the patient's long term disability and is considered the gold standard for such an assessment.<sup>31,32</sup> It is based on a 100-point system where lower scores correspond to improved outcome. The modified Prolo score is another useful scale for assessing outcomes, as it takes into account the impact of pain, functional status, economic status, and medications. Other methods of assessment used in some of the clinical case series included the Roland-Morris scale, Numeric Rating Score (NRS), North American Spine Society (NASS) score, American Academy of Orthopedic Surgeons (AAOS) standardized questionnaires, and SF-36 forms. The functional outcome data from the selected series are illustrated in Table 3.

Berringer and Mobasser<sup>24</sup> assessed long term outcome using a modified Prolo score preoperatively and postoperatively at 6 months. They noted a significant improvement in the mean modified Prolo score from 11 preoperatively to 18 at 6 months. Furthermore, there was reported improvement in axial lumbar pain in all patients. Resolution of preoperative radiculopathy was noted in 7 of 8 patients. Dhall et al<sup>25</sup> also employed the modified Prolo score in assessing outcomes in 12 patients who underwent MI-TLIF. There was an improvement in mean scores from 11 preoperatively to 19 postoperatively. They also compared this patient cohort to a matched cohort that had undergone open conventional TLIF. They noted no significant statistical difference in outcomes between both cohorts.

Jang and Lee<sup>22</sup> used NRS as well as ODI scores to evaluate outcomes in their series of 23 patients with degenerative spondylolisthesis. Based on NRS data, there was a significant improvement in back and leg pain. The mean NRS score decreased from 7.5 to 2.3 for back pain and from 7.4 to 0.7 for leg pain. ODI data were significant for a reduction from 33.1 to 7.6, suggesting a functional improvement following surgical intervention.

Peng et al<sup>18</sup> assessed outcome in 29 patients who underwent MI-TLIF, using several tools including VAS, NASS, ODI, and SF-36 forms at 2 years follow-up. They reported significant functional improvement in all assessment modalities. The VAS for leg pain improved from 7 preoperatively to 1. Similarly, there was an improvement in the VAS for back pain from 6.5 to 1 within the same time period. The NASS for neurogenic symptoms improved from 3.6 to 1.2 while the NASS for back pain similarly improved from 3.2 to 1.5. The ODI equally showed a significant improvement from 45.2 preoperatively to 16.2 at 2 years follow-up. Significant improvements in SF-36 parameters were noted at 2 years of follow-up as well. They also compared this patient cohort to a matched cohort that had undergone open conventional TLIF. They noted no significant statistical difference in outcomes between both cohorts.



Table 3

Postsurgical functional outcome data for patients undergoing minimally invasive transforaminal lumbar interbody fusion.

Reference	Number of patients in study	Functional outcome data
Peng et al, 2009 <sup>18</sup>	29	Leg pain VAS improved from 7 to 1 Back pain VAS improved 6.5 to 1 NASS for neurogenic symptoms improved from 3.6 to 1.2 NASS for back pain improved from 3.2 to 1.5 ODI improvement from 45.2 preoperatively to 16.2 at 2 Significant improvements in SF-36 parameters
Schizas et al, 2009 <sup>26</sup>	18	VAS improved from 7.7 to 3.5 ODI improved from 55 to 33
Dhall et al, 2008 <sup>25</sup>	21	Modified Prolo score improved from 11 to 19
Park et al, 2008 <sup>19</sup>	40	Leg pain VAS improved from 65 to 8 Back pain VAS improved from 52 to 15 ODI improved from 55 to 16
Scheufler et al, 2007 <sup>20</sup>	53	VAS improved from 5 to 1.5 Roland-Morris scores improved from 18 to 4 at 8 mos, and to 3 at 16 mos AAOS neuro score improved from 33 to 15 at 8 mos, then to 12 at 16 mos AAOS physical health and pain score improved from 65 to 22 at 8 mos, then to 18 at 16 months AAOS pain disability score improved from 80 to 40 at 8 mos, then to 25 at 16 mos
Beringer et al, 2006 <sup>24</sup>	8	Modified Prolo score improved from 11 to 18
Deutsch et al, 2006 <sup>21</sup>	20	VAS improved from 8.3 to 1.4 ODI improved from 57 to 18
Jang et al, 2005 <sup>22</sup>	23	Mean NRS score improved from 7.5 to 2.3 for back pain Mean NRS score improved from 7.4 to 0.7 for leg pain ODI improved 33.1 to 7.6
Schwender et al, 2005 <sup>15</sup>	49	VAS improved from 7.2 to 2.1, while the ODI improved from 46 to 14

Abbreviations: AAOS, American Academy of Orthopedic Surgeons; NASS, North American Spine Society; NRS, Numeric Rating Score; ODI, Oswestry Disability Index; VAS, Visual Analog Scale.

Schizas et al<sup>26</sup> evaluated functional outcomes in 18 patients status post-MI-TLIF, most of whom had isthmic spondylolisthesis using the VAS and ODI. The average follow-up was 22 months. The preoperative VAS improved from 7.7 to 3.5, while the ODI improved from 55 to 33. They also compared this patient cohort to a matched cohort that had undergone open conventional TLIF. They noted no significant statistical difference in outcomes between both cohorts. Using a similar tool, Park and Foley<sup>19</sup> assessed functional outcomes in their series of 40 patients who underwent MI-TLIF for spondylolisthesis, using the VAS and ODI. The mean follow-up was 35 months. They reported a significant improvement in the VAS and ODI. The mean VAS for leg pain improved from 65 to 8, while the VAS for back pain improved from 52 to 15. The ODI similarly improved from 55 to 16, which correspond, to an improvement from moderate to minimal disability. Similarly, Schwender et al<sup>15</sup> also employed the VAS and ODI in assessing functional outcomes in 49 patients who underwent MI-TLIF. Significant improvements in VAS as well as ODI were noted at 2 years follow-up. The VAS improved from 7.2 to 2.1, while the ODI improved from 46 to 14. Deustch and Musacchio<sup>21</sup> examined 20 patients following MI-TLIF using the VAS and ODI. They reported improved results in 85% of the patients. Within this subset of patients, the VAS improved from 8.3 to 1.4, while the ODI improved from 57 to 18.

Scheufler et al<sup>20</sup> used the AAOS lumbar spine follow-up questionnaire as well as the Roland-Morris low-back pain

score in their assessment of long term functional outcomes at 8 and 16 months in patients who underwent MI-TLIF. The VAS was only employed in the within the first operative week, which demonstrated a mean improvement from 5 to 1.5 during that time frame. With respect to the Roland-Morris and AAOS assessments, there was significant improvement in all modalities corresponding to intermediate success. The Roland-Morris scores improved from a preoperative score of 18 to 4 at 8 months and to 3 at 16 months. The AAOS neurological score improved from a preoperative score of 33 to 15 at 8 months and to 12 at 16 months. The AAOS physical health and pain score improved from a preoperative score of 65 to 22 at 8 months and to 18 at 16 months. The AAOS pain disability score improved from a preoperative score of 80 to 40 at 8 months and to 25 at 16 months. When this cohort was compared to historical cohort of 67 patients who underwent mini-open TLIF, the results were similar between the MI-TLIF and mini-open groups, suggesting equivalent outcomes.

## Discussion

The MI-TLIF procedure has gained popularity as an option for lumbar arthrodesis. The potential for decreased adjacent tissue injury, blood loss, and postoperative pain are attractive features when compared to conventional open TLIF. However, the long term outcomes of MI-TLIF have not been extensively studied. We, therefore, focused on 9

clinical studies,<sup>15,18–22,24–26</sup> each evaluating long term radiographic and functional outcomes in patients who underwent MI-TLIF.

The overall clinical indications for MI-TLIF are similar to conventional open TLIF. The general consensus from the reviewed studies was that surgery was clinically indicated for mechanical back pain and radicular symptoms. Radiographically, patients presented with spondylolisthesis – degenerative and isthmic, and DDD. For spondylolisthesis, MI-TLIF was only considered in patients with a lower Meyerding grade. For higher grade patients, conventional open TLIF was advocated to facilitate reduction. In all cases, surgery was the treatment of last resort following failure of conservative measures.

Radiographic fusion rates were variable and ranged from 65% to 100% with most studies showing a rate at least greater than 90%. The patients in the series with the lowest arthrodesis rate of 65%<sup>21</sup> did receive BMP at the time of surgery. It is unclear why the arthrodesis rate was low. Because radiographic follow-up was relatively short at 6 months, it is possible that a higher fusion rate would be observed at longer follow-up. Graft subsidence was noted in 13% of patients in Jang and Lee's series,<sup>22</sup> 5.6% in the series by Schizas et al.,<sup>26</sup> and 5% of patients in the series by Dhall et al.<sup>25</sup> There was an associated compromise of pedicle screw constructs with graft subsidence in respective series by Jang and Lee<sup>22</sup> and Dhall et al.<sup>25</sup>

Long term functional outcome data were ascertained through various questionnaires. The VAS<sup>15,18–21,26</sup> and ODI<sup>15,18,19,21,22,26</sup> were the most frequently used assessment tools in the clinical studies. Other less frequently used tools included the modified Prolo score,<sup>24,25</sup> NRS,<sup>22</sup> NASS,<sup>18</sup> SF-36,<sup>18</sup> AAOS lumbar spine follow-up questionnaire,<sup>20</sup> and Roland-Morris low-back pain score.<sup>20</sup> Of all these measures, the ODI is considered the gold standard for long term functional outcome. In general, there was a significant improvement in functional parameters in the vast majority of patients at follow-up in all of the studies. This corresponded with marked improvement in radicular and axial lumbar symptoms. In addition, some of the authors<sup>18,20,25,26</sup> also compared their MI-TLIF to a similar cohort of patients who had undergone conventional open TLIF. There was no significant statistical difference between patients who underwent MI-TLIF and conventional TLIF, with respect to long term outcome. In particular, Peng et al.<sup>18</sup> had a well-designed prospective study that assessed multiple functional parameters (VAS, NASS, SF-36, and ODI) and compared MI-TLIF patients to those who underwent conventional open TLIF. Long-term outcomes appeared to be equivalent. It appears, therefore, that MI-TLIF provides a less invasive surgical modality with similar long term outcomes as the conventional open TLIF.

Although not included in this review due to difference in surgical technique, similar outcomes have also been reported with minimally invasive posterior lumbar interbody fusion (MI-PLIF). In a prospective study, Park and Ha<sup>33</sup> compared 32 patients who underwent MI-PLIF with 29

patients who underwent open PLIF. At 1 year minimum follow-up there were no significant differences in fusion rate or outcomes assessed by the Prolo score. The fusion rate was 96.9% with MI-PLIF and 96.6% with open PLIF, and the Prolo score reflecting good to excellent results were 90.7% with MI-PLIF and 89.6% with open PLIF. The MI-PLIF group, however, was noted to have statistically significantly less blood loss, earlier ambulation, shorter hospital stays, and decreased back pain measured by the VAS postoperatively and at 1 year follow-up. Conversely, increased surgical time and technical complications were noted in the MI-PLIF group.

## Conclusion

The best available data on long term outcomes in patients undergoing MI-TLIF comes from primarily retrospective clinical studies. In carefully selected patients, MI-TLIF is a very effective surgical option that has similar long term outcomes when compared to conventional open TLIF with the potential benefits of decreased adjacent tissue injury.

## References

1. Cloward RB. The treatment of ruptured lumbar intervertebral discs by vertebral body fusion. I. Indications, operative technique, after care. *J Neurosurg* 1953;10:154–68.
2. Humphreys SC, Hodges SD, Patwardhan AG, Eck JC, Murphy RB, Covington LA. Comparison of posterior and transforaminal approaches to lumbar interbody fusion. *Spine (Phila Pa 1976)* 2001;26:567–71.
3. 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;120:343–7.
4. Harms JG, Joeszszky D. [No title available; article in German]. *Oper Orthop Traumatol* 1998;10:90–102.
5. Lowe TG, Tahernia AD. Unilateral transforaminal posterior lumbar interbody fusion. *Clin Orthop Relat Res* 2002;394:64–72.
6. Moskowitz A. Transforaminal lumbar interbody fusion. *Orthop Clin North Am* 2002;33:359–66.
7. Rosenberg WS, Mummaneni PV. Transforaminal lumbar interbody fusion: technique, complications, and early results. *Neurosurgery* 2001;48:569–75.
8. Gejo R, Matsui H, Kawaguchi Y, Ishihara H, Tsuji H. Serial changes in trunk muscle performance after posterior lumbar surgery. *Spine (Phila Pa 1976)* 1999;24:1023–8.
9. Styf JR, Willen J. The effects of external compression by three different retractors on pressure in the erector spine muscles during and after posterior lumbar spine surgery in humans. *Spine (Phila Pa 1976)* 1998;23:354–8.
10. Kawaguchi Y, Matsui H, Tsuji H. Back muscle injury after posterior lumbar spine surgery. A histologic and enzymatic analysis. *Spine (Phila Pa 1976)* 1996;21:941–4.
11. Kawaguchi Y, Matsui H, Tsuji H. Back muscle injury after posterior lumbar spine surgery. Part 2: Histologic and histochemical analyses in humans. *Spine (Phila Pa 1976)* 1994;19:2598–602.
12. Rantanen J, Hurme M, Falck B, et al. The lumbar multifidus muscle five years after surgery for a lumbar intervertebral disc herniation. *Spine (Phila Pa 1976)* 1993;18:568–74.
13. Sihvonen T, Herno A, Paljarvi L, Airaksinen O, Partanen J, Tapani-naho A. Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. *Spine (Phila Pa 1976)* 1993;18:575–81.

14. Mayer TG, Kondraske G, Mooney V, Carmichael TW, Butsch R. Lumbar myoelectric spectral analysis for endurance assessment. A comparison of normals with deconditioned patients. *Spine (Phila Pa 1976)* 1989;14:986–91.
15. Schwender JD, Holly LT, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion (TLIF): technical feasibility and initial results. *J Spinal Disord Tech* 2005;18(Suppl):S1–6.
16. Foley KT, Holly LT, Schwender JD. Minimally invasive lumbar fusion. *Spine (Phila Pa 1976)* 2003;28(15 Suppl):S26–35.
17. Foley KT, Lefkowitz MA. Advances in minimally invasive spine surgery. *Clin Neurosurg* 2002;49:499–517.
18. Peng CW, Yue WM, Poh SY, Yeo W, Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. *Spine (Phila Pa 1976)* 2009;34:1385–9.
19. Park P, Foley KT. Minimally invasive transforaminal lumbar interbody fusion with reduction of spondylolisthesis: technique and outcomes after a minimum of 2 years' follow-up. *Neurosurg Focus* 2008;25:E16.
20. Scheufler KM, Dohmen H, Vougioukas VI. Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. *Neurosurgery* 2007;60(4 Suppl 2):203–13.
21. Deutsch H, Musacchio MJ Jr. Minimally invasive transforaminal lumbar interbody fusion with unilateral pedicle screw fixation. *Neurosurg Focus* 2006;20:E10.
22. Jang JS, Lee SH. Minimally invasive transforaminal lumbar interbody fusion with ipsilateral pedicle screw and contralateral facet screw fixation. *J Neurosurg Spine* 2005;3:218–23.
23. Holly LT, Schwender JD, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion: indications, technique, and complications. *Neurosurg Focus* 2006;20:E6.
24. Beringer WF, Mobasser JP. Unilateral pedicle screw instrumentation for minimally invasive transforaminal lumbar interbody fusion. *Neurosurg Focus* 2006;20:E4.
25. Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. *J Neurosurg Spine* 2008;9:560–5.
26. Schizas C, Tzinieris N, Tsiridis E, Kosmopoulos V. Minimally invasive versus open transforaminal lumbar interbody fusion: evaluating initial experience. *Int Orthop* 2009;33:1683–88.
27. Fessler RG. Minimally invasive percutaneous posterior lumbar interbody fusion. *Neurosurgery* 2003;52:1512.
28. Foley KT, Gupta SK. Percutaneous pedicle screw fixation of the lumbar spine: preliminary clinical results. *J Neurosurg* 2002;97(1 Suppl):7–12.
29. Foley KT, Gupta SK, Justis JR, Sherman MC. Percutaneous pedicle screw fixation of the lumbar spine. *Neurosurg Focus* 2001;10:E10.
30. Mummaneni PV, Rodts GE Jr. The mini-open transforaminal lumbar interbody fusion. *Neurosurgery* 2005;57(4 Suppl):256–61.
31. Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine (Phila Pa 1976)* 2000;25:2940–52.
32. Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. *Physiotherapy* 1980;66:271–3.
33. Park Y, Ha JW. Comparison of one-level posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach. *Spine (Phila Pa 1976)* 2007;32:537–43.