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REVIEW ARTICLE

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

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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

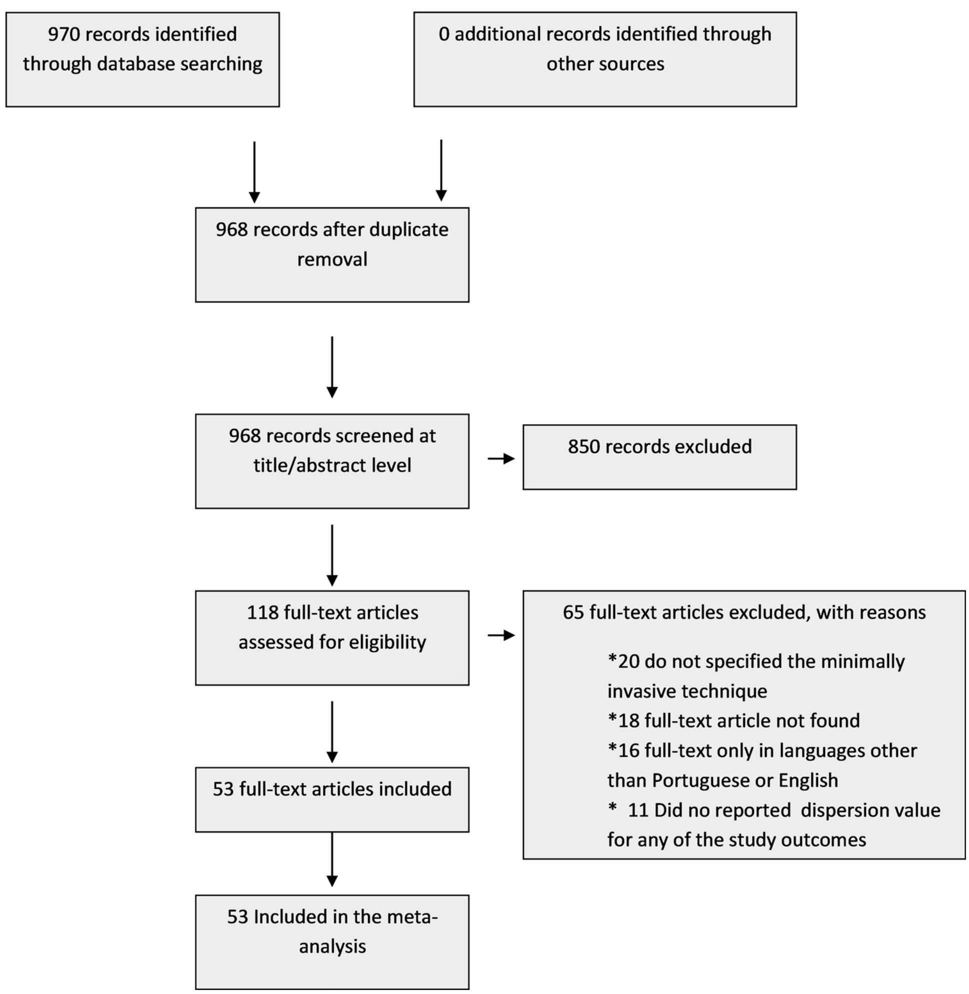
The electronic databases, including PubMed, Google Scholar, Ovid, and BVS, were systematically reviewed using the following Search strategy "(((((Minimally invasive) AND Open) AND Spine surgery) AND Degenerative)) AND Lumbar)." Only original articles in English or Portuguese were added to the review. 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

Fig. 1 Figure showing the flowchart of study selection and extraction



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 calculus 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 RoB-Risk2 Tool 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), totalizing 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 ($I^2 = 6\%$). 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 ($I^2 = 76\%$), 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 ($I^2 = 95\%$), 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

Table 1 (continued)

Article id	35	37	44	45
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 transforaminal 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
Preoperative ODI Open (SD)	46 (NA)	45.1 (NA)	42.1 (NA)	44.71 (5.42)
Last FUP ODI MIS (SD)	23 (NA)	20.49 (16.4)	27.87 (23.2)	17.23 (2.83)
Last FUP ODI Open (SD)	27 (NA)	19.56 (16.9)	26.21 (16)	18.24 (2.38)
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/148	NA/76	NA/15	NA/31
Complications Open (events/population)	NA/304	NA/181	NA/73	NA/30
Article id	88	113	124	125
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 for bilateral decompression 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)	11.61 (25.52)	NA (NA)	NA (NA)
Last FUP ODI open (SD)	NA (NA)	14.88 (22.07)	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/40	15/23	1/27

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	transforaminal lumbar interbody fusion in degenerative disk disease and spondylolisthesis grade I: minimally invasive versus open surgery	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	140\1	140\2	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 mini-open 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)

Table 1 (continued)

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\1	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
Gender open (female/male)	25/12	10/5	16/9	10/5
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 io	Shunwu	Wang	Ntoukas
Year	2010	2010	2010	2010

Table 1 (continued)

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	6/32	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
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	Transforaminal 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	196	245	290	378
Blood loss open (SD)	887.7 (553.2)	499 (431)	340.6 (25.2)	295 (81.4)
Surgical time MIS (SD)	203.6 (36.6)	240 (75)	52.2 (6.2)	60.4 (20.8)
Surgical time open (SD)	194.5 (47.2)	247 (93)	134.3 (15.8)	130.7 (45.1)
LoS MIS (SD)	9.5 (2)	2.7 (1.5)	6 (1.1)	NA (NA)
LoS open (SD)	15.2 (3.4)	3.6 (1.4)	13.1 (1.4)	NA (NA)
Preoperative ODI MIS (SD)	69.2 (17.6)	NA (NA)	53.8 (7.4)	50.3 (13.1)
Preoperative ODI open (SD)	69.2 (17.7)	NA (NA)	54 (6.3)	52.1 (13.6)
Last FUP ODI MIS (SD)	10.7 (4)	NA (NA)	12.8 (2.8)	NA (NA)
Last FUP ODI Open (SD)	21.2 (6.4)	NA (NA)	11.8 (1.7)	24.4 (7.7)
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/28	13/111	3/17	6/82
Complications open (events/population)	NA/31	28/116	2/19	NA/40
Article id	**446**	**531**	**642**	**670**
First author	Hyun	Gandhoke	Wang	Seng
Year	2017	2016	2014	2013
Title	Minimally invasive robotic versus open fluoroscopic-guided spinal instrumented fusions: a randomized controlled trial	A cost-effectiveness comparison between open transforaminal and minimally invasive lateral lumbar interbody fusions using the incremental cost-effectiveness ratio at 2-year follow-up	Comparison of the clinical outcome in overweight or obese patients after minimally invasive versus open transforaminal lumbar interbody fusion	Five-year outcomes of minimally invasive versus open transforaminal lumbar interbody fusion: a matched-pair comparison study
Pathology	Mixed	Mixed	Mixed	Mixed
Gender MIS (female/male)	21/9	8/7	29/13	33/7
Gender open (female/male)	22/8	10/5	27/12	33/7
Blood loss MIS (SD)	NA (NA)	200 (NA)	274 (99)	127.3 (45.7)
Blood loss Open (SD)	NA (NA)	295 (NA)	645 (163)	405 (80)
Surgical time MIS (SD)	208.5 (62.5)	300 (NA)	127 (25)	185 (8.7)
Surgical time Open (SD)	208.5 (66.7)	210 (NA)	168 (37)	166 (7)
LoS MIS (SD)	6.8 (2.1)	3 (NA)	NA (NA)	3.6 (0.3)
LoS open (SD)	9.4 (5.4)	5 (NA)	NA (NA)	5.9 (0.4)
Preoperative ODI MIS (SD)	24.5 (7.4)	39.6 (6.3)	41.1 (10.3)	41.3 (20.1)
Preoperative ODI open (SD)	28.9 (8.5)	34.3 (11.5)	40.2 (9.6)	42.1 (16.3)
Last FUP ODI MIS (SD)	11.7 (7.1)	15.7 (8.9)	18.2 (5.9)	13.6 (2.8)
Last FUP ODI open (SD)	16.6 (7.9)	17.1 (9.5)	17.4 (7.1)	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

Table 1 (continued)

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 transforaminal 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
Year	2015	2014	2012	2009
Title	Modified minimally invasive transforaminal 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 transforaminal lumbar interbody fusion	Clinical and radiological outcomes of open versus minimally invasive transforaminal lumbar interbody fusion	Avaliação clínica radiológica da artrodese lombar transforaminal 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 Table containing the risk of bias evaluation and study design of the selected articles

Article id	Study quality	Study design
17	7	Prospective
23	7	Retrospective
23	7	Retrospective
32	Some concerns	RCT
35	7	Retrospective
37	7	Prospective
44	3	Retrospective
45	5	Prospective
52	6	Retrospective
52	6	Retrospective
55	6	Prospective
88	6	Retrospective
113	7	Prospective
124	4	Retrospective
125	Some concerns	RCT
133	8	Retrospective
134	Some concerns	RCT
136	6	Retrospective
140	6	Retrospective
140	6	Retrospective
140	6	Retrospective
142	6	Prospective
149	7	Retrospective
151	6	Prospective
153	6	Retrospective
155	7	Retrospective
157	6	Prospective
157	6	Prospective
159	7	Retrospective
160	High	RCT
161	6	Prospective
165	7	Prospective
166	6	Prospective
169	6	Retrospective
173	6	Retrospective
182	7	Retrospective
185	Some concerns	RCT
187	6	Retrospective
188	4	Retrospective
196	7	Retrospective
245	6	Retrospective
290	6	Retrospective
378	7	Retrospective
446	Some concerns	RCT
531	7	Retrospective
642	7	Prospective
670	6	Retrospective
786	8	Retrospective
786	8	Retrospective

Table 2 (continued)

Article id	Study quality	Study design
828	6	Retrospective
836	7	Retrospective
888	6	Prospective
936	6	Retrospective
952	5	Retrospective
955	7	Retrospective
958	6	Retrospective
962	7	Retrospective
966	7	Retrospective
969	7	Retrospective

Table 3 Table containing a summary of the total pooled patients and total studies included in each of the analyzed outcomes

Variable	Total pooled patients	# Of included studies
Complications	4264	37
ODI "Last FUP"	1184	16
EBL	2197	29
Surgery time	2185	27
LoS	8153	29
Costs	6347	9

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 (SMD = − 0.79, 95%CI − 0.88 to − 0.70, $p < 0.0001$) (Fig. 5).

Length of stay

Twenty-nine studies reported the length of hospitalization, however, due to significant publication bias ($p = < 0.0001$), 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 (SMD = − 0.33, 95%CI − 0.60 to − 0.06, $p = 0.01$) (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 (SMD = − 2.69, 95%CI − 4.49 to − 0.90, $p = 0.002$) (Fig. 7).

Sensitivity analysis

All outcomes underwent a sensitivity analysis (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 SMD 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 (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

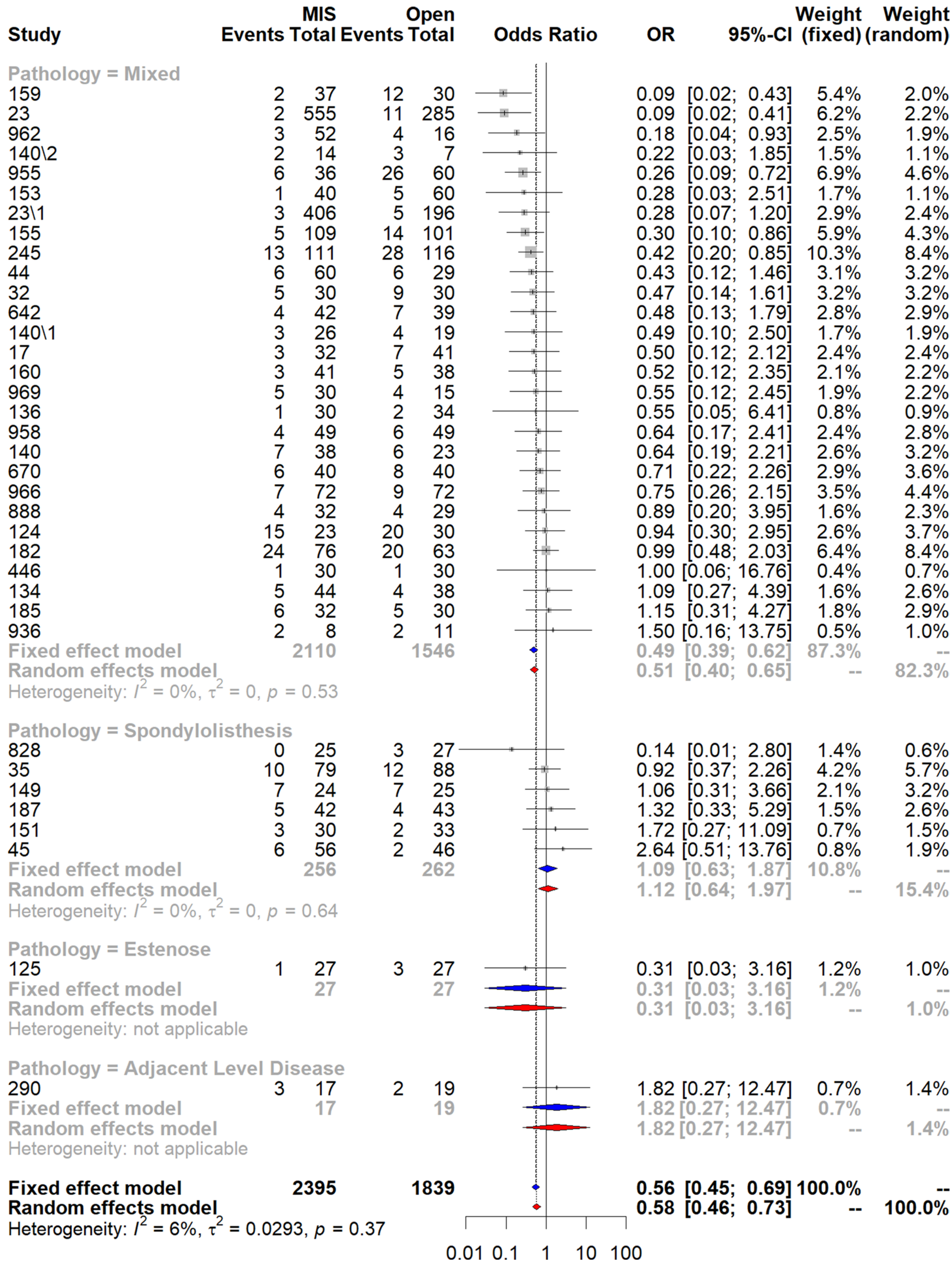


Fig. 2 Forest plot showing the Odds Ratio of complications in MIS versus Open Surgeries. *CI* Confidence interval, *MIS* Minimally invasive surgery, *OR* Odds ratio

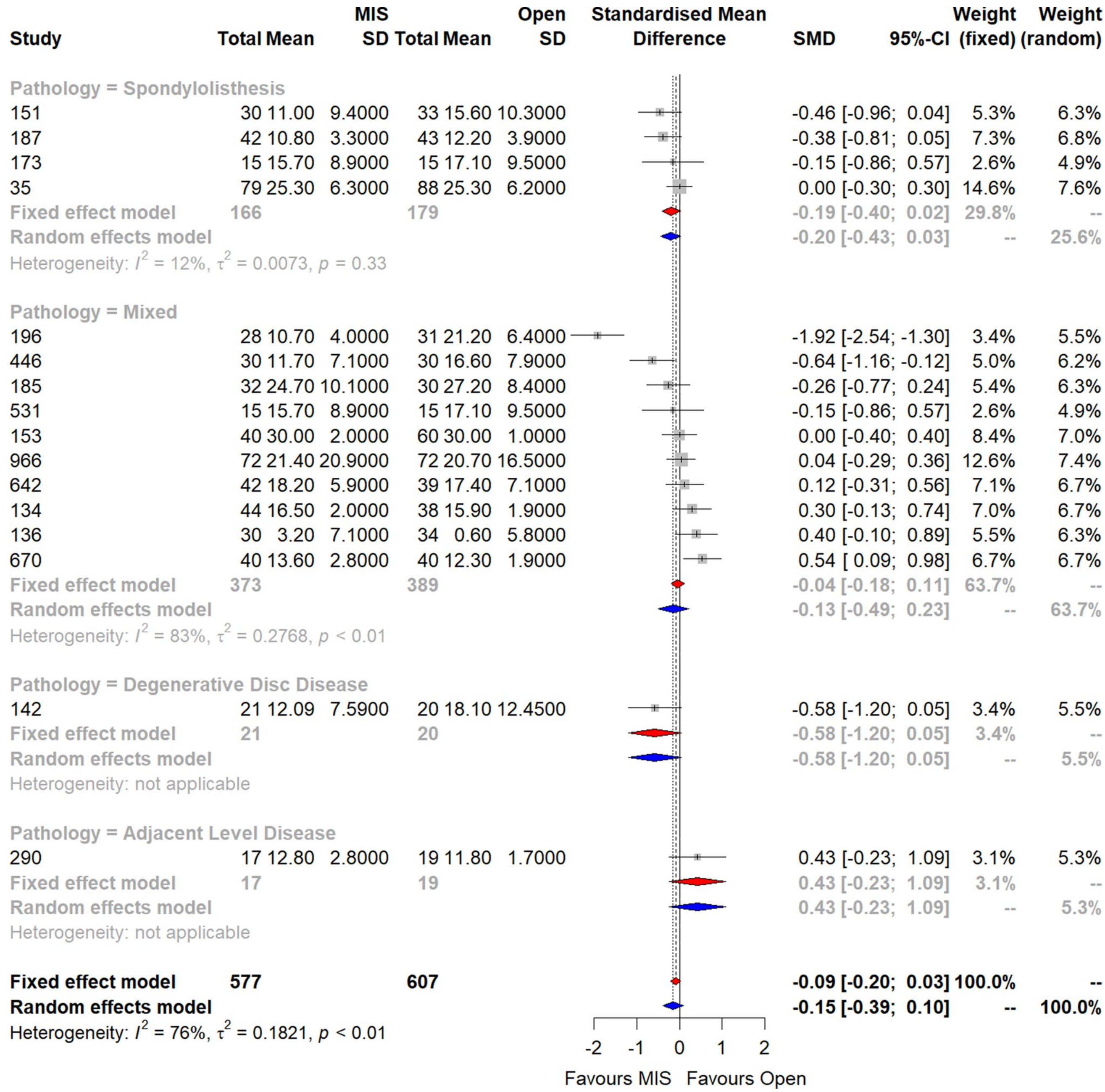


Fig. 3 Forest plot showing the SMD between MIS and Open Surgeries for the ODI Last FUP variable. *CI* Confidence interval, *MIS* Minimally invasive surgery, *SMD* Standard mean difference

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

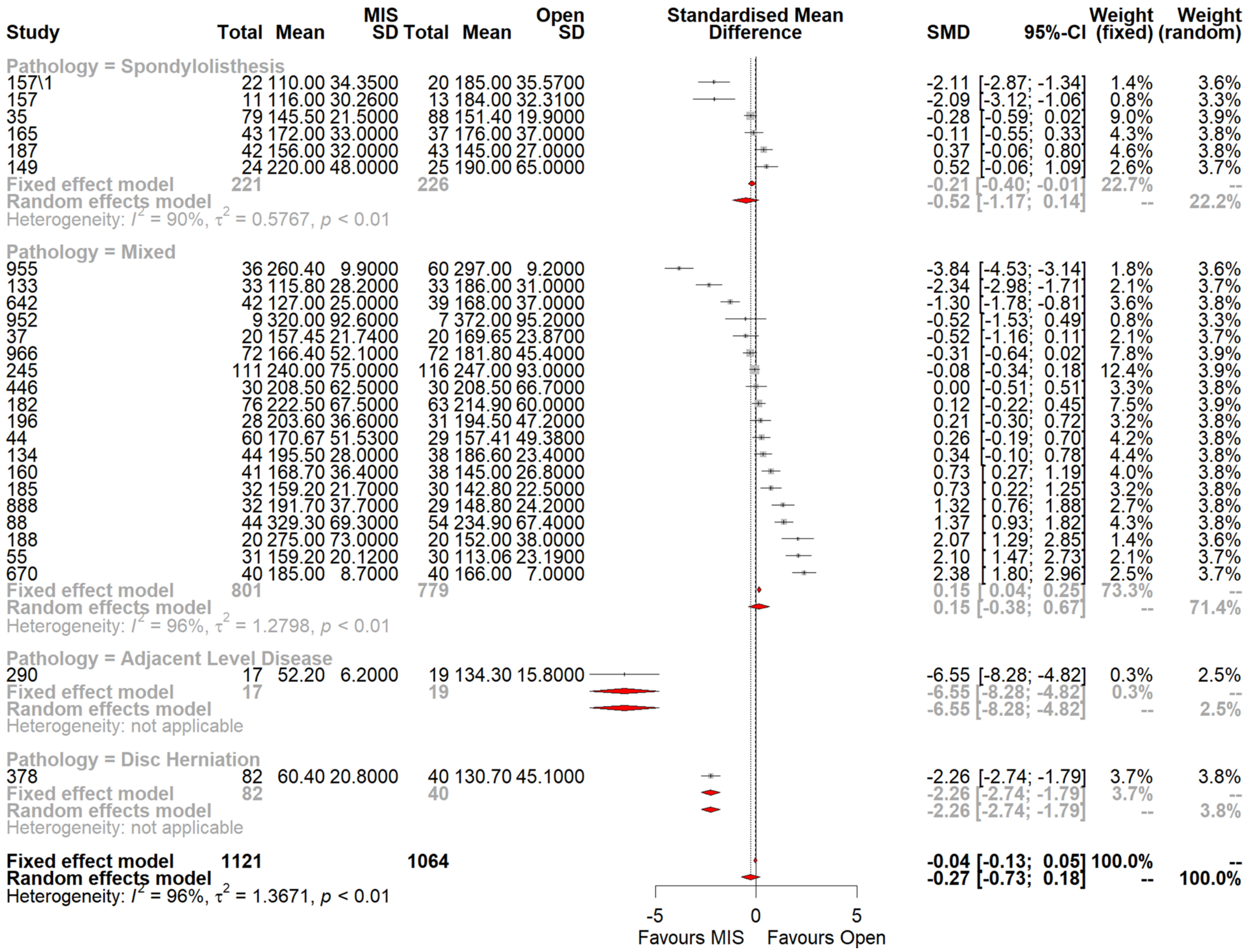


Fig. 4 Forest plot showing the SMD between MIS and Open Surgeries for the Surgery Time variable. *CI* Confidence interval, *MIS* Minimally invasive surgery, *SMD* Standard mean difference

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 loos, 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]

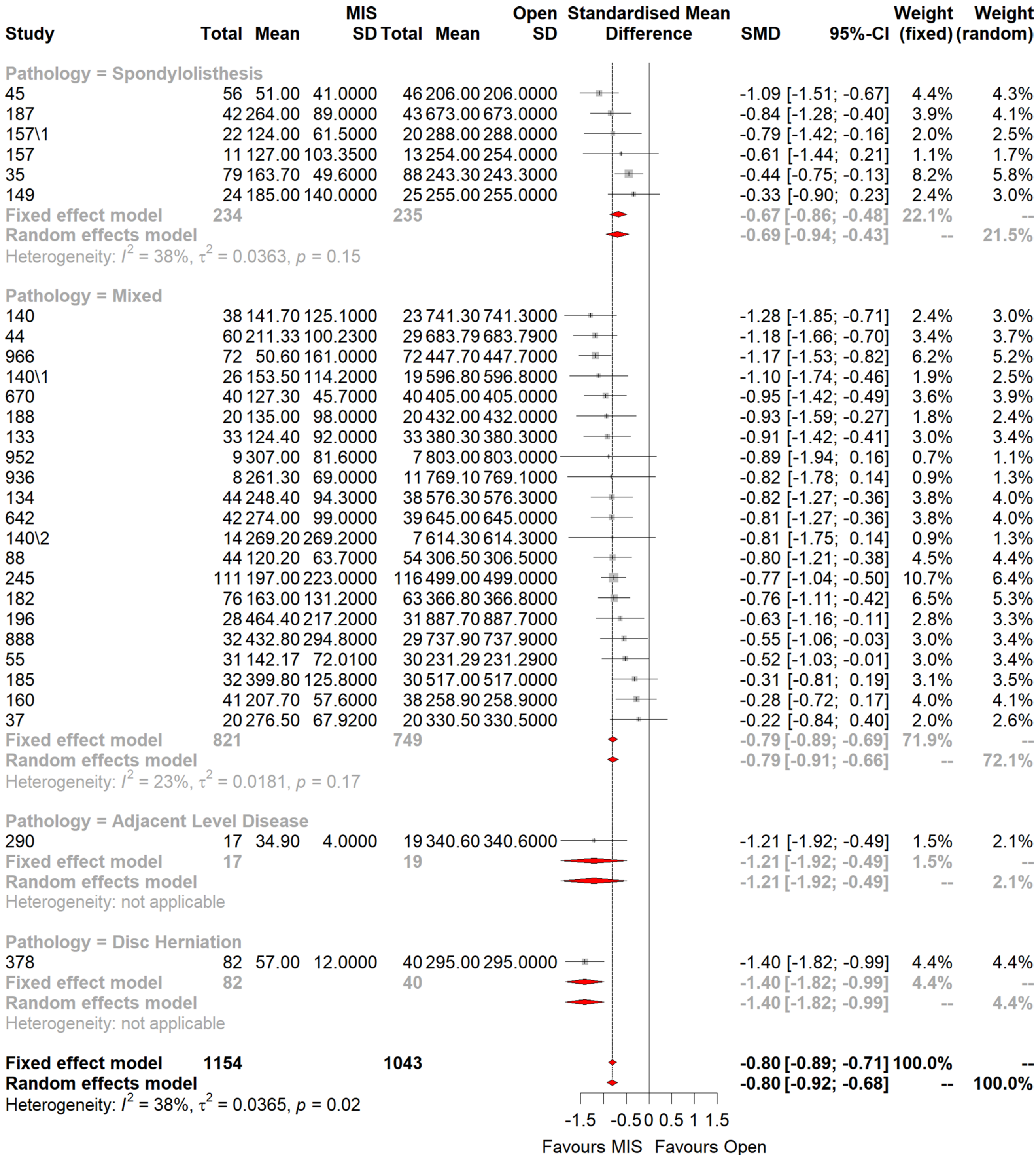


Fig. 5 Forest plot showing the SMD between MIS and Open Surgeries for the Estimated Blood Loss variable. *CI* Confidence interval, *MIS* Minimally invasive surgery, *SMD* Standard mean difference

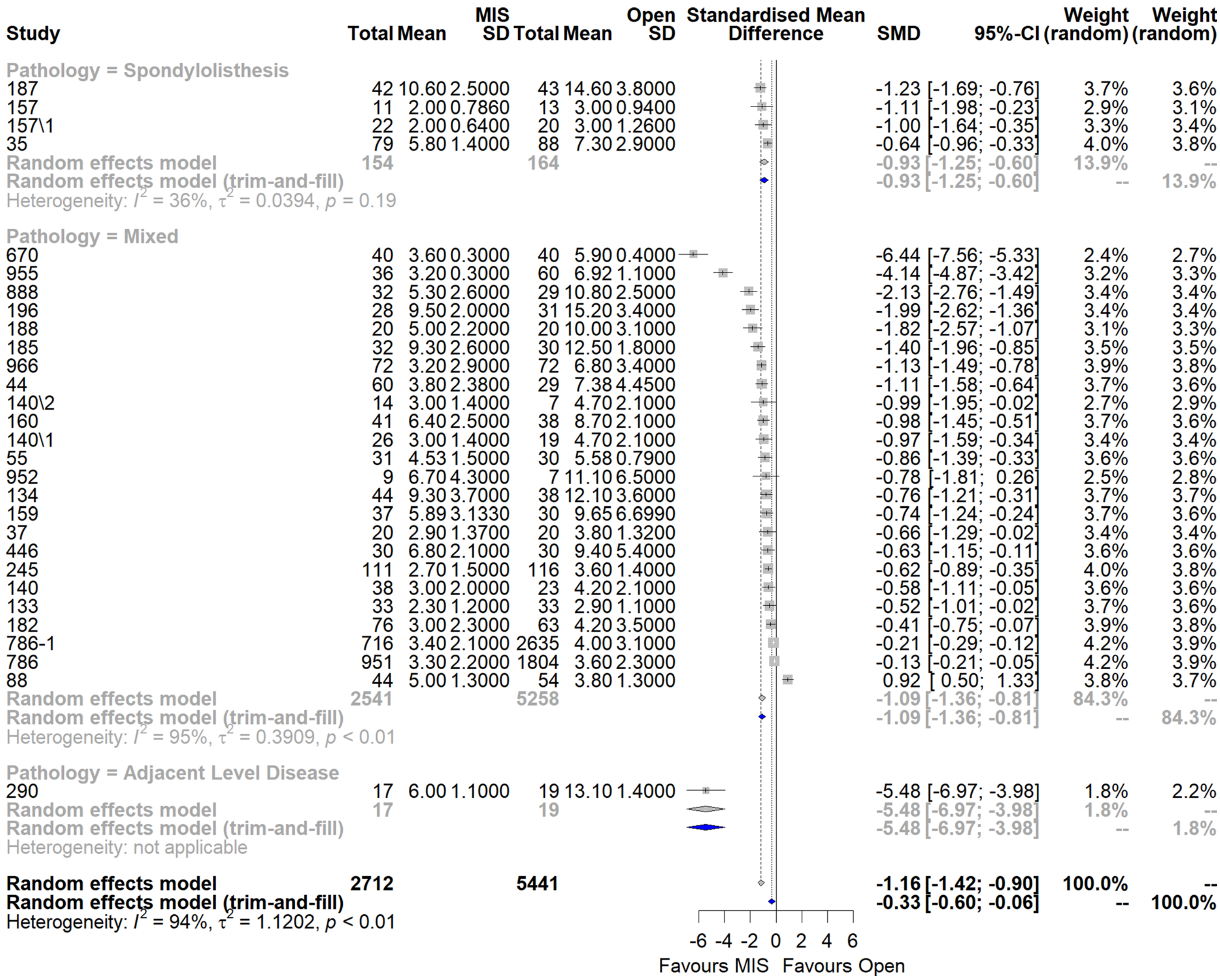


Fig. 6 Forest plot showing the SMD between MIS and Open Surgeries for the Length of Stay variable. *CI*: Confidence interval, *MIS* Minimally invasive surgery, *SMD* Standard mean difference

Quality of life

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 MIS and open surgeries have similar outcomes at two years of follow-up when treating degenerative lumbar diseases [33].

Finally, Miller et al., 2020 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].

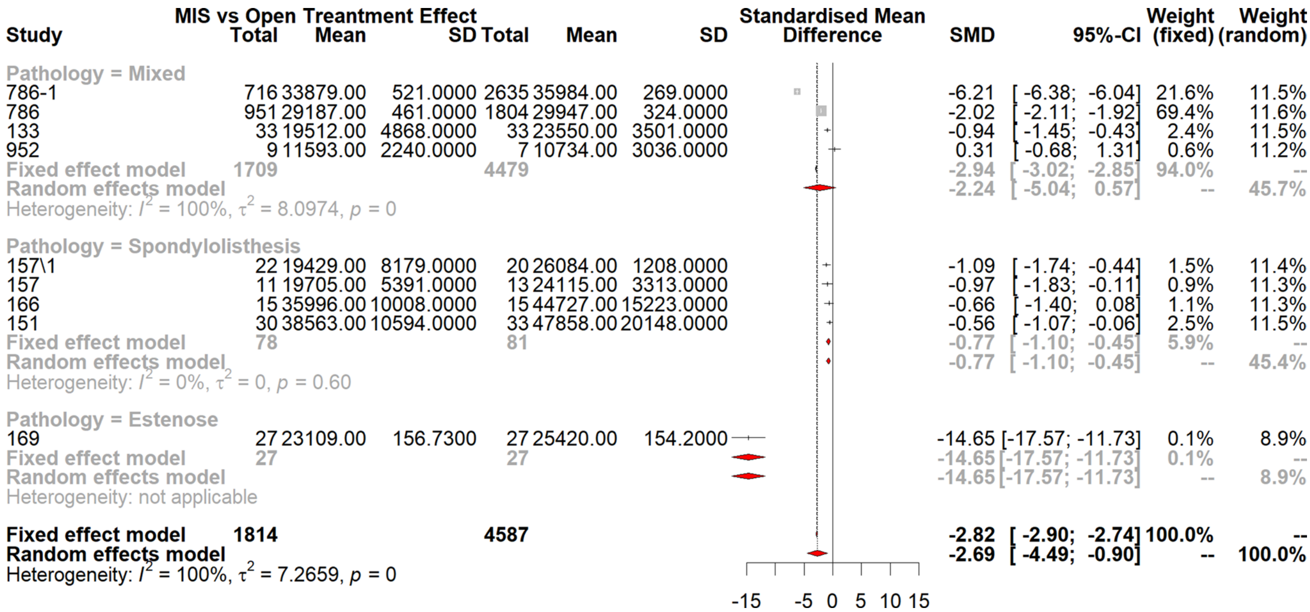


Fig. 7 Forest plot showing the SMD between MIS and Open Surgeries for the Costs variable. *CI* confidence interval, *MIS* Minimally invasive surgery, *SMD* Standard mean difference

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.

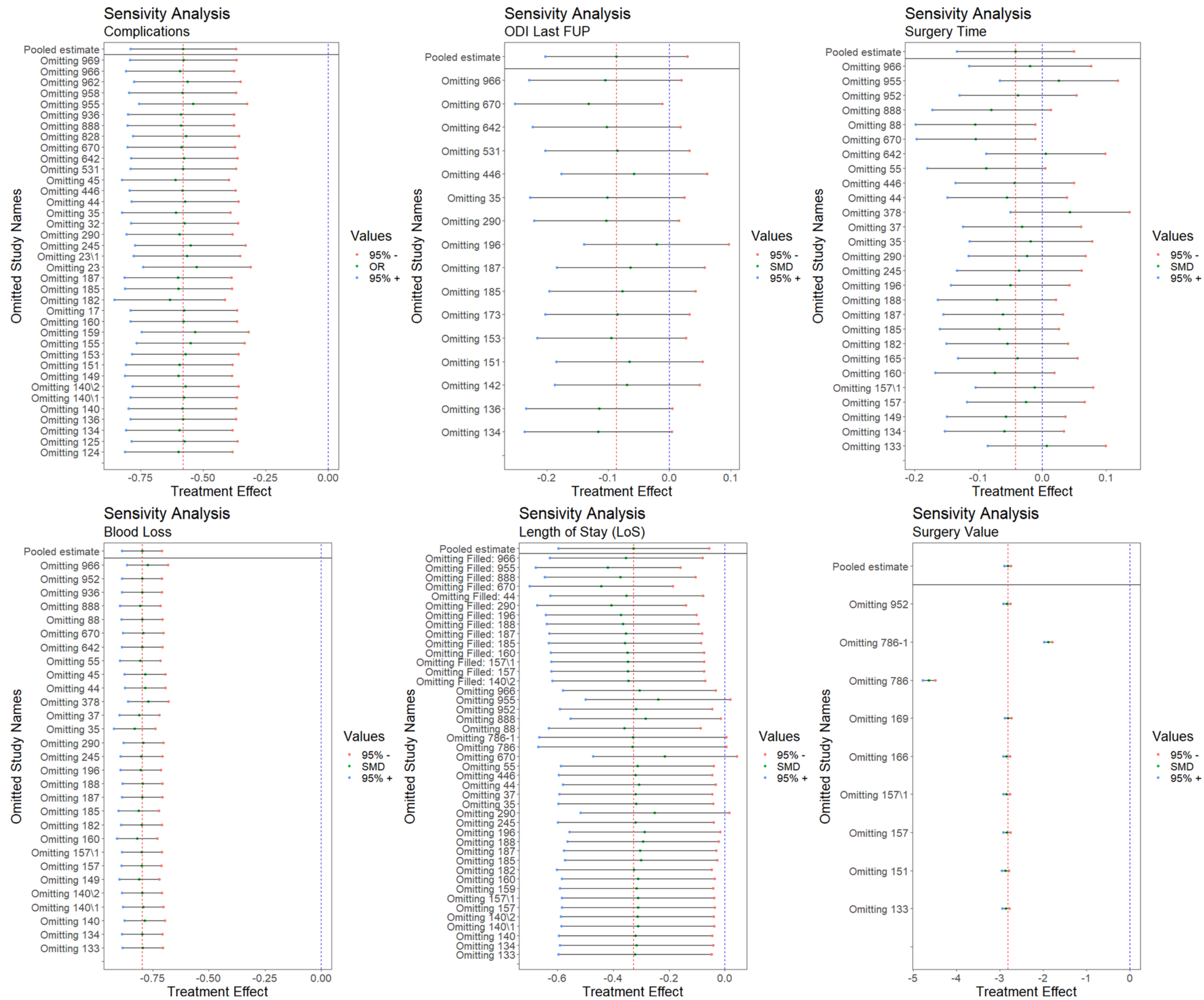


Fig. 8 Dot plots showing the sensitivity analysis for each of the analyzed variables

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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