Original Article

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Minimally Invasive Versus Open Spinal Fusion Surgery for Spondylolisthesis Treatment

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Learning Point of the Article:

Minimally invasive spinal fusion appears to be a safe and effective treatment for Grade I and II spondylolisthesis, with potential advantages in operative time and hospital stay duration compared to open surgery.

Abstract

Background: In recent years, there has been a growing utilization of minimally invasive (MI) techniques, which provide the potential advantages of minimizing surgical stress, post-operative pain, and hospitalization duration. Nevertheless, the existing body of literature primarily comprises of studies conducted at a single medical site, which are of low quality and lack a comprehensive analysis of treatment techniques exclusively focused on spondylolisthesis. We conducted this systematic review and meta-analysis to compare minimally invasive surgery (MIS) and open surgery (OS) spinal fusion outcomes for the treatment of spondylolisthesis. OS spinal fusion is an interventional option for patients with spinal illness who have not had success with non-surgical treatments.

Materials and Methods: This systematic review of the literature regarding MI and OS spinal fusion for spondylolisthesis treatment was performed using the preferred reporting items for systematic reviews and meta-analysis guidelines for article identification, screening, eligibility, and inclusion. Electronic literature search of Medline/PubMed, Cochrane Library, and Google Scholar databases yielded 1078 articles. These articles were screened against established criteria for inclusion into this study.

Results: A total of eight retrospective and four prospective articles with a total of 3354 patients were found. Reported spondylolisthesis grades were I and II only. Overall, MI was associated with lower operative time (mean difference [MD], −6.44 min; 95% confidence interval [CI], −45.57–32.71; P = 0.0001) and shorter length of hospital stay (MD, −0.49 days; 95% CI, −0.58 to −0.40; P = 0.000). There was no significant difference overall between MIS and OS in terms of functional or pain outcomes. Rates of complications were not significantly different between the MI group and the OS group, though overall 75 and 153 complications were observed in MI group and OS group.

Conclusion: Available data indicate that MI spinal fusion is a secure and efficient method for managing Grade I and Grade II spondylolisthesis. Furthermore, whereas prospective trials establish a connection between MI and improved functional outcomes, it is necessary to conduct longer-term and randomized trials to confirm any correlation identified in this study.

Keywords: Minimally invasive spinal fusion, open surgical spinal fusion, lumbar spine fusion, spondylolisthesis, functional outcomes, complication rates, systematic review, meta-analysis.

Introduction

Spondylolisthesis, a condition where a vertebral body is displaced, can lead to radiculopathy, neurogenic claudication, or mechanical low back discomfort [1]. There are two distinct causes of spondylolisthesis: Degenerative spondylolisthesis and isthmic spondylolisthesis. Studies indicate that surgery may be a

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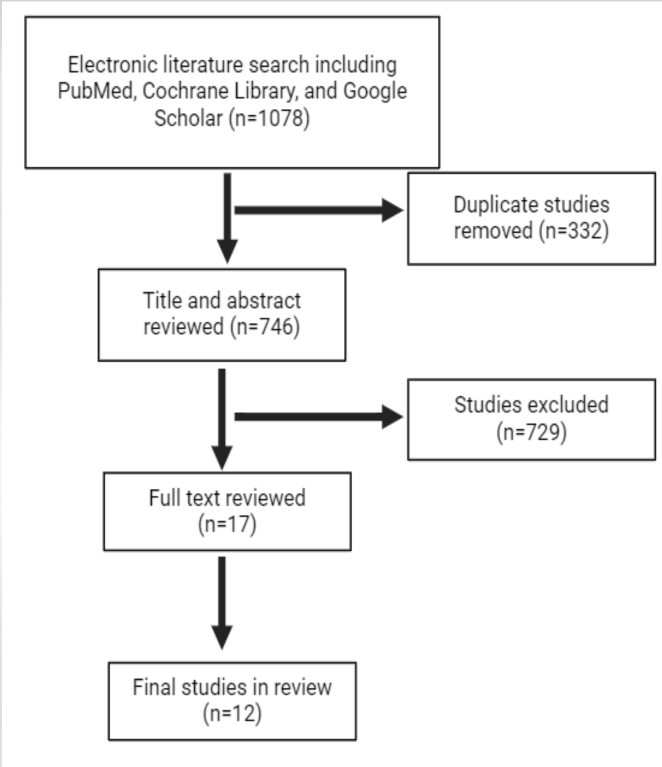

Figure 1 : Preferred reporting items for systematic reviews and meta-analysis flow chart showing the results of a systematic review of the literature with methods of study identification and exclusion

feasible option for individuals whose spondylolisthesis does not respond to conservative treatment, as it has the potential to improve the patient's quality of life [2-5]. Historically, open surgery (OS) with direct decompression and instrumented fusion has been the preferred surgical treatment for degenerative and isthmic spondylolisthesis, as it effectively addresses the instability caused by spinal slippage. Various fusion techniques include anterior lumbar interbody fusion, lateral interbody fusion, transforaminal lumbar interbody fusion (TLIF), posterior lumbar interbody fusion (PLIF), and posterior lumbar fusion (PLF). The prevalence of lumbar spine fusions rose from 9/100,000 person-years in 1997 to 30/100,000 person-years in 2018 [6]. Among women aged over 75 years, there was a 4-fold increase in the occurrence of lumbar spine fusions [5]. According to global estimates, almost 313 million procedures are conducted every year [7], with around 500,000 of these being lumbar spine surgeries in the United States [8]. Approximately 80% of individuals who undergo spine surgery encounter post-surgery discomfort, while over 20% of them will continue to experience severe post-surgical pain.

In the last decade, the MI technique has undergone significant advancements, offering notable benefits such as reduced pain and improved functionality after surgery, faster recovery, decreased blood loss, minimized harm to soft tissues, and preservation of the structural integrity of the paraspinal region while minimizing the formation of scar tissue [9]. The benefits of these advantages are particularly crucial when dealing with spondylolisthesis, as an open approach might exacerbate the instability of the facet joints, ligamentous structures, and muscles, which play a key role in providing support. Multiple studies have examined the perioperative, functional, and pain outcomes of minimally invasive (MI) versus OS for the treatment of common lumbar degenerative conditions including spinal stenosis, disk disease, and spondylolisthesis. As far as we know, only one review on spondylolisthesis has investigated the disparities in pain, function, and perioperative results between MI and OS [10]. The aim of this study was to assess the impact of MI and OS treatment on spondylolisthesis and analyze the results in comparison to other degenerative conditions affecting the lower back.

Materials and Methods

Search strategy

The preferred reporting items for systematic reviews and meta-analyses were used in this investigation. In January 2023, two reviewers (SWM and QAA) conducted independent electronic searches using PubMed, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, EMBASE, and Scopus, without any time constraints. ACP journal club trial registries, dissertations, conference

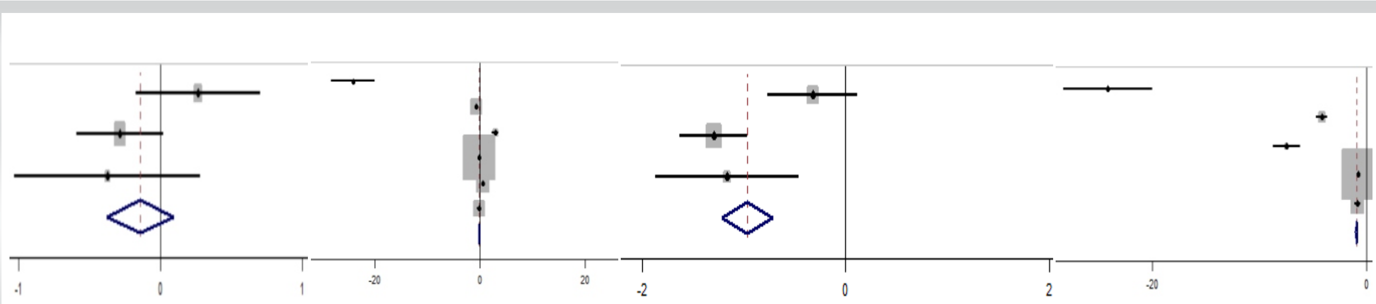

Figure 2: Comparison of perioperative outcomes of minimally invasive versus open spinal fusion spondylolisthesis treatment for (a): Operative time (min); (b): Intraoperative blood loss (mL); (c): Length of hospitalization (days)

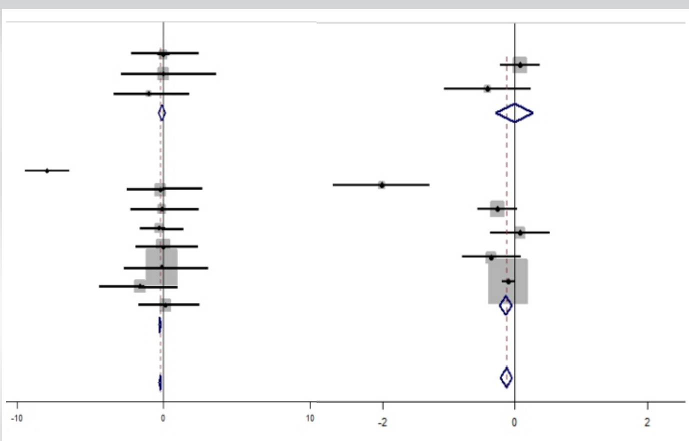

Figure 3: Comparison of final functional and pain outcomes for minimally invasive versus open spinal fusion in spondylolisthesis treatment with (a) Oswestry disability index; (b) Visual Analog Scale. CI: Indicates confidence interval; IV: Inverse variance; MIS: Minimally invasive surgery; OS: Open surgery; SD: Standard deviation

proceedings, and the Database of Abstracts of Review of Effectiveness were also examined for unpublished material. Citations written in English alone were taken into account. In every possible combination, the following terms were utilized in the search strategy as either keywords or Medical Subject Headings: “minimally invasive”/“minimal access,” “lumbar spine”/“lumbar vertebra,” “spinal fusion”/“surgical procedure,” and “spondylolisthesis.” The inclusion and exclusion criteria were applied to evaluate the generated reference lists after they had been compared and examined for possible relevancy.

Selection criteria

The studies included in this meta-analysis and systematic review examined the effectiveness of spinal fusion procedures for treating spondylolisthesis by assessing overall rates of operative success and occurrence of major complications. In this study, complete spinal exposure was necessary for OS treatments, while MI methods included percutaneous, mini-open, and muscle-splitting approaches to the spine. The study’s inclusion criteria consisted of the following: (1) A definitive diagnosis of either degenerative or isthmic lumbar spondylolisthesis only; (2) at least one of the following outcomes measured by the Oswestry disability index (ODI) and Visual Analog Scale (VAS), respectively, including scores for functional ability and pain before and after surgery; and (3) a study design that directly compares different groups or treatments. The exclusion criteria included trials with < 20 patients in each arm, cohorts with lumbar degenerative disorders other than spondylolisthesis, case reports and series without a comparison group, as well as editorials, reviews, opinion pieces, and commentary articles. To ensure that no relevant research was missed, a thorough examination of reference lists was conducted manually.

Data extraction

The data gathered included information on methodology, study design, patient demographics, operation aspects (such as the type of procedure and number of fused vertebral levels), intraoperative blood loss, and operative outcomes (such as length of hospital stay following surgery). The study’s conclusion also included reporting the functional findings, measured by the ODI on a scale ranging from 0% to 100%. The rating method requires individuals to have a bed-bound status ranging from 80% to 100%, and a minor impairment ranging from 0% to 20%. The back pain outcome determined by the VAS was also revealed at the completion of the trial follow-up. The VAS is a numerical scale ranging from 1 to 10, where a score of 1 indicates the absence of pain and a score of 10 represents the highest imaginable amount of misery. Other events that were described included wound infection, revision surgery, and intraoperative durotomy. If the mean and standard deviation of the numbers were not given, we used the available technique and graphs to generate the most accurate estimations [11, 12]. Two reviewers, VR and SK, collected data from papers, tables, and figures, while another reviewer, CM, ensured the accuracy of the data entry.

Cohort comparison

The patient demographics from the studies were analyzed to determine the average age, percentage of males, and number of surgery levels. This analysis was done using a weighted distribution method to account for variations in sample sizes. The continuous variables were compared using a two-sample t-test, while the number of surgical levels was compared using a two-proportion z-test. Statistical significance was determined for a two-tailed value of <0.05.

Meta-analysis of clinical outcomes

The summary statistics utilized were the odds ratio (OR), mean difference (MD), or weighted MD. The current study examined the efficacy of Cohen’s technique utilizing the common-effect inverse-variable model. The I2 statistic was employed to assess the fraction of overall variation among studies that can be attributable to heterogeneity rather than random chance. Values that are >50% are considered to be suggestive of substantial heterogeneity. Given the absence of raw data, it was not possible to carry out comprehensive analyses that consider confounding factors. The P values were computed using a two-tailed test. A pooled estimate of treatment impact for continuous variables was computed by calculating the MD and 95% confidence interval (CI) between outcomes in the MIS and open cohorts. This was done using an inverse-variance weighting method with

Table 1: Comparative demographics and operative outcomes of included studies

Author/year/country	Age (years)		Males/Females (%)		Transforaminal lumbar interbody fusion levels		Complications	
	MIS	OS	MIS	OS	MIS	OS	MIS	OS
Prospective studies								
Lau et al./2011/USA	46.9	56.9	40/60	42/58	L4-L5= 5	L4-L5=6	Wound infection(1), pseudarthrosis(1), intraoperative ventricular tachycardia	1patient(17%) reported pseudarthrosis.
					L5-S1=4	L5-S1=1	followed by deep wound infection requiring hardware removal(1), reoperation(1)	
					L4-S1=1	L4-S1=5	No complications in patients with spondylolisthesis	
Serban et al./2017/Romania	51.3±9.36	50.1±11.09	67/33	74/26	L3-4=2	L3-4=2	No post-operative complication	Superficial wound infection (n=2)
					L4-5=15	L4-5=14		
					L5-S1=23	L5-S1=24		
Wu et al./2018/China	58.1±12.8	55.3±14.0	42/58	43/57	L3-4=6	L3-4=6	Dural tear (1), Screw misplacement(1), contralateral radiculopathy(4), bone nonunion(1)	Dural tear(3), screw misplacement(1), contralateral radiculopathy (3), bone nonunion(1)
					L4-5=44	L4-5=51		
					L5-S1=29	L5-S1=31		
Hartmann et al./2022/Austria	53.7±8.7	59.1±12.6	27/73	22/78	L4-5=10	L4-5=13	Accidental durotomy (1) 6.7%	Accidental durotomy (2) 8.7%
					L5-S1=5	L5-S1=7		
					Bisegmental=0	Bisegmental=3		
Retrospective studies								
Sulaiman and Singh/2014/USA	61.1	56.4	30/70	36/64	L3-4=2	L3-4=4	7% [Malpositioned screw (3), dura tear (1)]	18% [Major wound infection (1), dura tear (1)]
					L4-5=37	L4-5=8		
					L5-S1=12	L5-S1=9		
Dibble et al./2022/USA	64.1±8.9	58±11.8	54/46	47/53	L1-2=0	L1-2=9	Pseudarthrosis (3), Adjacent segment disease (4), Hardware failure(1)	Pseudarthrosis(3), Adjacent segment disease(7), Hardware failure(4)
					L2-3=7	L2-3=7		
					L3-4=10	L3-4=13		
					L4-5=95	L4-5=92		
					L5-S1=2	L5-S=27		
Zawy Alsofy et al./2021/ Germany	52.2±10.5	57.5±12.9	53/47	53/47	L1-2=2	L1-2=4	Infection (2), Dura tear(3), Cerebrospinal fluid fistula(1), sensory motor deficits(2), screw malposition(4), cage malposition(1)	Infection(7), Dura tear(5), Cerebrospinal fluid fistula(2), sensory motor deficits(3), screw malposition(4), Cage malposition(2)
					L2-3=6	L2-3=5	Overall complication rate=18.9%	Overall complication rate=33.3%
					L3-4=9	L3-4=12		
					L4-5=48	L4-5=39		
					L5-S1=25	L5-S1=21		
Le et al./2021/ USA	62.1	61.4	40/60	40/60	Single level=25	Single level=25	Durotomy(3), Sarcoma(1), reoperation(1)	Deep wound infection(3), Sarcoma(2), Reoperation(4 - 1for ASD and 3 for Pseudarthrosis
					Two level=13	Two level=13		
Qin et al./2020/China	66.09±8.19	65.8±8.51	68/32	61/39	L3-4=11	L3-4=5	Superficial incision infection(1), temporary numbness of left lower extremity (1)	Superficial incision infection(2), cerebrospinal fluid leakage(1)
					L4-5=16	L4-5=21		
					L5-S1=7	L5-S1=11		
Observational studies								
McGirt et al./2017/USA	60.12±11.1	61.69±11.5	41/59	40/60	Single or Two level	Single or Two level	Surgical site infection(3), Hematoma(5), new neurological deficit(3), revision surgery(1)	Deep vein thrombosis(6), pulmonary embolism(5), stroke(1), myocardial infarction(8), surgical site infection(21), hematoma(10), new neurological deficit(7), revision surgery(3)
Chan et al./2023 /USA	62.1±10.6	59.5±11.7	44/56	36/64	Single level	Single level	Durotomy(2), hematoma(1), neurological deficit(1), myocardial infarction(4)	Durotomy(7), surgical site infection(5), neurological deficit(3), urinary tract infection(2), myocardial infarction(1)
Bisson et al./2020/USA	72.2±9.6	66.9±12.5	45/55	61/39	Single level	Single level	Complication rate=15.5%,	Complication rate=7.2% ,
							Durotomy (1), reoperation (10) due to reemergence of symptoms.	Durotomy(2), reoperation (3)

MIS: Minimally invasive surgery, OS: Open surgery

Table 2: Study design and features of included studies

Authors/year/country	Quality of evidence	Study context	Cohort (n)	MIS (n,%)	OS (n,%)	Type, grade(s) of spondylolisthesis	Procedure type	Reported complications	Follow-up (mo)
Prospective studies									
Lau et al./2011/USA	Low	Single institution/1 surgeon	22	10, 45.45	12, 54.55	DS, NR	TLIF	Mean operative time, post-operative drainage, patients receiving transfusion, mean length of hospitalization, complication rate.	12
Serban et al./2017/Romania	Low	Single institution/1 surgeon	80	40,50	40,50	DS, IS, I, II	TLIF	ODI, mean operative time, mean estimated blood loss, length of hospitalization, fusion rates.	12
Wu et al./2018/China	Low	Single institution/1 surgeon	167	79, 47.3	88, 52.7	DS, IS, I, II	TLIF	Mean operative time, estimated blood loss, length of hospitalization, VAS, ODI	24
Hartmann et al./2022/Austria	Low	Single institution/1 surgeon	38	15, 39.5	23, 60.5	DS, IS, I, II	TLIF	Mean operative blood loss, NRS, VAS, ODI, TUG, EQ-5D	3
Retrospective studies									
Sulaiman and Singh/2014/USA	Very low	Single Institution/1 surgeon	68	57, 84	11, 16.0	DS, I, II	TLIF	Average length of surgical time, length of hospitalization, estimated blood loss, ODI, VAS	≥ 12
Dibble et al./2022/USA	Very low	Single institution/6 Surgeons	267	114, 42.6	153, 57.4	DS, I	TLIF	NRS, ODI	14
Zawy Alsofy et al./2021/Germany	Very low	Single institution/NR	171	90, 52.6	81, 47.4	DS, I, II	PLIF, TLIF, PLF	Estimated blood loss, average length of surgical time, mean length of hospitalization, fusion rate, VAS, ODI	27
Le et al./2021/USA	Very low	Single institution/2 surgeons	76	38, 50	38,50	DS, I	TLIF	Estimated blood loss, average length of surgical time, length of hospitalization, Complications, reoperations, VAS, ODI	13
Qin et al./2020/China	Very low	Single institution/NR	81	34, 41.9	47, 58.1	DS, I, II	TLIF	Estimated blood loss, average length of surgical time, post-operative drainage volume, length of hospitalization, time to return to work, complications, fusion rate, VAS, ODI	12
McGirt et al./2017/USA	High	60 institutions/multiple surgeons	1947	467, 23.9	1480, 76.0	DS, I	TLIF, PLIF, PLF	Estimated blood loss, average length of surgical time, length of hospitalization, complications, revision surgery, VAS, ODI, EQ-5D	12
Chan et al./2022/USA	High	12 institutions/multiple surgeons	297	72,24.2	225, 75.8	DS, I	TLIF	Estimated blood loss, revision surgery, ODI, NRS, EQ-5D	60
Bisson et al./2020/USA	High	12 institutions/multiple surgeons	140	71, 50.7	69,49.3	DS, I	TLIF	Estimated blood loss, length of hospitalization, complications, revision surgery, ODI, NRS, EQ-5D	24

TLIF: Transforaminal lumbar interbody fusion, PLIF: Posterior lumbar interbody fusion, PLF: Posterior lumbar fusion, VAS: Visual Analog Scale, ODI: Oswestry disability index, MIS: Minimally invasive surgery, OS: Open surgery

Table 3: Comparison of final functional and pain outcomes for minimally invasive versus open spinal fusion in spondylolisthesis treatment with (A) Oswestry Disability Index (ODI); (B)Visual Analog Scale (VAS). CI indicates Confidence Interval; IV- Inverse Variance; MIS - Minimally Invasive Surgery; OS - Open Surgery; SD- Standard Deviation.

Study	MIS Mean SD Total	OS Mean SD Total	Weight	Mean difference IV, Random ,95% CI
A. Oswestry Disability Index (ODI)				
Prospective Studies				
Serban	11 6 40	11 6 40	3.07	0.00 (-0.43, 0.43)
Wu	25.3 6.3 79	25.3 6.2 88	6.4	0.00 (-0.30, 0.30)
Hartmann	40.8 13 15	56 16 23	1.23	-1.02 (-1.71,-0.32)
Subtotal (95% CI)	134	151	10.7	-0.11(-0.35, 0.11}
Heterogeneity : Q = 7.390 df= 2 p = 0.025 11= 72.9%				
Test for Overall effect: Z= - 0.981 p= 0.327				
Retrospective Studies				
Sulaiman	26.4 1 57	46.1 5.91 11	0.26	-7.95 (-9.45,-6.44)
Zawy	20.7 14.5 90	24.5 20.5 81	6.51	-0.21 (-0.51, 0.08)
Le	23 14.8 38	25.2 17.1 38	2.91	-0.14 (-0.59, 0.32)
Qin	14.7 1.21 34	15.2 1.97 47	3	-0.30 (-0.74,0.15)
Dibble	26.5 20.9 114	26.4 19.2 153	10.04	0.00 (-0.24, 0.25)
McGirt	48.4 15.7 467	50.3 15.4 1480	54.47	-0.13 (-0.23,-0.02)
Chan	18.9 18.4 72	46.2 16.3 225	6.74	-1.63 (-1.92, -1.33)
Bisson	40.9 18.9 71	38.3 17.0 69	5.36	0.15 (-0.19, 0.48)
Subtotal (95% CI)	943	2104	89.3	-0.25(-0.33,-0.17)
Heterogeneity : Q = 199.270 df= 7 p = 0.000 I^2= 96.5%				
Test for Overall effect: Z= - 5.823 p= 0.000				
Total 95% CI	1077	2255		-0.23 (-0.31, -0.15)
Heterogeneity: Q = 207.610 df= 10 p = 0.000 I^2= 95.2%				
Test for Overall effect: Z= -5.824 p= 000				
Test for subgroup differences: Q= 0.961 df= 1 p=0.328 I^2 = 0%				
B. Visual Analog Scale (Back pain)				
Prospective Studies				
Wu	1.77 1.39 79	1.67 1.33 88	8.44	0.07(-0.23, 0.38)
Heartman	0.76 0.3 15	0.86 0.2 23	1.8	-0.4(-1.07, 0.25)
Subtotal (95% CI)	94	111	10.24	-0.01(-0.29, 0.26)
Heterogeneity : Q = 1.710 df= 1 p = 0.190 I^2= 41.7%				
Test for Overall effect: Z= - 0.082 p= 0.934				
Retrospective Studies				
Sulaiman	3.2 1.0 57	5.1 0.5 11	1.46	-2.02(-2.75, -1.29)
Zawy	1.9 1.9 90	2.5 2.6 81	8.57	-0.27(-0.57, 0.04)
Le	6.1 2.5 38	5.9 2.7 38	3.85	0.08(-0.38, 0.53)
Qin	1.26 0.27 34	1.39 0.42 47	3.94	-0.36(-0.80, 0.09)
McGirt	680 2.6 467	7.03 2.4 1480	71.94	-0.10(-0.20,0.01)
Subtotal (95%CI)	686	1657	89.76	-0.15(-0.24, -0.05)
Heterogeneity : Q = 28.530 df= 4 p = 0.000 I^2= 86.0%				
Test for Overall effect: Z= - 3.065 p= 0.002				
Total 95% CI	780	1768	100%	-0.13(-0.22, -0.04)
Heterogeneity: Q = 31.060 df= 6 p = 0.000 I^2= 80.7%				
Test for Overall effect: Z= -2.930 p= 0003				
Test for subgroup differences: Q= 0.820 df= 1 p=0.367 I^2 = 0%				

Table 4: Complications for minimally invasive versus open spinal fusion in spondylolisthesis treatment

Study	MIS			OS			Weight	Odds Ratio
	Events	Total		Events	Total			M-H, Random, 95% CI
Prospective studies								
Lau	4	10		1	12		0.93	0.77 (0.54, 1.12)
Serban	1	40		2	40		2.95	1.02(0.94, 1.11)
Wu	7	79		8	88		6.20	1.00(0.92, 1.10)
Hartman	1	15		2	23		1.34	1.02(0.86, 1.021)
Subtotal (95% CI)	144			163			11.42	0.99(0.93, 1.06)
Total Events	12			13				
Heterogeneity: Q=2.510 df=3 P=0.473 12 =0%								
Test for overall effect: Z=−0.276 P=0.782								
Retrospective studies								
Sulaiman	4		57	2	11		1.35	1.10 (0.87, 1.41)
Dibble	8		114	14	153		9.64	1.02 (0.96, 1.09)
Zawy	13		90	23	81		6.01	1.12(0.99, 1.28)
Le	5		38	9	38		2.71	1.09(0.92, 1.30)
Qin	2		34	3	47		2.94	1.00(0.90, 1.12)
McGirt	12		467	61	1480		52.37	1.01(0.20, 1.03)
Chan	8		72	18	225		8.32	0.98(0.90, 1.05)
Bisson	11		71	10	69		5.24	0.20(0.9, 1.11)
Subtotal (95% CI)	943			2104			88.58	1.02(1.00, 1.04)
Total Events	63			140				
Heterogeneity: Q=5.250 df=7 P=0.629 e = 0% Test for overall effect: Z = 2.020 p = 0.043								
Total (95%CI)	1087			2267		100%		1.02 (0.20, 1.04)
Total events	75			153				
Test for overall effect: Z=1.778 P=0.075								
Test for subgroup differences: Q=7.200 df=11 P=0.783 12 = 0%								
CI: Confidence Interval; M-H: Mantel-Haenszel; MIS: Minimally invasive surgery; OS: Open surgery								

a random effects model. To compare the outcomes of dichotomous variables, such as complications, we generated a risk ratio and 95% CI using the Mantel-Haenszel method using a random effects model. The random effects model, in contrast to a fixed-effects model, yields a more cautious estimation of the treatment effect [13]. The use of this statistical approach was considered suitable due to the assumed diversity among the experiments. The statistical analysis was performed using Review Manager Version 5.3.2 (Cochrane Collaboration, Software Update, Oxford, UK). Forest plots have been generated to visually present the findings of each study and pooled estimations of the impact.

Evidence quality

Utilizing the Grades of Recommendation, Assessment, Development, and Evaluation (GRADE) process, two reviewers (VR and CM) evaluated the quality of evidence for each study separately. A total rating of high, moderate, low, or extremely low was assigned to each study according to its design, limits, findings, level of accuracy, and supporting documentation. Discrepancy cases were settled by conversation.

Results

Literature search

A total of 1078 papers were found using our search strategy (Fig. 1). The titles and abstracts of the 746 papers were subjected to inclusion/exclusion criteria following the removal of 332 duplicate publications. A full-text analysis was conducted on 17 of the articles that came from this. The current review includes 12 articles for both quantitative and qualitative analysis. All the included studies were observational cohort studies conducted at a single and multiple institutions; four of the studies were prospective [14-17] and eight of the studies were retrospective [18-25] (Table 1).

Patient demographics

A total of 3354 patients were included in the analysis of all studies. Among them, 1087 patients (32.44%) underwent MI for spondylolisthesis treatment, whereas 2267 patients (67.6%) underwent OS for spinal fusion. Table 2 presents comparative features. The mean age in the MI group was 59.15±9.96 years, while in the OS group, it was 59.04±8.88 years. The proportion of males in the MI group varied between 27% and 68%, while in the OS group it ranged from 22% to 74%. The mean number of fused levels ranged from 1 to 1.13 levels in the MI group and from 1 to 1.9 levels in the OS group. The fusion rates reported by both the MI and OS groups ranged from 90.2% to 100%. There was no statistically significant difference in the indicated characteristics between the MIS and OS groups. Four cohort studies examined both isthmic and degenerative spondylolisthesis, while the other investigations focused solely on degenerative spondylolisthesis.

Grade of spondylolisthesis

Eleven studies reported the severity of spondylolisthesis in their groups using the Meyerding classification (Table 2). Out of the total, five studies were classified as Grade I, whilst six studies were classified as both Grade I and Grade II. Only lower grades were taken into account.

Procedure type

Ten studies exclusively utilized TLIF for spinal fusion, whereas two studies employed a combination of TLIF, PLIF, and PLF for both MI and OS (Table 2).

Operative time

Operative time data could be extracted from nine studies (Fig. 2A) due to the availability of sufficient data. There was no substantial disparity in general between the MI and the OS group. Nevertheless, patients with OS in both the prospective and retrospective cohort studies experienced longer surgical procedures compared to MI patients, with average durations of 2085 min against 188 min for prospective trials and 185 min versus 176 min for retrospective cohorts.

Intraoperative blood loss

Eight studies provided sufficient data to quantify the amount of blood lost after surgery (Fig. 2B). In the MI group, the average volume of blood loss was 210.35 mL, compared to 339.56 mL in the OS group. The disparity was significant (P = 0.0000).

Length of hospitalization (LOH)

Seven studies provided adequate data on the LOH (Fig. 2C). The mean duration of LOH was 3.99 days in the MI group compared to 5.24 days in the OS group. The difference was significant (P = 0.000).

ODI

Eleven studies provided sufficient data to get final ODI scores (≥12 months) as a measure of disability (Fig. 3A). There was no significant disparity between the MI group and the OS group as a whole (Table 3). Nevertheless, patients with MI who participated in both prospective and retrospective cohort studies exhibited markedly lower final scores on the ODI compared to patients with OS. The weighted MD for prospective studies was

−0.11 (95% CI:−0.35–0.11), with pooled means of 25.7 and 30.7. For retrospective studies, the weighted MD was−0.23 (95% CI: −0.31–0.15), with pooled means of 27.43 and 34.02.

VAS-Back Pain

Seven studies provided enough data to obtain the final VAS scores, which were used as a measure of back pain for a duration of at least 12 months (Fig. 3B). There was no significant difference between the MI and OS group (Table 3).

Complications

All 12 studies provided enough data to obtain complication rates. A total of 75 complications were observed in the MI group, whereas the OS group had 153 (Table 4). The most frequently observed complications, reported in multiple studies, included surgical site infection (7 cases in MI group versus 41 cases in OS group), accidental dural tear (12 cases in MI group versus 15 cases in OS group), hardware malpositioning (9 cases in MI group versus 11 cases in OS group), and revision surgery (13 cases in MI group versus 10 cases in OS group). There was no significant difference between the MI group and the OS group with respect to overall complications.

Discussion

The acceptance of MI spinal surgery has risen due to the introduction of new concepts, improvements in surgical instruments, and the evolution of optical equipment. MI procedures have become more popular because to their smaller incisions, reduced iatrogenic soft-tissue injury, and faster functional recovery [26, 27]. After doing a meta-analysis on the existing comparative studies, it was found that MI is linked to a considerable reduction in intraoperative blood loss, shorter hospital stays, and no deterioration in functional, pain, or complication outcomes compared to OS. This is the third review, following the analyses by Lu et al. [10] and Qin et al. [28], specifically focusing on the outcomes related to spondylolisthesis.

Some of the studies included in this review examined patients with coexisting illnesses [17, 23, 24], which could have had an impact on functional and pain results [29]. Subsequent research indicates that these parameters will facilitate an enhanced understanding of post-operative functional and pain outcomes in both MI and OS. This review found no statistically significant difference in the long-term functional or pain outcomes between spondylolisthesis patients treated with MI or OS when comparing the ODI and VAS measurements. The aggregated findings of the meta-analysis align with other systematic reviews [8-11] that have investigated various degenerative lumbar conditions. There has been a significant reduction in intraoperative blood loss and hospital stay duration in MI. Comparable findings have been found in systematic reviews [30-33] that focus on lumbar disease in general. MI demonstrates reduced muscular atrophy and changes in blood circulation in comparison to OS. Smaller incisions and reduced retraction could expedite the recovery time. These are particularly beneficial for individuals with immune-related and hematologic problems, as they experience a decreased likelihood of infection and blood loss. The most significant conclusion of our meta-analysis is that there is no higher connection between complications and OS. Furthermore, our research indicates that the likelihood of surgical site infection is greatly diminished in patients who undergo MI compared to those who undergo OS (7 vs. 44). According to these data MI may offer a less intrusive option for treating spondylolisthesis, while yet achieving similar patient-rated outcomes and complication rates as in OS patients.

Strengths and limitations

This study has several strengths. First, it employed a thorough literature search method. Second, it strictly followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines [34]. Finally, it utilized the GRADE system to examine high-quality evidence. We were able to conduct the third meta-analysis and systematic review comparing MI versus OS, specifically focusing on spondylolisthesis. Nevertheless, the findings of this research must be validated through substantial, multi-institutional prospective randomized controlled trials with thorough long-term monitoring. Until now, this evidence is one of the most compelling arguments for the therapeutic effectiveness of MI in the treatment of spondylolisthesis.

A significant drawback of this study was the lack of information on the comparative outcomes of spinal fusion surgery for spondylolisthesis, specifically in cases of isthmic and higher-grade spondylolisthesis. Out of all the studies reviewed, only three [15-17] included outcomes specifically linked to isthmic spondylolisthesis. In addition, in two of these studies, the results for isthmic spondylolisthesis were mixed with those for degenerative spondylolisthesis. Wu et al. [16] found no noticeable distinction in the outcomes of degenerative and isthmic spondylolisthesis between the MI and OS groups. Moreover, the inclusion of studies using different surgical procedures (percutaneous, mini-open, and muscle splitting) may have led to a broader range of surgical outcomes for that group. This variation in the definition of MI could have potentially altered the findings of this meta-analysis.

Due to the absence of randomized controlled trials in our investigation and the inclusion of lower-quality retrospective and prospective studies, there is a possibility of selection bias. There is significant variability in the outcomes among these research studies. Several factors, such as the subjective nature of most outcomes, the variation in experience and workload among surgeons, and the inherent diversity of surgical techniques such as TLIF, PLIF, and PLF, can be attributed to this.

Conclusion

This is the third systematic evaluation of the literature that specifically compares the outcomes of MI spinal fusion with OS for the treatment of Grade I and Grade II spondylolisthesis. When comparing OS to MI, it was shown that MI was associated with a reduced duration of hospitalization, a lower amount of blood loss after surgery, and comparable rates of complications, discomfort, and overall functional improvement. Subgroup analysis of both prospective and retrospective studies found that MI was associated with longer operating durations and improved functional results. However, the existing research only concentrates on cases of low and extremely low quality, and there are no randomized clinical studies that investigate the outcomes of treating spondylolisthesis simply with MI or OS spinal fusion. Subsequent research will authenticate the findings of this investigation.

Clinical Message

MI spinal fusion offers shorter operative times and hospital stays compared to OS for treating spondylolisthesis, according to this study. While MI shows advantages in reducing surgical stress and post-operative recovery, there is no significant difference in functional or pain outcomes between the two approaches. Both MI and OS demonstrate similar complication rates. Although MI appears promising, further long-term, randomized studies are needed to confirm its sustained efficacy and safety in managing spondylolisthesis.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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