Meta Analysis

Comparison between Minimally Invasive Transforaminal Lumbar Interbody Fusion and Conventional Open Transforaminal Lumbar Interbody Fusion: An Updated Meta-analysis

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Abstract

Background: The previous studies agree that minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) has better function outcomes, less blood loss, and shorter hospital stay, when compared to open-TLIF. However, there are no significance differences on operative time, complication, and reoperation rate between the two procedures. This could be from less relative literatures and lower grade evidence. The further meta-analysis is needed with more and higher grade evidences to compare the above two TLIF procedures.

Methods: Prospective and retrospective studies that compared open-TLIF and MIS-TLIF were identified by searching the Medline, Embase, Web of Science, China National Knowledge Infrastructure, Wanfang, and VIP database (the literature search comprised Medical Subject Heading terms and key words or Emtree term). The retrieval time ranged from the date when the database was founded to January 2015. Pooled risk ratios (RRs) and weighted mean differences (WMDs) with 95% confidence intervals were calculated for the clinical outcomes and perioperative data.

Results: Twenty-four studies (n = 1967 patients) were included in this review (n = 951, open-TLIF, n = 1016, MIS-TLIF). MIS-TLIF was associated with a significant decrease in the visual analog score (VAS)-back pain score (WMD = −0.44; P = 0.001), Oswestry Disabilities Index (WMD = −1.57; P = 0.005), early ambulation (WMD = −1.77; P = 0.0001), less blood loss (WMD = −265.59; P < 0.00001), and a shorter hospital stay (WMD = −1.89; P < 0.0001). However, there were no significant differences in the fusion rate (RR = 0.99; P = 0.34), VAS-leg pain (WMD = −0.10; P = 0.26), complication rate (RR = 0.84; P = 0.35), operation time (WMD = −5.23; P = 0.82), or reoperation rate (RR = 0.73; P = 0.32).

Conclusions: MIS-TLIF resulted in a similar fusion rate with better functional outcome, less blood loss, shorter ambulation, and hospital stay; furthermore, it did not increase the complication or reoperation rate based on the existing evidence.

Key words: Clinical Outcomes; Meta-analysis; Minimally Invasive Surgery; Transforaminal Lumbar Interbody Fusion

Introduction

In 1943, the open bilateral posterior lumbar interbody fusion procedure was proposed by Cloward.¹ This technique not only enables nerve root decompression but also interbody fusion from a single posterior approach.² The clinical outcomes were satisfying. However, to further reduce the risk of neurological complications, transforaminal lumbar interbody fusion (TLIF), which achieves an interbody fusion through a unilateral posterior process, has obtained popularity.³ Since the introduction of TLIF by Harms and Rolinger, it has been used for treating multifarious lumbar

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degenerative disease.[4–7] TLIF results in higher rates of fusion compared with other interbody fusion approaches.[8] In 2003, Foley et al.[9] demonstrated that minimally invasive TLIF (MIS-TLIF) results in fewer muscle and tissue lesions compared with traditional open-TLIF; thus, this approach has a better outcome, although there are disadvantages.[10] Meta-analyses that have compared open-TLIF and MIS-TLIF have indicated that MIS-TLIF is associated with better functional outcomes, less blood loss, and a shorter hospital stay compared with open-TLIF. However, both of these procedures had no significant effect on the fusion rate, operation time, complications, or reoperation rate. Moreover, there were several limitations such as a lower evidence level and a lack of important data in some studies.[4–6] Thus, we aimed to determine whether MIS-TLIF and open-TLIF had a significant effect on the fusion and complication rate with the technical development of the minimally invasive approach and the inclusion of additional studies. The question arose as to whether an updated meta-analysis would provide additional information and a higher clinic reference value. Thus, we aimed to provide an updated review of the literature to compare these two methods.

**Methods**

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses.[10] The inclusion criteria were as follows: (1) English and Chinese literature; (2) the study design was a comparative article (MIS-TLIF versus open-TLIF); (3) the article reported at least one clinic outcome or perioperative data; (4) the patients suffered from degenerative disc diseases (disc herniation, canal stenosis, or spondylolisthesis); isthmic spondylolisthesis was also included; (5) the sample size comprised at least ten patients for both groups; and (6) the full text was available. Reduplicated studies, case reports, cadaveric or biomechanical studies, non-English/Chinese articles, and patients treated via MIS-TLIF or open-TLIF for other diseases were excluded.

**Data extraction**

We obtained data from the included studies in the following categories: (1) authors and year of publication; (2) study design; (3) class of evidence; (4) total number of enrolled patients and number per group (MIS-TLIF and open-TLIF); (5) mean follow-up time; (6) follow-up time and rate (%); (7) mean age; (8) percentage of male and female patients; (9) diagnosis (divided into three categories: degenerative disc disease, spondylolisthesis, and others); (10) inclusion/exclusion criteria; (11) clinical outcomes; (12) perioperative data; (13) fusion definition and evaluation measure; (14) number of lumbar segments treated; (15) level of fusion (divided into L4–L5, L5–S1, and others); (16) use of grafts and types; (17) use of cages and types; (18) use of screw fixation and means; and (19) number of complications. We did not define complications in advance. Rather, the overall complications were collected.

**Study quality**

The study evidence class was determined using the Oxford Centre for Evidence-based Medicine-Levels of Evidence (March 2009). Good quality randomized controlled trials (RCTs) were considered Class I evidence. Moderate or poor quality RCT and good quality cohort studies were considered Class II evidence. Moderate or poor quality cohort studies and case–control studies were considered Class III evidence. Case series studies were considered Class IV evidence.[11] The articles were independently assessed by two reviewers, and discrepancies were resolved by discussion until a consensus was reached.

**Statistical analysis**

Continuous variables (Oswestry Disabilities Index [ODI], visual analog score [VAS], mean blood loss, length of stay, and operation time) were analyzed using weighted mean differences (WMDs) with the 95% confidence interval (CI). Dichotomous data (fusion rate, overall complication rate, and reoperation rate) were analyzed using the relative risk (RR) measure and 95% CI. The included studies were different in several variables such as the fusion definition, estimation of
blood loss, VAS or ODI scale, surgical techniques, and patient conditions; thus, these variables were not the same for the overall studies within each group. Therefore, a random-effects model was more suited for this study because it enables a distribution in contrast to a fixed-effects model. All tests defined $P < 0.05$ as significant. Funnel plots were used to assess the publication bias. A symmetrical plot indicates no bias, whereas an asymmetric plot indicates publication bias [Supplementary Figure 1]. Further analysis of the database was conducted using Review Manager 5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014).

**RESULTS**

**Selected studies and characteristics**

The details of the search strategy and selection are shown in Figure 1. We identified 24 eligible, comparative cohort studies from 780 potential studies in the initial literature search by independently judging the titles, abstracts, and full texts of all potential studies. The eligible studies included one RCT, eight prospective, and 15 retrospective cohort studies.[13-36] All included studies were written in English or Chinese, and the full text was available. Ten studies were excluded because they included data from patients in previously published studies[37-46] and seven studies were removed because the included diseases did not fulfill the inclusion criteria.[47-53] One study had three subgroups, which were grouped by the number of surgery segments. We included only the one segment group because the number of patients in the other groups did not meet the inclusion criteria.[20] There were 1967 patients in this study. There were 19 studies in which the diagnoses included degenerative disc disease; however, the diagnostic information was not clearly classified in two studies. Eighteen papers reported patients with only one segment surgery and one paper did not provide relevant information. The interbody device was used in all studies. All papers reported the use of bone graft information. Five of the included studies applied rhBMP-2.[13-15,23,30] The detailed information regarding these studies is shown in Table 1.

We also compared the baseline of the 24 included studies. One study considered nine aspects when comparing the two groups, five studies considered eight aspects, twelve studies considered seven aspects, three studies considered six aspects, two studies considered five aspects, and one study considered three aspects. However, there were different factors in the same number of aspects in the comparison of the MIS and open groups. There were significant differences between groups in several study variables, including the number of patients in both groups in eight studies, the mean age in one study and gender in one study. The other baseline characteristics were not significantly different between the two groups in the included studies [Table 2].

**Methodological quality assessment**

There were one Level I evidence study, three Level II evidence studies, and twenty Level III evidence studies according to the previously described assessment criteria for class of evidence.

**Meta-analysis results**

**Functional outcomes**

Multiple measurements were used to assess the patient functional outcome, such as lower back and/or leg pain VAS (VAS-BP/LP), ODI, EuroQol-5D, Japanese Orthopaedic Association Scores (JOA), Short Form 12 Health Survey or Short Form 36 Health Survey; however, the most reported measurements were the VAS-BP/LP and ODI. Thus, we selected these variables as the functional outcome standard. The mean preoperative VAS-LP was MIS: open = 7.0:6.9; the VAS-BP was MIS: open = 6.9:6.9; and the ODI was MIS: open = 49:50. The details are shown in Table 3, and there were no significant differences between the groups.

Twenty studies reported the VAS-BP; however, four studies only reported a mean VAS-BP score. Statistical analysis was feasible after standardization pooling to compare the functional outcome. The pooled postoperative analysis indicated that the MIS group had a significantly lower mean VAS-BP compared with the open group (WMD = −0.44; 95% CI: −0.71 to −0.18; $P = 0.001$; random-effects model) [Figure 2]. In addition, nine studies reported the VAS-LP, including seven studies that reported the mean and standard deviation (SD) score. Statistical analysis was feasible after standardization pooling to compare the functional outcome. The pooled postoperative analysis indicated that the MIS group had a lower score; however, there was no significant difference between the groups (WMD = −0.10; 95% CI: −0.27 to 0.08; $P = 0.26$; random-effects model) [Figure 2].

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**Figure 1:** Flow diagram for the selection of studies.
### Table 1: Characteristics of the include trials

| Characteristics                  | Wong et al.\(^{[25]}\) | Sulaiman and Singh\(^{[30]}\) | Tian et al.\(^{[31]}\) | Singh et al.\(^{[18]}\) | Zheng et al.\(^{[32]}\) | Chu et al.\(^{[36]}\) |
|---------------------------------|--------------------------|--------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Year of publication             | 2014                     | 2014                           | 2014                     | 2014                     | 2014                     | 2014                     |
| Study design                    | Prospective cohort       | Retrospective cohort           | Retrospective cohort     | Retrospective cohort     | Retrospective cohort     | Retrospective cohort     |
| Class of evidence*              | III                      | III                            | III                      | III                      | III                      | III                      |
| Number of enrolled patient      | 198 (144:54)             | 68 (57:11)                     | 61 (30:31)               | 66 (33:33)               | 48 (22:26)               | 51 (15:36)               |
| Mean follow-up time             | 45.0:46.0                | 24:24                          | 25.63:25.63              | 6.0:6.0                  | 12:12                    | 13.6:13.6                |
| (months; MIS:open)              |                          |                                |                          |                          |                          |                          |
| Follow-up rate (% , months)     | 100:100 (33)             | NR (>33)                       | 100:100 (24)             | 100:100 (6)              | 100:100 (6)              | 100:100 (6)              |
| (MIS:open)                      |                          |                                | NR (>24)                 | NR (>6)                  | NR (>6)                  | NR (>6)                  |
| Mean age (years, MIS:open)      | 61.0:58.0                | 61.1:56.4                      | 48.21:48.90              | 51.7:49.9                | 49.4:50.7                | 53:53                    |
| Gender (% male; MIS:open)       | 42.4:46.3                | 30:36                          | 53:74                    | 69.7:63.6                | 31:8:42.3                | 66.7:66.7                |
| Diagnosis (MIS:open)            |                          |                                |                          |                          |                          |                          |
| DDD                             | 27:10                    | 57:11                          | 19:9                     | 6:9                      | 22:21                    | 15:36                    |
| Spondylolisthesis               |                          |                                |                          |                          |                          |                          |
| Others                          |                          |                                |                          |                          |                          |                          |
| Inclusion/exclusion criteria    | NR                       | Inclusion                      | Inclusion                | Inclusion                | Inclusion                | Inclusion                |
|                                 |                          | Evidence on magnetic resonance imaging of Grades I or II degenerative lumbar spondylolisthesis; Mechanical low back pain and radicular leg symptoms | Symptomatic degenerative disease of the lumbosacral spine (L2 to S1) No response to nonoperative treatments for 6 months Single-level involvement | Diagnosis of other lumbar DDD, degenerative spondylolisthesis, or spinal stenosis; Patients had failed conservative management, including medications, a minimum of 6 weeks of physical therapy, and epidural injections when indicated | Symptomatic and refractory to prior conservative treatment for low back pain with or without unilateral kg pain Single-level DDD or degenerative I grade spondylolisthesis; Lack of response to at least 12 weeks of conservative therapy | Patients need to have evidence on magnetic resonance imaging of lumbar DDD, degenerative Have mechanical low back pain and radicular symptoms Unresponsive to at least 12 weeks of conservative therapy At least 6 months of follow-up |
|                                 |                          | Exclusion                      | Exclusion                | Exclusion                | Exclusion                | Exclusion                |
|                                 |                          | Patient had an active medical or worker’s compensation lawsuit or any pre-existing spinal pathology | Age <18 years or >65 years Previous lumbar surgery Osteoporosis spinal trauma or infections | Age 18–80 years | Patients associated with previous spinal surgery, lumbar fracture, active infection, tumor, malformation | Patients associated with previous spinal surgery, lumbar fracture, active infection, tumor, malformation | Patients who have severe adjacent segment degeneration |
|                                 |                          | Exclusion                      | Exclusion                | Exclusion                | Exclusion                | Exclusion                |
|                                 |                          | | | | | |
| Clinical outcome                | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, VAS | OPT, MBL, complications, VAS, ODI, JOA, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate |
|                                 |                          |                                |                          |                          |                          |                          |

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Table 1: Contd...

| Characteristics | Wong et al.[25] | Sulaiman and Singh[29] | Tian et al.[31] | Singh et al.[18] | Zheng et al.[32] | Chu et al.[36] |
|-----------------|----------------|-------------------------|----------------|----------------|----------------|----------------|
| Definition fusion/evaluation measure | NR/dynamic flexion-extension lumbar radiographs in conjunction with a CT scan within the 16–24 months | NR | Grades I or II (Bridwell interbody fusion grading system)/radiographs (antero-posterior and lateral images) were employed to affirm the fusion rates and CT scans at 24 months | NR | Trabecular bony bridges between contiguous vertebral bodies at the instrumented levels, and <4° segmental movement/dynamic flexion-extension lumbar radiographs in conjunction with a CT scan within the 24 months | Trabecular bony bridges between contiguous vertebral bodies at the instrumented levels, and <4° segmental movement/dynamic flexion-extension lumbar radiographs |

Surgical information

| Number of segments treated | One (79:35) | One (45:2) | One (30:30) | One (33:33) | One (22:26) | One (15:36) |
|---------------------------|-------------|------------|-------------|-------------|-------------|-------------|
| Level of fusion           |             |            |             |             |             |             |
| L4–L5                     | 62:14       | 37:8       | 14:17       | NR          | NR          | NR          |
| L5 to S1                  | 65:21       | 12:9       | 14:13       | NR          | 11:15       | NR          |
| Others                    | 17:9        | 2:4        | 2:1         | 0:1         | 11:10       | NR          |
| Interbody device          | PEEK cage   | PEEK cage  | PEEK/titanium cage | Cage | PEEK cage | Cage |
| Graft use                 | Autologous  | Autologous | Autologous  | Autologous  | Autologous  | Autologous  |
| Screw use                 | Bilateral   | Bilateral  | Bilateral   | Bilateral (O) | Bilateral | Bilateral |

Characteristics

| Characteristics | Parker et al.[17] | Saetia et al.[29] | Gu et al.[31] | Brodano et al.[27] | Zaier et al.[26] | Lau et al.[14] |
|----------------|-------------------|-------------------|---------------|-------------------|-----------------|---------------|
| Year of publication | 2013              | 2013              | 2013          | 2013              | 2013            | 2013          |
| Study design     | Prospective cohort | Retrospective cohort | Prospective cohort | Retrospective cohort | Retrospective cohort | Retrospective cohort |
| Class of evidence* | II                | III               | III           | III               | III             | III           |
| Number of enrolled patient (MIS:open) | 100 (50:50) | 24 (12:12) | 82 (44:38) | 64 (30:34) | 100 (40:60) | 127 (78:49) |
| Mean follow-up time (months; MIS:open) | 24:24 | 28:28 | 20.6:20.0 | 23:25 | 27:30:0 | NR |
| Follow-up rate (% months) (MIS:open) | 100:100 (24) | 100:100 (24) | 100:100 (16) | 100:100 (12) | 100:100 (24) | NR |
| Mean age (years, MIS:open) | 53.5±5.2 | 63.10±6.74 | 66.4±6.41 | 46.51 | 49.48 | 54.1±5.2 |
| Gender (% male; MIS:open) | 32.0±3.6 | 10.50 | 43.1±3.95 | 60.58:8 | 50:47 | 52.2±5.0 |
| Diagnosis (MIS:open) | DDD | Others |
| DDD | 50:50 | 12:12 | 29:27 | | | |
| Others | 29:27 | | | | | |

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### Table 1: Contd...

| Characteristics | Parker et al. [17] | Saetia et al. [29] | Gu et al. [28] | Brodano et al. [27] | Zairi et al. [26] | Lau et al. [14] |
|-----------------|--------------------|--------------------|---------------|--------------------|-----------------|---------------|
| Inclusion/exclusion criteria | Inclusion | Inclusion | Inclusion | Inclusion | Inclusion | Inclusion |
| Patients need to have evidence on magnetic resonance imaging of Grade I degenerative lumbar spondylolisthesis; Have mechanical low back pain and radicular symptoms Unresponsive to at least 6 weeks of conservative therapy Age 18–70 years | Patients were Grades I or II spondylolisthesis presenting with mechanical low back pain, radiculopathy, and/or neurogenic claudication Preoperative evaluation with static (antero-posterior and lateral) and dynamic (flexion-extension) plain L-S spine radiography and MRI | Two-level fusions were needed between L3 and S1 Persistent or recurrent low back pain or leg pain lasting at least 6 months and resulting in a significant reduction of quality of life, despite conservative therapy, including physical therapy and pain management Segmental instability was >4 mm of translation or 10 of angular motion on preoperative flexion-extension radiographs | Symptomatic and refractory to prior conservative treatment low back pain with or without unilateral leg pain Single-level DDD or degenerative I grade spondylolisthesis documented with both X-Ray and MRIs of the lumbar spine Minimum follow-up period after operation 6 months | Patients who underwent single-level TLIF for DDD or degenerative low-grade (1 or 2) spondylolisthesis | NR |
| Inclusion | Inclusion | Inclusion | Inclusion | Inclusion | Inclusion | Inclusion |
| Undergone a previous back operation An extraspinal cause of back pain or sciatica An active medical or workman’s compensation lawsuit Any pre-existing spinal pathology Unwilling or unable to participate with follow-up procedures | Patients had failed conservative management (minimum 6 months) before surgery | Patients associated with previous spinal surgery, lumbar fracture, active infection, severe osteoporosis, and severe obesity Combination of coronal and/or sagittal deformities that needed a surgical correction Degenerative spondylolisthesis with major instability or ischemic spondylolisthesis Any major psychological problem | Patients with DDD or degenerative spondylolisthesis at more than one level Patients with spinal stenosis with neurogenic claudication or bilateral leg pain Patients with isthmic spondylolisthesis Patients with <12 months follow-up Patients who had previously undergone spinal surgery | Patients with DDD or degenerative spondylolisthesis Patients with spinal stenosis with neurogenic claudication or bilateral leg pain Patients with isthmic spondylolisthesis Patients with <12 months follow-up Patients who had previously undergone spinal surgery | NR |

| Clinical outcome | OPT, MBL, LOS, complications, VAS, ODI, SF-12, QALY, EQ-5D | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate |
|------------------|--------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Definition fusion/evaluation measure | NR | Grades I or II (Bridwell interbody fusion grading System)plain film and CT of the L-S spine at 24 months | Grades I or II (Bridwell interbody fusion grading system)radiographs (AP and lateral images) at 12 months | NR/posterior-anterior and lateral view as well as dynamic X-rays of the lumbar spine (max flexion - max extension) at 12 months | Bony bridging anterior to the cage and bony continuity between the two endplates through the cage/CT scan at 12 months |
| Surgical information | One (50:50) | One (12:12) | Two (44:38) | One (30:34) | One (40:60) | One (23:38) |
| Number of segments treated | | | | | | |

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Table 1: Contd...

| Characteristics | Parker et al. [17] | Saetia et al. [29] | Gu et al. [28] | Brodano et al. [27] | Zairi et al. [26] | Lau et al. [14] |
|-----------------|-------------------|-------------------|----------------|--------------------|------------------|----------------|
| Level of fusion | L4-L5             | L5 to S1          | Others         | L5 to S1           | Others           |                |
|                 | 32:30             | 14:17             | 4:3            | 14:17              | 4:3              | 32:30          |
|                 | 11:7              | 1:3               | 0:2            | 1:3                | 0:2              | 11:7           |
| Interbody device | Cage              | Cage              | Cage           | Cage               | PEEK cage        | PEEK cage      |
| Graft use       | Autologous        | Autologous        | Autologous     | Autologous         | Autologous       | Autologous     |
| Screw use       | Bilateral         | Bilateral         | Bilateral      | Unilateral         | Bilateral        | Bilateral      |

| Characteristics | Rodríguez-Vela et al. [19] | Yang et al. [33] | Lee et al. [32] | Lau et al. [19] | Wang et al. [34] | Liang et al. [35] |
|-----------------|-----------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Year of publication | 2013                       | 2013            | 2012            | 2011            | 2011            | 2011            |
| Study design    | Prospective cohort          | Retrospective cohort | Prospective cohort | Retrospective cohort | Randomized controlled trial | Retrospective cohort |
| Class of evidence* | III                        | III             | II              | III             | I               | III             |
| Number of enrolled patient (MIS:open) | 41 (21:20) | 147 (43:104) | 144 (72:72) | 22 (10:12) | 79 (41:38) | 87 (42:45) |
| Mean follow-up time (months; MIS:open) | 45:04:50 | 21:23 | 24:0:24:0 | 15:2:12:6 | 32:7:32:7 | 33:6:34:8 |
| Follow-up rate (%; months) (MIS:open) | 100:100 (36) | 100:100 (18) | 95:8:100 (6) | 100:100 (12) | 100:100 (24) | 100:100 (26) |
| Mean age (years, MIS:open) | 41.81:43.15 | 55:52 | 52:2:56.6 | 46:9:56.9 | 65:9:60.5 | 54:8:57.8 |
| Gender (% male; MIS:open) | 66.7:65.0 | 34.9:35.6 | 27.8:30.6 | 40.0:42.0 | 5:6 | 11:14 |
| Diagnosis (MIS:open) | DDD | 21:20 | 23:52 | NR | 5:6 | 30:24 |
| Others | Spondylolisthesis | 20:52 | 4:6 | 1:0 | 11:14 | 42:45 |
| Inclusion/exclusion criteria | Inclusion | Inclusion | Inclusion | NR | Inclusion | Inclusion |
| Patients without previous medical conditions, who underwent a one-level TLIF | Diagnosis of either lumbar DDD, degenerative spondylolisthesis, or spinal stenosis | Single-level TLIF (open or MIS) | MIS cases utilizing sextant ITM (Medtronic, MN) pedicle screw-rod instrumentation and capstone (Medtronic MN) interbody cage | Previous spinal instrumentation | Unilateral or bilateral lower limb pain, numbness, or symptoms of intermittent claudication, with or without significant low back pain | Diagnosis of either lumbar DDD, degenerative spondylolisthesis, or spinal stenosis |
| 6 months of failed nonoperative treatment or neurologic deficit progression | No response to nonoperative treatments for 3 months | Imaging studies showing single-level lumbar disc herniation, spinal stenosis, or spondylolisthesis | Imaging studies showing single-level lumbar disc herniation, spinal stenosis, or spondylolisthesis |
| DDD | Patients with lumbar stenosis or isthmic spondylolisthesis | Patients with clinic dates with at least 18 months of follow-up | Imaging studies showing single-level lumbar disc herniation, spinal stenosis, or spondylolisthesis | Imaging studies showing single-level lumbar disc herniation, spinal stenosis, or spondylolisthesis | Informed consent | Imaging studies showing single-level lumbar disc herniation, spinal stenosis, or spondylolisthesis |
### Table 1: Contd...

| Characteristics                                                                 | Rodriguez-Vela et al.[19] | Yang et al.[31] | Lee et al.[16] | Lau et al.[15] | Wang et al. [34] | Liang et al. [35] |
|---------------------------------------------------------------------------------|---------------------------|----------------|----------------|----------------|-----------------|-----------------|
| Previous lumbar spine surgery (except single discectomy)                        | Exclusion                | Tumor spinal pathologies | Spinal infections | Acute spinal trauma | Exclusion | Exclusion |
| Presence of MRI degenerative changes in other lumbar levels                     | Undergone a previous back operation | | | Multisegment lumbar herniation, spinal stenosis or, abnormal vertebral alignment | | |
|                                                                                 | Any pre-existing spinal pathology | | | Severe osteoporosis or other metabolic bone disease | | |
|                                                                                 | Any major psychological problem | | | Fractured vertebra, cracked pedicle, or a congenital, isthmic or other abnormal bone structure | | |
|                                                                                 | Undergone a previous back operation | | | Infection in the intervertebral space or other areas | | |
|                                                                                 | Any pre-existing spinal pathology | | | Previous surgical treatment of segmental defects | | |
|                                                                                 | Any major psychological problem | | | Severe systemic disease which contraindicated surgery | | |
|                                                                                 | Consent not given | | | Consent not given | | |
| Clinical outcome                                                                | Complications, VAS, ODI, SF-36, NASS | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate, SF-36, NASS, ambulation time | OPT, MBL, complications, ambulation time, postoperative drainage, pain outcome scores | OPT, MBL, LOS, complications, VAS, ODI | ORT, MBL, complications, VAS, ODI, fusion rate |
| Definition fusion/evaluation measure                                             | NR                        | Fusion was defined as Brantigan–Steffee classification D or E, translation movement <2 mm and SA <5°/dynamic flexion-extension lumbar radiographs in conjunction with a CT scan within the 12 months | The fusion was defined as Grades I or II. (Bridwell interbody fusion grading system)/static and dynamic plain at 6 months and 24 months | NR | NR | NR |
| Surgical information                                                            | One (21:20)               | One (43:104)       | One (72:72)     | One (9:7) Two (1:5) | One (41:38) | One (42:45) |
| Number of segments treated                                                       |                          |                |                |                |                |                |
| Level of fusion                                                                  | NR                        | 24:63           | 54:49          | 5:6            | 11:15           | 21:21           |
| L4-L5                                                                           | 17:39                     | 14:17           | 4:1            | 11:10          | 16:11           | 5:7             |
| L5 to S1                                                                         | 2:2                       | 4:6             | 1:5            | 0:1            |                 |                 |
| Others                                                                          |                           |                 |                |                |                |                 |
| Interbody device                                                                 | CIO®/CAPASTONE®          | Cage            | PEEK/titanium cage | Cage | PEEK cage | PEEK cage |
| Graft use                                                                        | Autologous               | Autologous and DBM | Autologous | Autologous | Autologous | PMMA |
| Screw use                                                                        | Bilateral                | Bilateral       | Bilateral      | Bilateral      | Bilateral       | Bilateral       |

*Contd...*
| Characteristics                  | Shunwu et al. | Wang et al. | Villavicencio et al. | Schizas et al. | Dhall et al. | Scheufler et al. |
|---------------------------------|---------------|------------|----------------------|----------------|--------------|------------------|
| Year of publication             | 2010          | 2010       | 2010                 | 2009           | 2008         | 2007             |
| Study design                    | Prospective cohort | Prospective cohort | Retrospective cohort | Prospective cohort | Retrospective cohort | Retrospective cohort |
| Class of evidence*              | II            | III        | III                  | III            | III          | III              |
| Number of enrolled patient     | 62 (32:30)    | 85 (42:43) | 139 (76:63)          | 36 (18:18)     | 42 (21:21)   | 94 (43:51)       |
| Mean follow-up time (months; MIS:open) | 24.0±24.0   | 26.3±26.3  | 37.5±37.5            | 22.0±24.0      | 24.0±34.0    | 16.0±16.0        |
| Follow-up rate (%; months)      | 96.9±24 (24)  | 100:100 (13) | 100:100 (24)        | 100:100 (12)  | 100:100 (>12) | 100:100 (16)     |
| Mean age (years; MIS:open)      | 51.4±5.2     | 47.9±53.2  | 50.5±58.9            | 45.5±48.1      | 53.0±53.0    | 52.6±53.4        |
| Gender (% male; MIS:open)       | 56.3±46.7    | 30.1±37.2  | 38.0±45.0            | NR             | NR           | 45.2±47.8        |
| Diagnosis (MIS:open)            | Inclusion    | Inclusion  | Inclusion            | Inclusion      | Inclusion    | Inclusion        |
| DDD                             | NR            | 2:6        | 15:12                | 1:0            | 14:10        | 18:25            |
| Spondylolisthesis               | 5:8           | 24:22      | 15:12                | 1:0            | 7:11         | 33:37            |
| Others                          | 3:4           | 18:21      | NR                   | NR             | NR           | NR               |
| Inclusion/exclusion criteria    | Inclusion     | Inclusion  | Inclusion            | Inclusion      | Inclusion    | Inclusion        |
| One-level pathological process  | Patients with degenerative or ischemic spondylolisthesis | Patients presented low back pain as their predominant complaint, with varying degrees of radiating pain, neurological complaints, or a combination of these | Patients with degenerative or ischemic spondylolisthesis | Patients presented low back pain as their predominant complaint, with varying degrees of radiating pain, neurological complaints, or a combination of these | Patients with degenerative or ischemic spondylolisthesis | Patients presented with either axial back pain, neurogenic claudication, radiculopathy, pseudoradicular pain, or a combination of these |
| Postoperative drainage          | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, LOS, complications, VAS, ODI, fusion rate | OPT, MBL, VAS, fusion rate, Roland-Morris low back pain, AOS-Lumbar spine questionnaire |

Contd...
| Characteristics                  | Shunwu et al. [22] | Wang et al. [24] | Villavicencio et al. [23] | Schizas et al. [21] | Dhall et al. [13] | Scheufler et al. [20] |
|---------------------------------|--------------------|------------------|---------------------------|--------------------|-------------------|----------------------|
| Definition fusion/evaluation    | Bony trabeculation | Trabecular bone  | Trabecular bone bridging  | NR/CT scans at 12  | NR/dynamic         | Formation of         |
| measure                         | crossed the cages or endplate interfaces/CT scans at 6 months | bridges between contiguous vertebral bodies at the instrumented levels, and <4° segmental movement/static and dynamic plain X-rays at 6 months | on the CT scans and less than a 5° difference in angular motion between flexion and extension, and/or no radiolucency lines >2 mm in thickness covering more than 50% of the superior or inferior surface of the grafts on the plain radiographs/CT scans or plain radiographs | months | radiographs and with CT scans in questionable cases at 12 months | trabecular bony bridges between contiguous vertebral bodies at the instrumented levels/2-mm thin-slice CT scans at 16 months |
| Surgical information            |                    |                  |                           |                    |                   |                      |
| Number of segments treated      | One (32:30)        | One (42:43)      | One (47:57)               | NR                 | One (21:21)       | One (43:51)         |
| Level of fusion                 |                    |                  |                           |                    |                   |                      |
| L4–L5                           | 20 : 16            | 21 : 23          | NR                        | 12 : 11            | NR                |                      |
| L5 to S1                        | 11 : 12            | 18 : 17          |                           |                    |                   |                      |
| Others                          | 1 : 2              | 3 : 3            |                           |                    |                   |                      |
| Interbody device                | Titanium cage      | PEEK cage        | Structural allograft      | PEEK cage          | Cage              | PEEK cage           |
| Graft use                       | Autologous         | Autologous       | Autologous                | Autologous         | Autologous        | Autologous          |
| Screw use                       | Bilateral          | Bilateral        | Bilateral                 | Bilateral          | Bilateral         |                      |

*Class of evidence was assessed by Oxford Centre for Evidence-based Medicine-Levels of Evidence (March 2009). MIS: Minimally invasive surgery; Open: open surgery; CT: Computed tomography; MRI: Magnetic resonance imaging; BCP: Biphasic calcium phosphate; PEEK: Polyether ether ketone; DBM: Demineralized bone matrix; PM: Polymethyl methacrylic; OPT: Operation time; MBL: Mean blood loss; LOS: Length of hospital stay; VAS: Visual analog score; ODI: Oswestry Disabilities Index; SF-36: Short Form 36 Health Survey; SF-12: Short Form 12 Health Survey; NASS: North American Spine Society; EQ-5D: EuroQol-5D; AAOS: American Academy of Orthopedic Surgeons; mPS: Modified Prolo Scale; NR: Not report; DDD: Degenerative disc disease; JOA: Japanese Orthopaedic Association Scores; L-S: Lumbo-sacral; TLIF: Transforaminal lumbar interbody fusion.
### Table 2: Comparison of baseline characteristics between the MIS group and open group

| Studies                  | Gender | Mean age | BMI | Number of enrolled patients | Level of surgery | Comorbidities | Preoperative diagnosis | Preoperative pain score | Preoperative function score |
|--------------------------|--------|----------|-----|------------------------------|------------------|---------------|------------------------|--------------------------|---------------------------|
| Wong et al.[13]          | NS     | NS       | NR  | S                            | NS               | NS            | NS                     | NS                       | NS                        |
| Sulaiman and Singh[19]   | S      | NS       | NS  | S                            | NS               | NS            | NS                     | NS                       | NS                        |
| Tian et al.[11]          | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Singh et al.[14]         | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Chu et al.[14]           | NS     | NS       | NS  | S                            | NS               | NS            | NS                     | NS                       | NS                        |
| Zheng et al.[12]         | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Saetia et al.[29]        | S      | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Gu et al.[20]            | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Brodano et al.[21]       | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Zairi et al.[26]         | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Lau et al.[14]           | NS     | NS       | NS  | S                            | NS               | NS            | NS                     | NS                       | NS                        |
| Rodriguez-Vela et al.[19] | NS    | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Parker et al.[17]        | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Yang et al.[13]          | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Lee et al.[16]           | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Lau et al.[15]           | NS     | S        | NR  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Wang et al.[26]          | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Liang et al.[28]         | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Shunwu et al.[32]        | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Wang et al.[26]          | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Villavicencio et al.[27] | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Schizas et al.[21]       | NR     | NR       | NR  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Dhall et al.[13]         | NS     | NS       | NS  | NS                           | NS               | NS            | NS                     | NS                       | NS                        |
| Scheufler et al.[29]     | NS     | NS       | NS  | S                            | NS               | NS            | NS                     | NS                       | NS                        |

BMI: Body mass index; NS: No statistical significance (P>0.05); S: Statistical significance (P<0.05); NR: Not report; MIS: Minimally invasive surgery.

### Table 3: Preoperative VAS-BP/LP score and ODI of included studies (MIS: open), mean±SD

| Studies                  | VAS-BP | VAS-LP | ODI   |
|--------------------------|--------|--------|-------|
| Wong et al.[13]          | 6.37±7.2 | 8.90±8.82 | 52.8±51.2 |
| Sulaiman and Singh[19]   | 7.3±0.91| 9.17±1.34| 62.15±5.20|
| Tian et al.[11]          | 4.86±1.16| 6.35±1.38 | 45.26±6.05|
| Singh et al.[14]         | 6.94±1.85| 6.12±1.35 | 51.2±4.85|
| Chu et al.[14]           | 7.64±0.78| 6.96±1.78 | 52.1±4.85|
| Zheng et al.[12]         | 4.9±2.54 | 6.6±2.54  | 25.3±10.72|
| Saetia et al.[29]        | 8.75±1.60| 6.09±1.09 | 51.0±6.89|
| Gu et al.[20]            | 7.3±1.27 | 7.6±0.97  | 34.3±4.33|
| Brodano et al.[21]       | 7.8±1.48 | 7.1±0.78  | 42.6±7.14|
| Zairi et al.[26]         | 7.3±7.2  | 6.0±6.0   |       |
| Rodriguez-Vela et al.[19]| 7.04±1.22| 7.31±1.13 | 30.85±5.22|
| Parker et al.[17]        | 8.1±2.95 | 6.5±3.69  | 32.3±7.34|
| Yang et al.[13]          | 7.79±0.89| 5.78±3.62 | 57.95±4.61|
| Lee et al.[16]           | 6.3±2.99 | 5.8±3.62  | 49.16±4.28|
| Wang et al.[26]          | 4.9±1.05 | 5.88±6.75 |       |
| Liang et al.[28]         | 5.7±1.53 | 7.1±1.37  | 80.9±6.813|
| Shunwu et al.[32]        | 6.8±1.26 | 4.97±11.52|       |
| Wang et al.[26]          | 7.2±1.70 | 4.12±6.35 |       |
| Villavicencio et al.[27] | 7.4±8.0  | 6.9±1.77  |       |
| Schizas et al.[21]       | 7.7±5.0  | 6.55±5.53 |       |

VAS-BP/LP: Visual analog score-back pain/leg pain; ODI: Oswestry Disabilities Index; SD: Standard deviation; NR: Not report; MIS: Minimally invasive surgery.

Eighteen studies reported the ODI score; however, only 15 studies provided the mean and SD of the ODI. Statistical analysis was feasible after standardization pooling to compare the functional outcome. The pooled postoperative analysis indicated that the MIS group had a significantly lower ODI score compared with the open...
group ($WMD = -1.57; 95\% CI: -2.66$ to $-0.48; P = 0.005$; random-effects model) [Figure 2]. To more effectively compare both the procedures, we also pooled the mean VAS-LP, VAS-BP, and ODI.

**Figure 2:** Forest plot: postoperative VAS-BP/LP and ODI. MIS: Minimally invasive surgery; Open: Open surgery; VAS-BP/LP: Visual analog score-back pain/leg pain; ODI: Oswestry Disabilities Index; CI: Confidence interval; SD: Standard deviation.
improvement [Table 4]. The findings suggested that the MIS group exhibited a better outcome compared with the open procedure; the mean VAS-LP, VAS-BP, and ODI improvement were 0.2, 0.5, and 2.9, respectively.

**Operation time**

Twenty-two studies reported the mean operation time; however, only 15 studies provided both the mean and SD of the operation time. Statistical analysis was feasible after standardization pooling to compare the functional outcome. The pooled postoperative analysis indicated that MIS had a similar operation time to open group (WMD = −5.23; 95% CI: −50.55 to 40.09; P = 0.82; random-effects model) [Figure 3].

We also compared the overall mean surgical operation time between the groups [Table 4]. The findings indicated that the operation time of the two groups was basically the same (MIS: open = 195:198).

**Mean blood loss**

Twenty-three studies reported the mean blood loss for both the MIS and open-TLIF procedures; however, seven studies did not provide the mean and SD of the mean blood loss. Statistical analysis was feasible after standardization pooling to compare the functional outcome. The findings indicated that there was less blood loss in the MIS group. The pooled analysis suggested that the MIS group had significantly less blood loss compared with the open group (WMD = −265.59; 95% CI: −351.31 to −179.86; P < 0.00001; random-effects model) [Figure 3].

We also compared the overall mean surgical estimation of blood loss between the groups [Table 4]. The findings indicated that MIS-TLIF was associated with less blood loss (224.4 ml) and reduced bleeding (506.8 ml).

**Length of hospital stay**

Twenty-one studies reported the mean length of stay; however, only 15 studies provided the mean and SD of the hospital stay. Statistical analysis was feasible after standardization pooling to compare the functional outcome. Nineteen studies indicated a shorter hospital stay in the MIS group. Our pooled analysis suggested that the MIS group had a significantly shorter length of stay compared with the open group (WMD = −1.77; 95% CI: −2.68 to −0.86; P = 0.0001; random-effects model) [Figure 3].

We also compared the overall mean length of stay between the groups [Table 3]. The findings suggested that MIS-TLIF decreased the hospital stay about 2 days compared with open-TLIF.

**Ambulation time**

Four studies reported the ambulation time; however, one study did not report the mean and SD. Statistical analysis was feasible after standardization pooling to compare the functional outcome. All studies indicated a shorter time to ambulate in the MIS group. The pooled analysis suggested that the MIS group had a significantly shorter ambulation time compared with the open group (WMD = −1.77; 95% CI: −2.68 to −0.86; P = 0.0001; random-effects model) [Figure 3].

**Fusion rate**

Sixteen studies reported the fusion rate from a minimum of 6 months to a maximum of 24 months. Fusion was assessed with the use of dynamic flexion-extension radiographs and/or computed tomography scan. However, only 13 studies reported the fusion definition. The fusion rate was 95.9% (658/686) in the MIS-TLIF group and 97.7% (668/684) in the open-TLIF group. There was no significant difference in the fusion rate between the two groups (RR = 0.99; 95% CI: 0.97–1.01; P = 0.34; random-effects model) [Figure 4].

**Complication rate**

Twenty-two studies reported the complication rate. The complication rate was 15.1% (142/940) in the MIS-TLIF group and 16.4% (142/867) in the open-TLIF group. The pooled analysis suggested that the MIS group had a lower complication rate; however, there was no significant difference between the two groups (RR = 0.84; 95% CI: 0.58–1.21; P = 0.35; random-effects model) [Figure 4].

**Reoperation rate**

Thirteen studies reported the reoperation rate. The reoperation rate was 0.4% (34/788) in the MIS-TLIF group and 0.5% (37/767) in the open-TLIF group. The pooled analysis suggested that the MIS group had a lower reoperation rate; however, there was no significant difference between the two groups (RR = 0.73; 95% CI: 0.39–1.35; P = 0.32; random-effects model) [Figure 4].

**Discussion**

To determine the efficacy of both treatments, we analyzed the relative information as much detail as possible. Our findings indicated that MIS-TLIF had a better performance in all fields with the exception of the fusion rate [Table 4]. The meta-analysis suggested that MIS-TLIF attained a similar fusion rate, with a significantly shorter hospital stay and quicker ambulation, as well as less blood loss compared with open-TLIF. Patients suffered fewer lesions with less blood loss. MIS-TLIF resulted in quicker rehabilitation.

### Table 4: Comparison between the MIS group and open group

| Mean    | Fusion rate (%) | Complication rate (%) | Reoperation rate (%) | VAS-LP improvement | VAS-BP improvement | ODI improvement | MBL (ml) | OPT (min) | LOS (days) | Ambulation time (days) |
|---------|----------------|-----------------------|----------------------|--------------------|--------------------|-----------------|----------|----------|------------|------------------------|
| MIS (overall) | 95.9           | 15.1                  | 0.4                  | 5.2                | 4.7                | 31.6            | 224.4    | 195      | 5.1        | 1.9                    |
| Open (overall) | 97.7           | 16.4                  | 0.5                  | 5.0                | 4.2                | 28.7            | 506.8    | 198      | 6.9        | 3.7                    |

MIS: Minimally invasive surgery; Open: Open surgery; OPT: Operation time; MBL: Mean blood loss; LOS: Length of hospital stay; VAS-BP/LP: Visual analog score-back pain/leg pain; ODE: Oswestry Disabilities Index.
Figure 3: Forest plot: Operation time, mean blood loss, hospital stay, and ambulation time. MIS: Minimally invasive surgery; Open: Open surgery; CI: Confidence interval; SD: Standard deviation.
and less complications because patients exhibited earlier ambulation, as well as lower medical costs and a shorter hospital stay. For clinical functional outcomes, the preoperative baseline variables were similar between the groups, and the pooled analysis suggested that the MIS group exhibited significantly lower postoperative VAS and ODI scores compared with the open group. Thus, MIS-TLIF resulted in better outcomes and less trauma. These findings are consistent with the studies by Wu et al.[4] and Tian et al.[5]

Despite the many fusion technologies, TLIF has become a widely accepted and familiar surgical approach, which decreases the relative nervous complication rate.[34-36] However, open-TLIF technology also requires splitting of the paraspinal muscle. Although it does not hurt, it breaks a major section of the posterior compartment, which may result in relevant muscle complications and low back pain.[57] Therefore, minimally invasive TLIF was introduced by Foley and Lefkowitz[58] approximately 10 years ago. To date, it has become an increasingly accepted approach with advantages,
compared with traditional open surgery, that are attributed to decreased damage to spinal soft tissues and paravertebral muscles.[20,36,59]

The advantages associated with MIS-TLIF may be attributed to the less intraoperative dissection and retraction of paravertebral muscles.[4,5,8,60]

Our meta-analysis indicated that MIS-TLIF was associated with a shorter operation time and lower complication and reoperation rate; however, there was no significant difference between MIS and open-TLIF, which is consistent with the findings of Tian et al.[5] Nevertheless, it is interesting that the compilation and reoperation rate were significantly decreased in the MIS group compared with the open-TLIF group. As shown in Figure 5, there are several potential reasons for this phenomenon; one major reason may be that the learning curve is very steep and it requires more years and experience to absorb and master minimally invasive surgery skills.[5,13,15,21] The other major one may be possible with surgical devices and the development of equipment.

There are several potential weaknesses in our meta-analysis. First, we included only prospective and retrospective studies in this study; thus, methodological defects were inevitable in these studies and included incorrect blinding or nonblinding, data bias, insufficient baseline comparisons, and insufficient data collection. Second, there were fewer outcome measures in the current study; additional objective or subjective parameters should be used to estimate the clinical outcomes. Third, the fusion definition and judgment were different across the included studies. Moreover, many of the studies comprised short- or medium-term research. Additional, long-term, follow-up studies should be conducted to evaluate both the approaches. Finally, there was unavoidable bias when the data were pooled. Despite these limitations, this updated meta-analysis provides an important clinical reference for the field.

In conclusion, the current meta-analysis indicated that MIS-TLIF resulted in a similar fusion rate with better functional outcome, less blood loss, shorter amputation, and hospital stay. Furthermore, MIS-TLIF was not associated with an increase in the complication or reoperation rate based on the existing evidence. Thus, we recommend minimally invasive surgery as the first option if the patient meets the indication because it results in fewer lesions, better outcome, and a similar fusion rate compared with the traditional open surgery. Interestingly, MIS-TLIF has been associated with

| Complication rate |
|-------------------|
| **Study or Subgroup** | **Total Events** | **Total Weight** | **Risk Ratio** | **Risk Ratio** |
| **MIS** | **Open** | **M.H. Random** | **95% CI** | **Year** |
| Dhali 2009 | 1 | 1 | 1.00 | 0.00 | 2009 |
| Schiliz 2009 | 6 | 2 | 1 | 3.00 | 0.70, 12.93 | 2009 |
| Shunwu 2010 | 24 | 8 | 1 | 0.99 | 0.61, 1.62 | 2010 |
| Villavicencio 2010 | 4 | 1 | 1 | 0.99 | 0.61, 1.62 | 2010 |
| Wang 2010 | 5 | 2 | 1 | 1.00 | 0.70, 12.93 | 2010 |
| Lau 2011 | 4 | 1 | 1 | 1.00 | 0.70, 12.93 | 2011 |
| Wang 2011 | 3 | 1 | 1 | 0.99 | 0.61, 1.62 | 2011 |
| Liang 2012 | 0 | 0 | 1 | 0.99 | 0.61, 1.62 | 2012 |
| Lai et al. 2013 | 1 | 0 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Zain 2013 | 1 | 1 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Lau 2013 | 9 | 7 | 1 | 1.00 | 0.70, 12.93 | 2013 |
| Saeed 2013 | 4 | 2 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Vanz 2013 | 3 | 2 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Tasker 2013 | 5 | 0 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Rodriguez-Valia 2013 | 2 | 1 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Ou 2013 | 4 | 4 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| B/uploads 2013 | 4 | 4 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Chu 2014 | 1 | 1 | 1 | 1.00 | 0.70, 12.93 | 2014 |
| Wong 2014 | 48 | 47 | 1 | 1.00 | 0.70, 12.93 | 2014 |
| Zheng 2014 | 0 | 0 | 1 | 0.99 | 0.61, 1.62 | 2014 |
| Tian 2014 | 2 | 0 | 1 | 0.99 | 0.61, 1.62 | 2014 |

| Total (%) (95% CI) | 658 | 597 | 100.0% | 0.59 | 0.41, 0.83 |

| Reoperation rate |
|-------------------|
| **Study or Subgroup** | **Total Events** | **Total Weight** | **Risk Ratio** | **Risk Ratio** |
| **MIS** | **Open** | **M.H. Random** | **95% CI** | **Year** |
| Dhali 2009 | 2 | 1 | 1 | 0.99 | 0.61, 1.62 | 2009 |
| Schiliz 2009 | 2 | 1 | 1 | 0.99 | 0.61, 1.62 | 2009 |
| Wang 2010 | 2 | 1 | 1 | 0.99 | 0.61, 1.62 | 2010 |
| Villavicencio 2010 | 7 | 6 | 1 | 1.00 | 0.70, 12.93 | 2010 |
| Shunwu 2010 | 0 | 0 | 1 | 0.99 | 0.61, 1.62 | 2010 |
| Wang 2010 | 5 | 2 | 1 | 1.00 | 0.70, 12.93 | 2010 |
| Liang 2011 | 0 | 0 | 1 | 0.99 | 0.61, 1.62 | 2011 |
| Lau 2011 | 1 | 1 | 1 | 0.99 | 0.61, 1.62 | 2011 |
| Yang 2011 | 1 | 1 | 1 | 0.99 | 0.61, 1.62 | 2011 |
| Brodana 2013 | 2 | 1 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Parker 2013 | 5 | 5 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Rodriguez-Valia 2013 | 2 | 1 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Ou 2013 | 4 | 5 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| B/uploads 2013 | 4 | 4 | 1 | 0.99 | 0.61, 1.62 | 2013 |
| Chu 2014 | 1 | 1 | 1 | 0.99 | 0.61, 1.62 | 2014 |
| Wong 2014 | 2 | 2 | 1 | 0.99 | 0.61, 1.62 | 2014 |
| Zheng 2014 | 0 | 0 | 1 | 0.99 | 0.61, 1.62 | 2014 |
| Tian 2014 | 2 | 2 | 1 | 0.99 | 0.61, 1.62 | 2014 |

| Total (%) (95% CI) | 18 | 19 | 100.0% | 0.38 | 0.22, 0.66 |

**Figure 5:** Forest plot: Complication rate and reoperation rate. MIS: Minimally invasive surgery; Open: Open surgery; CI: Confidence interval.
significantly decreased complication and reoperation rate in the recent years. We suggest that this finding is a result of greater acceptance in using MIS-TLIF, familiarity with the procedure, the ability to grasp and master minimally invasive surgery skills, and the relevant development of surgical instructions and apparatuses. Additional, high-quality studies are needed to confirm these findings and further compare the two methods.

**Supplementary information is linked to the online version of the paper on the Chinese Medical Journal website.**

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**Conflicts of interest**

There are no conflicts of interest.

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Supplementary Figure 1: Funnel plots. Complication rate. SE: Standard error; RR: Relative risk.