Minimally invasive versus open surgery for degenerative lumbar pathologies: a systematic review and meta-analysis

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Abstract

Introduction With the increase in life expectancy and consequent aging of the population, degenerative lumbar spine diseases tend to increase its number exponentially. Several treatment options are available to treat degenerative spinal diseases, such as laminectomies, posterior fusions, and interbody fusions, depending on their locations, correction necessities, and surgeon philosophy. With the advance in technology and surgical knowledge, minimally invasive techniques (MIS) arose as a solution to reduce surgical morbidity, while maintaining the same benefits as the traditionally/open surgeries. Several studies investigated the possible advantages of MIS techniques against the traditional open procedures. However, those articles are usually focused only on one technique or on one pathology.

Methods The electronic databases, including PubMed, Google Scholar, Ovid, and BVS, were systematically reviewed. Only original articles in English or Portuguese were added to the review, the revision was performed following the PRISMA guideline.

Results Fifty-three studies were included in the meta-analysis. Of the studied outcomes the Length of Stay Odds of complications, Blood Loss, and Surgery costs presented significantly favored MIS approaches, while the Last FUP ODI score, and Surgery Time did not differ among the groups.

Conclusion Minimally invasive techniques are a remarkably interesting option to traditional open surgeries, as these procedures showed a significant reduction in blood loss, hospitalization time, complications, and surgical costs.

Keywords Minimally invasive surgery · Open surgery · Systematic review · Clinical outcomes · Surgical outcomes

Introduction

With the increase in life expectancy and consequent aging of the population, degenerative lumbar spine diseases tend to increase its number exponentially [1, 2]. Furthermore, the daily life impact of degenerative spinal diseases is not the only negative impact of those conditions; it is estimated that low back pain and similar pathologies become the first cause of work absenteeism worldwide [3].

Several treatment options are available to treat degenerative spinal diseases, such as laminectomies, posterior fusions, and interbody fusions, depending on their locations, correction necessities, and surgeon philosophy [4–6]. Traditionally those techniques were made in an open fashion, which allowed a great visualization of the surgical field; however, it comes with a more morbid and tissue-damaging procedure [7, 8]. Therefore, with the advance in technology and surgical knowledge, minimally invasive techniques (MIS) arose as a solution to reduce surgical morbidity, while maintaining the same benefits of the traditionally/open surgeries, in this way allowing older and weakened patients could have access to the benefits of those surgeries with a reduced risk of complications [9, 10].

Several studies investigated the possible advantages of MIS techniques against the traditional open procedures. Showing that the MIS procedures were usually associated with reduced blood loss, and length of hospital stay, were usually like open surgeries regarding the clinical benefits and surgical duration, and with incremental cost–benefit varying according to the techniques included in the studies [11–13]. However, those articles are usually focused only on one technique or on one pathology [14–16], which might raise questions about whether the observed effects are
exclusively related to a specific condition or technique or if they might be true in a more general aspect.

Therefore, trying to investigate how MIS approaches compare to open techniques in a more general aspect, this work aims to perform a broad systematic revision to identify the effects of minimally invasive surgery versus open surgery without restraining to a specific technique or lumbar degenerative pathology.

Methods

Search and retrieval strategy

The electronic databases, including PubMed, Google Scholar, Ovid, and BVS, were systematically reviewed using the following Search strategy “(((Minimally invasive) AND Open) AND Spine surgery) AND Degenerative)) AND Lumbar).” Only original articles in English or Portuguese were added to the review. Two authors checked all the retrieved references, and any disputes on whether to include an article were settled by mutual consensus. The step-by-step selection process is depicted as a flowchart as recommended by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) (Fig. 1). This study is registered in PROSPERO. However, it has not been evaluated due to the COVID-19 pandemic.

Selection and inclusion criteria

The authors performed the study selection in a two-step fashion. The first consisted of a brief title/abstract analysis in which the authors seek evidence on whether to pass or not the work to the next round. In this round, articles that raised doubt about whether they met the inclusion criteria went to the second round.

For the second round, the author performed a full-text check of the remaining articles. For this time, the inclusion criteria were the following: The article compares an MIS with an open technique (i) it is distinguishable or mentioned which technique is open and which is MIS, (ii) the article presents one of the following outcomes (ODI, VAS, Length of Hospitalization, Blood Loss or Cost analysis, (iii) the article presents mean values and side deviation for both
techniques, (iv) the article is a randomized clinical trial, or a prospective study, or a retrospective study (Fig. 1).

Data extraction

Two authors independently extracted the articles’ data, and any disputes were solved by consensus between the authors. The inclusion of continuous variables only occurred if the article informed the standard deviation or contained information that allowed the calculation of standard deviation for each group. Studies presenting two or more subgroups were divided into the number of the presented subgroups by adding the “− x” to the article id’s side (Ex: 949, 949–1).

Study outcomes

In the current meta-analysis, the outcomes were divided into three categories. One consisted of intraoperative variables, estimated blood loss, and surgical time. Other composed of surgical outcomes, ODI Last FUP, (defined as the last follow up with more than 12 months), the number of complications, and finally, a third category made up of only surgery costs.

Quality assessment

To assess the quality of the included articles, the authors used two tools, for Randomized Clinical Trials, the RoB2Tool from Cochrane Foundation [17], and the Newcastle Ottawa scale (NOS) [18] for Prospective and Retrospective studies. Table 2 presents the itemized and total risk of bias of each article. Two independent authors applied the tools for each article, and in cases of disputes, the “worst” result was kept.

Sensitivity analysis

The sensibility analysis was performed with the leave-one-out method, where one article was removed from the specific outcome meta-analysis. Then the results of each study were plotted into a Cleveland dot plot to show the variation of the result for each of the leave-one-out studies.

Statistical analysis

The results for continuous variables were presented in standard mean differences (SMD), while dichotomous variables in odds ratios (OR). Meanwhile, inter-study heterogeneity was assessed using Cochran’s Q-statistic test, and heterogeneity between the studies included was evaluated using the chi-square test, with a <0.05 indicating heterogeneity. In the presence of heterogeneity, the random-effects model was employed, and in the other cases, the fixed-effects model. Moreover, the publication bias was assessed using the funnel plot and the eggers regression, in which values p <0.05 indicated publication bias. In cases of publication bias, the authors opted to use the trim-fill method of the “meta” package in R, which estimated and adjusted the meta-analysis results to account for the possible publication bias. Moreover, the authors chose to use the fixed-random model when performing the trim-fill [19–21].

Results

Study selection and risk of bias

After the final screening, fifty-three articles were included, with four articles divided into two pieces and one into three pieces (Table 1), totaling fifty-nine analyzed studies. Table 1 also contains the extracted values of each article.

As for the risk of bias, the RCTs in its majority (5/6) had some concerns, with only one bearing an elevated risk of bias. As for the retrospective and prospective cohort articles, only one article (1/47) received a score of 3, with most of the articles receiving a score of 6 (21/47) (Table 2).

Table 3 contains the number of pooled patients and the number of studies included in each of the analyses.

Complications

Thirty-seven articles reported complications after the procedures and were included in the analysis. The included studies presented significant publication bias (p=0.94) or heterogeneity (I² = 6%). The analysis showed a significant reduction in the risk of complications when adopting an MIS approach (OR = 0.56, 95%CI 0.45–0.69, p <0.0001) (Fig. 2).

ODI Last FUP

Sixteen articles harbored enough information and length of FUP to enter the ODI analysis. There was significant heterogeneity (I² = 76%), but no significant publication bias (p=0.20). The results showed that the MIS procedures do not present a significant impact on the reduction of ODI (SMD = −0.14, 95%CI −0.39 to 0.09; p=0.23) (Fig. 3).

Surgical time

Regarding the total surgery duration, twenty-seven articles were included. The sample presented significant heterogeneity (I² = 95%), but no significant publication bias (p=0.32). The MIS approaches did not exert any significant impact on the surgical duration (SMD = −0.27, 95%CI −0.73–0.18, p=0.24) (Fig. 4).
Table 1  Table containing the summary of the collected variables from the selected articles

| Article id | 17       | 23       | 23\1     | 32       |
|-----------|----------|----------|----------|----------|
| First author   | Byval’tsev | Mueller  | Mueller  | Yang     |
| Year         | 2018     | 2019     | 2019     | 2018     |
| Title         | [Minimally invasive dorsal decompression-stabilization surgery in patients with overweight and obesity] | The difference in surgical site infection rates between open and minimally invasive spine surgery for degenerative lumbar pathology: a retrospective single center experience of 1442 cases | The difference in surgical site infection rates between open and minimally invasive spine surgery for degenerative lumbar pathology: a retrospective single center experience of 1442 cases | Microendoscopy-assisted minimally invasive versus open transforaminal lumbar interbody fusion for lumbar degenerative diseases: 5-Year outcomes |

| Pathology      | Mixed   | Mixed   | Mixed   | Mixed   |
|----------------|---------|---------|---------|---------|
| Gender MIS (female/male) | 11/21   | NA/NA   | NA/NA   | 13/17   |
| Gender open (female/male) | 13/28   | NA/NA   | NA/NA   | 20/10   |
| Blood loss MIS (SD) | 130 (NA) | 19 (NA) | 92.3 (NA) | 187.5 (NA) |
| Blood loss open (SD) | 490 (NA) | 60.4 (NA) | 266.4 (NA) | 467.5 (NA) |
| Surgical time MIS (SD) | 105 (NA) | 98.6 (NA) | 186.5 (NA) | 180 (NA) |
| Surgical time open (SD) | 145 (NA) | 121.9 (NA) | 246.4 (NA) | 150 (NA) |
| LoS MIS (SD) | 9 (NA)   | 1.5 (NA) | 4.3 (NA) | 2.5 (NA) |
| LoS open (SD) | 13 (NA)  | 2.5 (NA) | 6.5 (NA) | 4 (NA) |
| Preoperative ODI MIS (SD) | 81 (NA) | NA (NA) | NA (NA) | 52 (NA) |
| Preoperative ODI open (SD) | 79 (NA) | NA (NA) | NA (NA) | 48 (NA) |
| Last FUP ODI MIS(SD) | 8 (NA)   | NA (NA) | NA (NA) | 7 (NA) |
| Last FUP ODI open (SD) | 20 (NA)  | NA (NA) | NA (NA) | 7 (NA) |
| Cost MIS (SD) | NA (NA)  | NA (NA) | NA (NA) | NA (NA) |
| Cost open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | 3/32 | 2/555 | 3/406 | 5/30 |
| Complications open (events/population) | 7/41 | 11/285 | 5/196 | 9/30 |

| Article id | 35       | 37       | 44       | 45       |
|-----------|----------|----------|----------|----------|
| First author   | Wu       | Marengo  | Lee      | Ohba     |
| Year         | 2018     | 2018     | 2017     | 2017     |
| Title         | Comparison of minimally invasive and open transforaminal lumbar interbody fusion in the treatment of single segmental lumbar spondylolisthesis: minimum two-year follow up | Cortical Bone trajectory screws in posterior lumbar interbody fusion: minimally invasive surgery for maximal muscle sparing—a prospective comparative study with the traditional open technique | Outcomes of minimally invasive surgery compared to open posterior lumbar instrumentation and fusion | Comparison of serum markers for muscle damage, surgical blood loss, postoperative recovery, and surgical site pain after extreme lateral interbody fusion with percutaneous pedicle screws or traditional open posterior lumbar interbody fusion |

| Pathology      | Spondylolisthesis | Mixed   | Mixed   | Spondylolisthesis |
|----------------|--------------------|---------|---------|-------------------|
| Article id | 35    | 37    | 44    | 45    | 52   | 52\1 | 55    |
|-----------|-------|-------|-------|-------|------|------|-------|
| Gender MIS (female/male) | 46/33 | 8/12  | 34/26 | 31/15 |      |      |       |
| Gender open (female/male) | 50/38 | 11/9  | 13/16 | 29/27 |      |      |       |
| Blood loss MIS (SD) | 163.7 (49.6) | 276.5 (67.92) | 211.33 (100.23) | 51 (41) |      |      |       |
| Blood loss open (SD) | 243.3 (70.2) | 330.5 (90.41) | 683.79 (1161.1) | 206 (191) |      |      |       |
| Surgical time MIS (SD) | 145.5 (21.5) | 157.45 (21.74) | 170.67 (51.53) | NA (NA) |      |      |       |
| Surgical time open (SD) | 151.4 (19.9) | 169.65 (23.87) | 157.41 (49.38) | NA (NA) |      |      |       |
| LoS MIS (SD) | 5.8 (1.4) | 2.9 (1.37) | 3.8 (2.38) | NA (NA) |      |      |       |
| LoS open (SD) | 7.3 (2.9) | 3.8 (1.32) | 7.38 (4.45) | NA (NA) |      |      |       |
| Preoperative ODI MIS (SD) | 60.7 (10.6) | 68 (37) | 50.95 (18.55) | 21.2 (6.9) |      |      |       |
| Preoperative ODI open (SD) | 62.1 (10.6) | 58 (15) | 55.17 (11.64) | 19.2 (6.5) |      |      |       |
| Last FUP ODI MIS (SD) | 25.3 (6.3) | 9 (10) | 25.48 (12.92) | 9.2 (7.4) |      |      |       |
| Last FUP ODI open (SD) | 25.3 (6.2) | 23 (9) | 36.41 (10.91) | 13.5 (6.4) |      |      |       |
| Cost MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |      |      |       |
| Cost Open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |      |      |       |
| Complications MIS (events/population) | 10/79 | NA/20 | 6/60 | 6/56 |      |      |       |
| Complications open (events/population) | 12/88 | NA/20 | 6/29 | 2/46 |      |      |       |
| Article id | 46 | 52 | 52\1 | 55 |
| First author | Price | Mummaneni | Mummaneni | Tian |
| Year | 2018 | 2017 | 2017 | 2017 |
| Title | Clinical and radiologic comparison of minimally invasive surgery with traditional open transforaminal lumbar interbody fusion: a review of 452 patients from a single center | Minimally invasive versus open fusion for Grade I degenerative lumbar spondylolisthesis: analysis of the quality outcomes database | Minimally invasive versus open fusion for grade I degenerative lumbar spondylolisthesis: analysis of the quality outcomes database | Computer-assisted minimally invasive transformaminal lumbar interbody fusion may be better than open surgery for treating degenerative lumbar disease |
| Pathology | Mixed | Spondylolisthesis | Spondylolisthesis | Mixed |
| Gender MIS (female/male) | 99/49 | 42/34 | 11/4 | 14/16 |
| Gender open (female/male) | 198/106 | 115/66 | 39/34 | 8/23 |
| Blood loss MIS (SD) | 133 (NA) | 143 (NA) | 220 (NA) | 142.17 (72.01) |
| Blood loss open (SD) | 411 (NA) | 290 (NA) | 512 (NA) | 231.29 (109.84) |
| Surgical time MIS (SD) | 149 (NA) | 212 (NA) | 282 (NA) | 159.2 (20.12) |
| Surgical time open (SD) | 190 (NA) | 190 (NA) | 226 (NA) | 113.06 (23.19) |
| LoS MIS (SD) | 3.2 (NA) | 3.21 (NA) | 4 (NA) | 4.53 (1.5) |
| LoS open (SD) | 4.3 (NA) | 3.36 (NA) | 3.88 (NA) | 5.58 (0.79) |
| Preoperative ODI MIS (SD) | 42 (NA) | 48.1 (NA) | 55.3 (NA) | 43.56 (4.85) |
Table 1 (continued)

| Article id | 46 | 52 | 52\1 | 55 |
|------------|----|----|------|----|
| First author | Guan | Adogwa | Radcliff | Mobbs |
| Year | 2016 | 2015 | 2014 | 2014 |
| Title | Comparison of clinical outcomes in the national neurosurgery quality and outcomes database for open versus minimally invasive transforaminal lumbar interbody fusion | A prospective, multi-institutional comparative effectiveness study of lumbar spine surgery in morbidly obese patients: does minimally invasive transforaminal lumbar interbody fusion result in superior outcomes? | What is the rate of lumbar adjacent segment disease after percutaneous versus open fusion? | Outcomes after decompressive laminectomy for lumbar spinal stenosis: comparison between minimally invasive unilateral laminectomy and open laminectomy: clinical article |
| Pathology | Mixed | Mixed | Mixed | Estenose |
| gender MIS (female/male) | 25/19 | 20/20 | 16/7 | 22/5 |
| Gender open (female/male) | 24/30 | 61/47 | 17/13 | 13/14 |
| Blood loss MIS (SD) | 120.2 (63.7) | NA (NA) | NA (NA) | 40 (NA) |
| Blood loss open (SD) | 306.5 (165.7) | NA (NA) | NA (NA) | 110 (NA) |
| Surgical time MIS (SD) | 329.3 (69.3) | NA (NA) | NA (NA) | NA (NA) |
| Surgical time open (SD) | 234.9 (67.4) | NA (NA) | NA (NA) | NA (NA) |
| LoS MIS (SD) | 5 (1.3) | NA (NA) | NA (NA) | NA (NA) |
| LoS open (SD) | 3.8 (1.3) | NA (NA) | NA (NA) | NA (NA) |
| Preoperative ODI MIS (SD) | 24.1 (7.5) | 50.18 (16.74) | NA (NA) | 51.4 (19.4) |
| Preoperative ODI open (SD) | 22.9 (8.3) | 49.15 (15.21) | NA (NA) | 46.6 (18.9) |
| Last FUP ODI MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Last FUP ODI open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Cost MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Cost open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | NA/44 | NA/76 | NA/15 | NA/31 |
| Complications Open (events/population) | NA/304 | NA/181 | NA/73 | NA/30 |


Table 1 (continued)

| Article id | 88 | 113 | 124 | 125 |
|------------|----|-----|-----|-----|
| Complications open (events/population) | NA/54 | NA/108 | 20/30 | 3/27 |
| Article id | 133 | 134 | 136 | 140 |
| First author | Singh | Gu | Brodano | Lau |
| Year | 2014 | 2014 | 2015 | 2013 |
| Title | A perioperative cost analysis comparing single-level minimally invasive and open transforaminal lumbar interbody fusion | Comparison of minimally invasive versus open transforaminal lumbar interbody fusion in two-level degenerative lumbar disease | Comparison of minimally invasive versus open surgery for degenerative disk disease and spondylolisthesis grade I | Comparison of perioperative outcomes following open versus minimally invasive transforaminal lumbar interbody fusion in obese patients |
| Pathology | Mixed | Mixed | Mixed | Mixed |
| Gender MIS (female/male) | 10/23 | 25/19 | 12/18 | 19/19 |
| Gender Open (female/male) | 12/21 | NA/15.23 | 14/20 | 11/12 |
| Blood loss MIS (SD) | 124.4 (92) | 248.4 (94.3) | 230 (NA) | 141.7 (125.1) |
| Blood loss open (SD) | 380.3 (191.2) | 576.3 (176.2) | 620 (NA) | 741.3 (453.7) |
| Surgical time MIS (SD) | 115.8 (28.2) | 195.5 (28) | 2.4 (NA) | NA (NA) |
| Surgical time open (SD) | 186 (31) | 186.6 (23.4) | 1.7 (NA) | NA (NA) |
| LoS MIS (SD) | 2.3 (1.2) | 9.3 (3.7) | 4.1 (NA) | 3 (2) |
| LoS open (SD) | 2.9 (1.1) | 12.1 (3.6) | 7.4 (NA) | 4.2 (2.1) |
| Preoperative ODI MIS (SD) | NA (NA) | 43.7 (4.3) | 2.6 (6.2) | NA (NA) |
| Preoperative ODI open (SD) | NA (NA) | 44.3 (5.2) | 0.66 (6.6) | NA (NA) |
| Last FUP ODI MIS (SD) | NA (NA) | 16.5 (2) | 3.2 (7.1) | NA (NA) |
| Last FUP ODI open (SD) | NA (NA) | 15.9 (1.9) | 0.6 (5.8) | NA (NA) |
| Cost MIS (SD) | 19,512 (4868) | NA (NA) | NA (NA) | NA (NA) |
| Cost open (SD) | 23,550 (3501) | NA (NA) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | NA/33 | 5/44 | 1/30 | 7/38 |
| Complications open (events/population) | NA/33 | 4/38 | 2/34 | 6/23 |
| Article id | 140/1 | 140/2 | 142 | 149 |
| First Author | Lau | Lau | Rodriguez-Vela | Archavlis |
| Year | 2013 | 2013 | 2013 | 2013 |
| Title | Comparison of perioperative outcomes following open versus minimally invasive transforaminal lumbar interbody fusion in obese patients | Comparison of perioperative outcomes following open versus minimally invasive transforaminal lumbar interbody fusion in obese patients | Clinical outcomes of minimally invasive versus open approach for one-level transforaminal lumbar interbody fusion at the 3- to 4-year follow-up | Comparison of minimally invasive fusion and instrumentation versus open surgery for severe stenotic spondylolisthesis with high-grade facet joint osteoarthritis |
Table 1 (continued)

| Article id | 1401 | 1402 | 142 | 149 |
|------------|------|------|-----|-----|
| Pathology  | Mixed| Mixed| Degenerative disc disease | Spondylolisthesis |
| Gender MIS (female/male) | 14/12 | 7/7 | 7/14 | 14/10 |
| Gender open (female/male) | 11/8 | 4/3 | 7/13 | 17/8 |
| Blood loss MIS (SD) | 153.5 (114.2) | 269.2 (269.2) | NA (NA) | 185 (140) |
| Blood loss Open (SD) | 596.8 (415.7) | 614.3 (449.7) | NA (NA) | 255 (468) |
| Surgical time MIS (SD) | NA (NA) | NA (NA) | NA (NA) | 220 (48) |
| Surgical time open (SD) | NA (NA) | NA (NA) | NA (NA) | 190 (65) |
| LoS MIS (SD) | 3 (1.4) | 3 (1.4) | NA (NA) | 7 (NA) |
| LoS open (SD) | 4.7 (2.1) | 4.7 (2.1) | NA (NA) | 11 (NA) |
| Preoperative ODI MIS (SD) | NA (NA) | NA (NA) | 28.85 (5.52) | 46 (NA) |
| Preoperative ODI open (SD) | NA (NA) | NA (NA) | 27.19 (8.19) | 48 (NA) |
| Last FUP ODI MIS (SD) | NA (NA) | NA (NA) | 12.09 (7.59) | 23 (NA) |
| Last FUP ODI open (SD) | NA (NA) | NA (NA) | 18.1 (12.45) | 24 (NA) |
| Cost MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Cost open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | 3/26 | 2/14 | NA/21 | 7/24 |
| Complications open (events/population) | 4/19 | 3/7 | NA/20 | 7/25 |

| Article id | 151 | 153 | 155 | 157 |
|------------|-----|-----|-----|-----|
| First author | Parker | Zairi | Lucio | Pelton |
| Year | 2014 | 2013 | 2012 | 2012 |
| Title | Minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis: comparative effectiveness and cost-utility analysis | Transforaminal lumbar interbody fusion: comparison between open and minimally invasive approaches with two years follow-up | Economics of less invasive spinal surgery: an analysis of hospital cost differences between open and minimally invasive instrumented spinal fusion procedures during the perioperative period | A comparison of perioperative costs and outcomes in patients with and without workers’ compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion |

| Pathology | Spondylolisthesis | Mixed | Mixed | Spondylolisthesis |
| Gender MIS (female/male) | 34/16 | 20/20 | 61/48 | 2/9 |
| Gender open (female/male) | 32/18 | 32/28 | 56/45 | 3/10 |
| Blood loss MIS (SD) | NA (NA) | 148 (NA) | NA (NA) | 127 (103.35) |
| Blood loss Open (SD) | NA (NA) | 486 (NA) | NA (NA) | 254 (48.66) |
| Surgical time MIS (SD) | NA (NA) | 170 (NA) | 162.3 (NA) | 116 (30.26) |
| Surgical time open (SD) | NA (NA) | 186 (NA) | 156.5 (NA) | 184 (32.31) |
| LoS MIS (SD) | NA (NA) | 4.5 (NA) | 1.2 (NA) | 2 (0.786) |
| LoS open (SD) | NA (NA) | 5.5 (NA) | 3.2 (NA) | 3 (0.94) |
| Article id | 151 | 153 | 155 | 157 |
|-----------|-----|-----|-----|-----|
| Preoperative ODI MIS (SD) | 32.3 (6.7) | 60 (2) | NA (NA) | NA (NA) |
| Preoperative ODI open (SD) | 34.3 (7.9) | 60 (2) | NA (NA) | NA (NA) |
| Last FUP ODI MIS (SD) | 11 (9.4) | 30 (2) | NA (NA) | NA (NA) |
| Last FUP ODI Open (SD) | 15.6 (10.3) | 30 (1) | NA (NA) | NA (NA) |
| Cost MIS (SD) | 38,563 (10,594) | NA (NA) | 25,272 (NA) | 19,705 (5391) |
| Cost open (SD) | 47,858 (20,148) | NA (NA) | 23,686 (NA) | 24,115 (3313) |
| Complications MIS (events/population) | 3/30 | 1/40 | 5/109 | NA/11 |
| Complications open (events/population) | 2/33 | 5/60 | 14/101 | NA/13 |

| Article id | 157/1 | 159 | 160 | 161 |
|-----------|-------|-----|-----|-----|
| First author | Pelton | Mobbs | Wang | Harris |
| Year | 2012 | 2012 | 2011 | 2011 |
| Title | A comparison of perioperative costs and outcomes in patients with and without workers’ compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion | Minimally invasive surgery compared to open spinal fusion for the treatment of degenerative lumbar spine pathologies | Minimally invasive lumbar interbody fusion via MAST quadrant retractor versus open surgery: a prospective randomized clinical trial | Mini-open versus open decompression and fusion for lumbar degenerative spondylolisthesis with stenosis |
| Pathology | Spondylolisthesis | Mixed | Mixed | Spondylolisthesis |
| Gender MIS (female/male) | 8/14 | 18/19 | 17/24 | 20/10 |
| Gender open (female/male) | 9/11 | 14/16 | 15/23 | 12/9 |
| Blood loss MIS (SD) | 124 (61.5) | NA (NA) | 207.7 (57.6) | 208 (NA) |
| Blood loss Open (SD) | 288 (121.17) | NA (NA) | 258.9 (122.2) | 335 (NA) |
| Surgical time MIS (SD) | 110 (34.35) | NA (NA) | 168.7 (36.4) | 150 (NA) |
| Surgical time open (SD) | 185 (35.57) | NA (NA) | 145 (26.8) | 156 (NA) |
| LoS MIS (SD) | 2 (0.64) | 5.889 (3.133) | 6.4 (2.5) | 2.5 (NA) |
| LoS open (SD) | 3 (1.26) | 9.655 (6.699) | 8.7 (2.1) | 3.2 (NA) |
| Preoperative ODI MIS (SD) | NA (NA) | 54.56 (19.47) | NA (NA) | 45.7 (NA) |
| Preoperative ODI open (SD) | NA (NA) | 52.38 (17.25) | NA (NA) | 45.7 (NA) |
| Last FUP ODI MIS (SD) | NA (NA) | 22.97 (16.5) | NA (NA) | 13.9 (NA) |
| Last FUP ODI open (SD) | NA (NA) | 28.09 (16.71) | NA (NA) | 6.4 (NA) |
| Cost MIS (SD) | 19,429 (8179) | NA (NA) | NA (NA) | NA (NA) |
| Cost open (SD) | 26,084 (1208) | NA (NA) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | NA/22 | 2/37 | 3/41 | NA/30 |
Table 1 (continued)

| Article id | 157 | 159 | 160 | 161 |
|------------|-----|-----|-----|-----|
| Complications open (events/population) | NA/20 | 12/30 | 5/38 | NA/21 |

| Article id | 165 | 166 | 169 | 173 |
|------------|-----|-----|-----|-----|
| First author | Kotani | Parker | Parker | Adogwa |
| Year | 2012 | 2012 | 2013 | 2011 |
| Title | Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis | Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years | Cost-utility analysis of minimally invasive versus open multilevel hemilaminectomy for lumbar stenosis | Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life |
| Pathology | Spondylolisthesis | Spondylolisthesis | Estenose | Spondylolisthesis |
| Gender MIS (female/male) | 29/14 | 8/7 | 9/18 | 8/7 |
| Blood loss MIS (SD) | 181 (NA) | 200 (NA) | NA (NA) | 200 (NA) |
| Blood loss open (SD) | 453 (NA) | 295 (NA) | NA (NA) | 295 (NA) |
| Surgical time MIS (SD) | 172 (33) | 300 (NA) | NA (NA) | 300 (NA) |
| Surgical time open (SD) | 176 (37) | 210 (NA) | NA (NA) | 210 (NA) |
| LoS MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| LoS open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Preoperative ODI MIS (SD) | 52 (13.2) | 36.9 (6.3) | NA (NA) | 36.9 (6.3) |
| Preoperative ODI open (SD) | 48.96 (10.8) | 34.3 (11.5) | NA (NA) | 34.3 (11.5) |
| Last FUP ODI MIS (SD) | NA (NA) | NA (NA) | NA (NA) | 15.7 (8.9) |
| Last FUP ODI open (SD) | NA (NA) | NA (NA) | NA (NA) | 17.1 (9.5) |
| Cost MIS (SD) | NA (NA) | 35,996 (10,008) | 23,109 (156.73) | NA (NA) |
| Cost open (SD) | NA (NA) | 44,727 (15,223) | 25,420 (154.2) | NA (NA) |
| Complications MIS (events/population) | NA/43 | NA/15 | NA/27 | NA/15 |
| Complications open (events/population) | NA/37 | NA/15 | NA/27 | NA/15 |

| Article id | 182 | 185 | 187 | 188 |
|------------|-----|-----|-----|-----|
| First author | Villavice | Shunwu | Wang | Ntoukas |
| Year | 2010 | 2010 | 2010 | 2010 |
| Article id | 182 | 185 | 187 | 188 |
|-----------|-----|-----|-----|-----|
| Title     | Minimally invasive versus open transforaminal lumbar interbody fusion | Minimally invasive transforaminal lumbar interbody fusion for the treatment of degenerative lumbar diseases | Comparison of one-level minimally invasive and open transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2 | Minimally invasive approach versus traditional open approach for one level posterior lumbar interbody fusion |
| Pathology | Mixed | Mixed | Spondylolisthesis | Mixed |
| Gender MIS (female/male) | 31/45 | 14/18 | 29/13 | 7/13 |
| Gender open (female/male) | 25/38 | 16/14 | 27/16 | 9/11 |
| Blood loss MIS (SD) | 163 (131.2) | 399.8 (125.8) | 264 (89) | 135 (98) |
| Blood loss open (SD) | 366.8 (298.2) | 517 (147) | 673 (145) | 432 (151) |
| Surgical time MIS (SD) | 222.5 (67.5) | 159.2 (21.7) | 156 (32) | 275 (73) |
| Surgical time open (SD) | 214.9 (60) | 142.8 (22.5) | 145 (27) | 152 (38) |
| LoS MIS (SD) | 3 (2.3) | 9.3 (2.6) | 10.6 (2.5) | 5 (2.2) |
| LoS open (SD) | 4.2 (3.5) | 12.5 (1.8) | 14.6 (3.8) | 10 (3.1) |
| Preoperative ODI MIS (SD) | NA (NA) | 49.7 (11.8) | 41.2 (6.6) | 74 (5) |
| Preoperative ODI open (SD) | NA (NA) | 52 (12) | 38.5 (7.4) | 72 (6) |
| Last FUP ODI MIS (SD) | NA (NA) | 24.7 (10.1) | 10.8 (3.3) | 15 (4) |
| Last FUP ODI open (SD) | NA (NA) | 27.2 (8.4) | 12.2 (3.9) | 18 (3) |
| Cost MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Cost open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | 24/76 | 49/32 | 5/42 | NA/20 |
| Complications Open (events/population) | 20/63 | 5/30 | 4/43 | NA/20 |

| Article id | 196 | 245 | 290 | 378 |
|-----------|-----|-----|-----|-----|
| First author | Fan Ge Zhu Kuang | Ge Zhu Kuang | Kuang |
| Year | 2010 | 2019 | 2018 | 2017 |
| Title | Multifidus muscle changes and clinical effects of one-level posterior lumbar interbody fusion: minimally invasive procedure versus conventional open approach | Comparative analysis of two transforaminal lumbar interbody fusion techniques: open TLIF versus Wiltse MIS TLIF | Comparing stand-alone oblique lumbar interbody fusion with posterior lumbar interbody fusion for revision of rostral adjacent segment disease: a STROBE-compliant study | Transforminal lumbar interbody fusion versus mini-open anterior lumbar interbody fusion with oblique self-a hored stand-alone cages for the treatment of lumbar disc herniation: a retrospective study with 2-year follow-up |
| Pathology | Mixed | Mixed | Adjacent level disease | Disc herniation |
| Gender MIS (female/male) | 18/10 | 55/56 | 10/7 | 24/18 |
| Gender open (female/male) | 15/16 | 61/55 | 10/9 | 23/17 |
| Blood loss MIS (SD) | 464.4 (217.2) | 197 (223) | 34.9 (4) | 57 (12) |
Table 1 (continued)

| Article id | Blood loss open (SD) | Surgical time MIS (SD) | Surgical time open (SD) | LoS MIS (SD) | LoS open (SD) | Preoperative ODI MIS (SD) | Preoperative ODI open (SD) | Last FUP ODI MIS (SD) | Last FUP ODI Open (SD) | Cost MIS (SD) | Cost open (SD) | Complications MIS (events/population) | Complications open (events/population) |
|------------|---------------------|-----------------------|------------------------|--------------|--------------|--------------------------|--------------------------|------------------------|----------------------|-------------|-------------|--------------------------------------|--------------------------------------|
| 196        | 887.7 (553.2)       | 203.6 (36.6)          | 194.5 (47.2)           | 9.5 (2)      | 15.2 (3.4)   | 69.2 (17.6)             | 69.2 (17.7)             | 10.7 (4)               | 21.2 (6.4)           | NA (NA)     | NA (NA)     | NA/28                                | NA/31                                |
| 245        | 499 (431)           | 240 (75)              | 247 (93)               | 2.7 (1.5)    | 3.6 (1.4)    | NA (NA)                 | NA (NA)                 | NA (NA)                | NA (NA)             | NA (NA)     | NA (NA)     | 13/111                               | 28/116                               |
| 290        | 340.6 (25.2)        | 52.2 (6.2)            | 134.3 (15.8)           | 6 (1.1)      | 13.1 (1.4)   | 53.8 (7.4)             | 54 (6.3)                | 12.8 (2.8)             | 11.8 (1.7)           | NA (NA)     | NA (NA)     | 3/17                                  | 2/19                                 |
| 378        | 295 (81.4)          | 60.4 (20.8)           | 130.7 (45.1)           | NA (NA)      | NA (NA)      | 50.3 (13.1)            | 52.1 (13.6)            | NA (NA)                | 24.4 (7.7)           | NA (NA)     | NA (NA)     | 6/82                                  | NA/40                                |

| Article id | First author | Year | Title | Pathology | Gender MIS (female/male) | Blood loss MIS (SD) | Surgical time MIS (SD) | Surgical time Open (SD) | LoS MIS (SD) | LoS open (SD) | Preoperative ODI MIS (SD) | Preoperative ODI open (SD) | Last FUP ODI MIS (SD) | Last FUP ODI open (SD) |
|------------|--------------|------|-------|-----------|--------------------------|---------------------|------------------------|------------------------|--------------|--------------|--------------------------|--------------------------|------------------------|-------------------------|
| 446        | Hyun         | 2017 | Minimally invasive robotic versus open fluoroscopic-guided spinal instrumented fusions: a randomized controlled trial | Mixed          | 21/9                     | NA (NA)              | 208.5 (62.5)           | 208.5 (66.7)           | 6.8 (2.1)    | 9.4 (5.4)    | 24.5 (7.4)               | 28.9 (8.5)               | 11.7 (7.1)             | 16.6 (7.9)              |
| 531        | Gandhoke     | 2016 | A cost-effectiveness comparison between open transformaminal and minimally invasive lateral lumbar interbody fusions using the incremental cost-effectiveness ratio at 2-year follow-up | Mixed          | 8/7                      | 200 (NA)             | 300 (NA)               | 210 (NA)               | 3 (NA)       | 5 (NA)       | 39.6 (6.3)               | 34.3 (11.5)               | 15.7 (8.9)             | 17.1 (9.5)              |
| 642        | Wang         | 2014 | Comparison of the clinical outcome in overweight or obese patients after minimally invasive versus open transformaminal lumbar interbody fusion | Mixed          | 29/13                    | 274 (99)             | 645 (163)              | 168 (37)               | NA (NA)      | NA (NA)      | 41.1 (10.3)              | 40.2 (9.6)               | 18.2 (5.9)             | 17.4 (7.1)              |
| 670        | Seng         | 2013 | Five-year outcomes of minimally invasive versus open transformaminal lumbar interbody fusion: a matched-pair comparison study | Mixed          | 33/7                     | 127.3 (45.7)          | 405 (80)               | 166 (7)                | 3.6 (0.3)    | 5.9 (0.4)    | 41.3 (20.1)              | 42.1 (16.3)               | 13.6 (2.8)             | 12.3 (1.9)              |
Table 1 (continued)

| Article id | 446 | 531 | 642 | 670 |
|------------|-----|-----|-----|-----|
| Cost MIS (SD) | NA (NA) | NA (NA) | NA (NA) | 21,722 (NA) |
| Cost open (SD) | NA (NA) | NA (NA) | NA (NA) | 20,759 (NA) |
| Complications MIS (events/population) | 1/30 | 0/15 | 4/42 | 6/40 |
| Complications open (events/population) | 1/30 | 0/15 | 7/39 | 8/40 |

| Article id | 786 | 786–1 | 828 | 836 |
|------------|-----|-------|-----|-----|
| First author | Wang | Wang | Ghahreman | Tsutsumimoto |
| Year | 2012 | 2012 | 2010 | 2009 |
| Title | Acute hospital costs after minimally invasive versus open lumbar interbody fusion: data from a US national database with 6106 patients | Acute hospital costs after minimally invasive versus open lumbar interbody fusion: data from a US national database with 6106 patients-1 | Minimal access versus open posterior lumbar interbody fusion in the treatment of spondylolisthesis | Mini-open versus conventional open posterior lumbar interbody fusion for the treatment of lumbar degenerative spondylolisthesis: comparison of paraspinal muscle damage and slip reduction |
| Pathology | Mixed | Mixed | Spondylolisthesis | Spondylolisthesis |
| Gender MIS (female/male) | NA/NA | NA/NA | 13/12 | 8/2 |
| Gender open (female/male) | NA/NA | NA/NA | 14/13 | 7/3 |
| Blood loss MIS (SD) | NA (NA) | NA (NA) | NA (NA) | 352.6 (NA) |
| Blood loss open (SD) | NA (NA) | NA (NA) | NA (NA) | 282 (NA) |
| Surgical time MIS (SD) | NA (NA) | NA (NA) | 220 (NA) | 148.3 (NA) |
| Surgical time open (SD) | NA (NA) | NA (NA) | 203 (NA) | 155.8 (NA) |
| LoS MIS (SD) | 3.3 (2.2) | 3.4 (2.1) | 4 (NA) | NA (NA) |
| LoS open (SD) | 3.6 (2.3) | 4 (3.1) | 7 (NA) | NA (NA) |
| Preoperative ODI MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Preoperative ODI open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Last FUP ODI MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Last FUP ODI open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Cost MIS (SD) | 29,187 (461) | 33,879 (521) | NA (NA) | NA (NA) |
| Cost open (SD) | 29,947 (324) | 35,984 (269) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | NA/951 | NA/716 | 0/25 | NA/10 |
| Complications open (events/population) | NA/1804 | NA/2635 | 3/27 | NA/10 |

| Article id | 888 | 936 | 952 | 955 |
|------------|-----|-----|-----|-----|
| First author | Park | Kim | Luna | Virdee |
| Article id | 888 | 936 | 952 | 955 |
|-----------|-----|-----|-----|-----|
| Year      | 2007 | 2005 | 2018 | 2017 |
| Title     | Comparison of one-level Posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach | Comparison of multifidus muscle atrophy and trunk extension muscle strength: percutaneous versus open pedicle screw fixation | TLIF-MIS vs. TLIF-open: cost evaluation | Comparison of peri-operative and 12-month lifestyle outcomes in minimally invasive transforminal lumbar interbody fusion versus conventional lumbar fusion |
| Pathology | Mixed | Mixed | Mixed | Mixed |
| Gender MIS (female/male) | 24/8 | 5/3 | 6/3 | NA/NA |
| Gender open (female/male) | 16/13 | 7/4 | 4/3 | NA/NA |
| Blood loss MIS (SD) | 432.8 (294.8) | 261.3 (69) | 307 (81.6) | NA (NA) |
| Blood loss open (SD) | 737.9 (224.3) | 769.1 (253.6) | 803 (701.3) | NA (NA) |
| Surgical time MIS (SD) | 191.7 (37.7) | 260 (NA) | 320 (92.6) | 260.4 (9.9) |
| Surgical time open (SD) | 148.8 (24.2) | 258.6 (NA) | 372 (95.2) | 297 (9.2) |
| LoS MIS (SD) | 5.3 (2.6) | 8 (NA) | 6.7 (4.3) | 3.2 (0.3) |
| LoS open (SD) | 10.8 (2.5) | 9.2 (NA) | 11.1 (6.5) | 6.92 (1.1) |
| Preoperative ODI MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Preoperative ODI open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Last FUP ODI MIS(SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Last FUP ODI open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Cost MIS (SD) | NA (NA) | NA (NA) | 11,593 (2240) | NA (NA) |
| Cost open (SD) | NA (NA) | NA (NA) | 10,734 (3036) | NA (NA) |
| Complications MIS (events/population) | 4/32 | 2/8 | NA/9 | 6/36 |
| Complications open (events/population) | 4/29 | 2/11 | NA/7 | 26/60 |

| Article id | 958 | 962 | 966 | 969 |
|-----------|-----|-----|-----|-----|
| First author | Zhang Yee Lee Menezes | Yee | Lee | Menezes |
| Year | 2015 | 2014 | 2012 | 2009 |
| Title | Modified minimally invasive transforminal lumbar interbody fusion using a trans-multifidus approach: a safe and effective alternative to open-TLIF | Comparison of adjacent segment disease after minimally invasive or open transforminal lumbar interbody fusion | Clinical and radiological outcomes of open versus minimally invasive transforminal lumbar interbody fusion | Avaliação clinica radiológica da artrodese lombar transforminal aberta versus minimamente invasiva |
| Pathology | Mixed | Mixed | Mixed | Mixed |
| Gender MIS (female/male) | 27/22 | 28/24 | 52/20 | 13/17 |
| Gender open (female/male) | 27/22 | 11/5 | 50/22 | 7/8 |
| Blood loss MIS (SD) | 75.2 (NA) | NA (NA) | 50.6 (161) | NA (NA) |
Table 1 (continued)

| Article id | 958  | 962  | 966  | 969  |
|------------|------|------|------|------|
| Blood loss open (SD) | 215.2 (NA) | NA (NA) | 447.7 (519.2) | NA (NA) |
| Surgical time MIS (SD) | 91.3 (NA) | NA (NA) | 166.4 (52.1) | 221 (NA) |
| Surgical time open (SD) | 82.5 (NA) | NA (NA) | 181.8 (45.4) | 222 (NA) |
| LoS MIS(SD) | 3.7 (NA) | NA (NA) | 3.2 (2.9) | 3.3 (NA) |
| LoS Open (SD) | 6.9 (NA) | NA (NA) | 6.8 (3.4) | 1.8 (NA) |
| Preoperative ODI MIS (SD) | 51 (NA) | NA (NA) | 48.1 (18.8) | 46.6 (NA) |
| Preoperative ODI open (SD) | 52 (NA) | NA (NA) | 44.4 (18) | 42.3 (NA) |
| Last FUP ODI MIS (SD) | 15 (NA) | NA (NA) | 21.4 (20.9) | 12.6 (NA) |
| Last FUP ODI open (SD) | 16 (NA) | NA (NA) | 20.7 (16.5) | 13.5 (NA) |
| Cost MIS (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Cost open (SD) | NA (NA) | NA (NA) | NA (NA) | NA (NA) |
| Complications MIS (events/population) | 4/49 | 3/52 | 7/72 | 5/30 |
| Complications open (events/population) | 6/49 | 4/16 | 9/72 | 4/15 |

NA Not available

Table 2

| Article id | Study quality | Study design |
|------------|--------------|-------------|
| 17  | 7 Prospective  |  |
| 23  | 7 Retrospective |  |
| 32  | 7 Retrospective |  |
| 44  | 3 Retrospective |  |
| 45  | 5 Prospective |  |
| 52  | 6 Retrospective |  |
| 642  | 7 Retrospective |  |
| 786  | 8 Retrospective |  |
Estimated blood loss

Twenty-nine studies meet the criteria to undergo analysis regarding blood loss. Preliminary analysis showed no significant publication bias \((p = 0.89)\) nor significant heterogeneity among the studies \((I^2 = 38\%)\). As for the treatment effect, MIS surgeries promoted a significant reduction in surgical blood loss \((\text{SMD} = -0.79, 95\% \text{CI} = -0.88 \text{ to } -0.70, p < 0.0001\) \((\text{Fig. 5})\).

Length of stay

Twenty-nine studies reported the length of hospitalization, however, due to significant publication bias \((p = 0.89)\), we applied the trim-fill method. After the trim-fill, 14 artificial studies to balance the publication bias were added to the meta-analysis (marked as “filled: X”). The trim-fill, as expected, showed no publication bias \((p = 0.56)\). Moreover, it presented a significant heterogeneity \((I^2 = 95\%)\) and showed a small reduction of the LoS when using MIS approaches \((\text{SMD} = -0.33, 95\% \text{CI} = -0.60 \text{ to } -0.06, p = 0.01)\) \((\text{Fig. 6})\).

Surgical costs

Nine studies evaluated the total costs of surgery. No publication bias was evidenced by the analysis \((p = 0.86)\). The meta-analysis demonstrated a high heterogeneity \((I^2 = 99\%)\), and that MIS approaches did exert significant effect regarding costs \((\text{SMD} = -2.69, 95\% \text{CI} = -4.49 \text{ to } -0.90, p = 0.002)\) \((\text{Fig. 7})\).

Sensitivity analysis

All outcomes underwent a sensitivity analysis \((\text{Fig. 8})\). ODI “Last FUP,” Surgical Time, and Length of Stay had articles that when removed could change the interpretation of the results, of whether the differences were or not significant. For the ODI, one article \((670)\) when removed led to the LoS and its 95% interval to be under 0 (significantly favoring MIS approaches). For the surgical time, two articles \((88, 670)\) when removed led to the SMD and its 95% interval to be under 0 (significantly favoring MIS approaches). As for the LoS, five articles \((290, 670, 789, 789-1, 955)\) when removed led to the upper 95% of the expected distribution of the SMD crossing the 0-threshold line (No significant differences among the approaches). However, even for those outcomes, the central SMD or OR values were close to the original values for most of the sensitivity analysis \((\text{Fig. 8})\).

Summary of results

Table 4 contains a summary of the treatment effects reported on the above items (Table 4).

Discussion

Minimally invasive techniques were and still are one of the greatest revolutions in spinal surgery, as those techniques allowed surgeons to treat patients that usually require but were too weakened to receive an open procedure and to face its complications \([22]\). However, the MIS techniques are not without pitfalls such as pricy materials and steep learning curves \([23, 24]\).

Complications and length of stay

One of the key points of minimally invasive surgery is its theoretical ability to reduce the intra and postoperative complications involving lumbar surgery. Goldstein et al., 2016 showed in a meta-analysis that using MIS PLIF or TLIF could lead to reduced medical complications compared to the open version of the same procedures \([25]\). Similarly, Hu et al., 2016 showed that using MIS TLIF
**Fig. 2** Forest plot showing the Odds Ratio of complications in MIS versus Open Surgeries. CI Confidence interval, MIS Minimally invasive surgery, OR Odds ratio
significantly reduced the complications rate when compared with the open TLIF procedure [26].

Interestingly studies investigating specifically the use of MIS technology to treat spondylolisthesis showed a significant reduction in length of stay, but not in the complication rates [27, 28].

**Surgical duration and blood loss**

In a recent study comparing MIS versus open TLIFs Hockley et al., showed that patients who underwent MIS procedures had significantly lower surgical time and blood loss [29]. Further, Lu et al., showed that using MIS techniques
to treat spondylolisthesis could lead to a significant reduction in surgical time and blood loss [27].

Similar to when comparing open with MIS decompressions for extraforaminal diskectomy, Akinduro et al., 2017 showed that MIS techniques showed lower blood loss and surgical time [30]. Also, when studying the effects of MIS decompression against open decompressions, Evaniew et al., 2021 showed that patients receiving MIS decompressions had lower blood loss and surgical time [31].

Finally, Qin et al., 2018, also showed the advantages of MIS-TLIFs over open TLIFs in blood loss, however, differently than the previous study, the authors reported higher operative in the MIS-TLIF group [28], in consonance with the findings of the prospective subgroup of Lu et al., 2017 study that showed an increased operative time in MIS surgeries [27], also similar to the findings presented by Miller et al., 2020, who reported no differences in surgical time between patients receiving MIS-TLIF or open TLIF for single-level degenerative pathologies. [32]
**Fig. 5** Forest plot showing the SMD between MIS and Open Surgeries for the Estimated Blood Loss variable. *CI* Confidence interval, *MIS* Minimally invasive surgery, *SMD* Standard mean difference
Like the present study, there is heterogeneity between the effects of MIS surgeries compared to open surgeries regarding the improvement of the quality-of-life measures. Evaniew et al., 2019, in a registry study, reported that patients receiving MIS or open had similar leg pain improvement, with MIS patients having a slightly lower chance to achieve back pain MCIDs at 12 months [31]. Further, Heemserk et al., 2021 showed that pain severity between MIS and open patients was similar, however, the ODI at the last follow-up slightly favored MIS techniques [32] results consistent with the presented by Qin et al., 2019 that reported better ODI outcomes for patients receiving MIS TLIFs to treat spondylolisthesis [28].
Surgical costs

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

In a study published in 2016, Goldstein and collaborators reported a cost-saving from MIS procedures ranging from 2.5 to 49% [25]. Further Vertuani et al. 2018, in a simulation of costs and cost-effectiveness based on the United Kingdom and Italy surgical prices for both MIS and open surgeries, showed that in both countries the MIS techniques were presented with increased cost-effectiveness compared to open procedures [34]. Finally, Droehaag et al. 2021, showed in a recent meta-analysis that MIS-TLIF was more cost-effective than Open TLIF, with all the four included studies lying in the “Less Costly & More Effective” [35].

Limitations

As with every study this study presents its pitfalls and drawbacks. First, we only included studies where the author specified and differentiated between the MIS and open procedure, which might exclude studies where the MIS and open procedures were “of common knowledge,” however, the author assumed that it would be better to leave those studies out than accidentally compare open versus open or MIS versus MIS studies. Another limitation is the high heterogeneity found among several outcomes, which might reduce the true impact of the findings presented in the study. The authors assumed that this heterogeneity is born from the broad revision proposed and the intrinsic difference that occurs in the literature regarding MIS and open techniques comparison. Finally, only studies in Portuguese or English were included, which might have excluded studies published in other languages.

Conclusion

Minimally invasive techniques are a remarkably interesting option to traditional open surgeries, as these procedures showed a significant reduction in blood loss, hospitalization time, complications, and surgical costs.
Fig. 8 Dot plots showing the sensitivity analysis for each of the analyzed variables

Table 4 Summary of the results obtained after the meta-analysis

| Variable                     | Unit   | Treatment effect | Lower CI | Upper CI | p value | Interpretation                        |
|------------------------------|--------|------------------|----------|----------|---------|---------------------------------------|
| Complications                | OR     | -0.56            | -0.78    | -0.36    | <0.001  | Favors MIS                            |
| ODI “last FUP”               | SMD    | -0.14            | -0.39    | 0.09     | 0.23    | No effect                             |
| Surgical time                | SMD    | -0.27            | -0.73    | 0.18     | 0.24    | No effect                             |
| Estimated blood loss (EBL)   | SMD    | -0.79            | -0.91    | -0.68    | <0.001  | Favors MIS (high effect)              |
| Length of stay (LOS)         | SMD    | -0.33            | -0.60    | -0.06    | 0.01    | Favors MIS (small effect)             |
| Costs                        | SMD    | -2.69            | -4.49    | -0.90    | <0.001  | Favors MIS (high effect)              |

CI: Confidence interval; FUP: Follow-up surgery; SMD: Standard mean difference; OR: Odds ratio
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Declarations

Conflict of interest Dr. Luiz Pimenta and Dr. Rodrigo Amaral receive consultancy fees from Alphatec.

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