REVIEW ARTICLE

Long-Term Clinical and Imaging Results of Oblique Lateral Interbody Fusion for Degenerative Lumbar Spondylolisthesis: A Systematic Review and Meta-Analysis

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The efficacies and safety of oblique lateral interbody fusion (OLIF) for degenerative lumbar spondylolisthesis (DLS) remains controversial, and long-term clinical efficacies in particular need to be explored. This study is designed accordingly, therefore, we searched PubMed, Embase, Scopus, Web of Science, Cochrane Library, ProQuest, OVID, and SinoMed for literature, regardless of publication date or language. Taking 12 months after operation as the shortest limit, the outcome measures were extracted, including visual analog scale (VAS), Oswetry dysfunction index (ODI), Japanese Orthopaedic Association (JOA) score, intervertebral disk height (IDH), foraminal height (FH), lumbar lordosis (LL), segment lordosis (SL), slip ratio, and incidence of surgical complications. Meta-analysis was performed by RevMan 5.4 and Stata 16.0, and results were expressed with *MD* and 95% *CI,* and two-sided *p*-values with $p < 0.05$ being statistically significant. In total, 17 clinical studies ($n = 689$ patients) were screened, with an average patient age of 63.4 years. Our study revealed that VAS decreased by 4.55 (low back pain) and 5.46 (leg pain) points, respectively. And ODI score decreased by an average of 33.82% while JOA score increased by an average of 11.56 points. In terms of imaging indicators, mean IDH and FH increased by 4.18 and 4.91 mm, mean LL and SL improved by 9.22° and 2.46°, respectively. Besides, mean slip ratio decreased by 10.45%. The incidence of complications was statistically analyzed in 18 studies, with a rate of 4%–54% and an overall incidence of 19%. To sum up, our study was the first to focus on the long-term efficacies of OLIF treatment for DLS, and to provide further clinical evidence. However, long-term follow-up multicenter randomized controlled trials are still needed for further evaluation.

Key words: Postoperative complications; Radiography; Spinal fusion; Spondylolisthesis; Treatment outcome

Introduction

Degenerative lumbar spondylolisthesis (DLS) refers to forward slippage of the upper vertebral body relative to the lower vertebral body when the isthmus is intact.[1,2] It is common among middle-age and elderly individuals >50 years of age (and more common in females), usually occurring at lumbar (L) levels L4 and L5, with a slip rate of <30%.[1] The pathological basis is chronic lumbar degeneration, which is often accompanied by intervertebral instability, reduced lordosis of lesion segments, decreased height of the intervertebral space, and spinal stenosis, resulting in low back pain (LBP), root neuralgia, intermittent claudication, and other clinical symptoms, seriously affecting the quality of life of affected patients.[1,3,4] With the aging of the population, the incidence of DLS has significantly increased. Therefore, selection of appropriate therapeutic

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strategies for DLS has become a popular topic in the field of spine surgery.

When conservative treatment for DLS fails, nerve decompression and fixation fusion can be considered. Surgical methods for DLS include various fixation and fusion techniques with direct decompression as the core, such as posterolateral *in situ* fusion, reduction and fixation fusion, and intervertebral body fusion. Oblique lateral lumbar interbody fusion (OLIF) is a minimally invasive technique that exposes the disc in front of the psoas major muscle *via* a retroperitoneal approach and inserts at a large cage.[5,6] OLIF has been widely used to treat a variety of lumbar diseases. The placement of a larger fusion device in the intervertebral space during OLIF has the following advantages. First, indirect decompression of the foramina and central spinal canal can be achieved by restoring the height of the intervertebral space and increasing the tension of the annulus fibrosus and ligamentum flavum.[7,8] Second, owing to the preservation of ligament structure to maintain the stability of the segment, the stability of the surgical segment can be increased after the implantation of the fusion device. Third, OLIF effectively restores lordosis of the operative segment and corrects scoliosis.[7]

The OLIF technique for DLS can yield indirect nerve decompression, stabilize segmental lesions, and restore segmental alignment.[9] It has been reported that OLIF surgery has the advantages of short operative time, less intraoperative blood loss, low incidence of complications, and low surgical cost.[10] In addition, OLIF combined with posterior fixation has been reported to provide greater stability during interbody fusion and reduce surgical complications, such as fusion device settling and displacement, thereby reducing revision rates.[11] However, the efficacy and safety of OLIF for the treatment of DLS have not been validated in large randomized controlled trials. Moreover, previous literature reports addressing this issue have predominantly been published in only the past 2 years.[12–25]

In addition, most published studies focused more on short-term efficacy after surgery but did not investigate or discuss, in depth, whether the long-term efficacy and safety of OLIF are stable.[16,25,26] Most meta-analyses of interbody fusion in recent years have also focused on early postoperative efficacy and ignored long-term efficacy.[27–29] However, with changes that occur postoperatively, both clinical function and imaging indicators among patients with DLS treated with OLIF also change.

The present meta-analysis summarized and analyzed clinical studies investigating OLIF treatment for DLS published in recent years, and explored long-term clinical efficacy and safety to provide a reference for clinicians in designing and selecting optimal surgical procedures.

Methods

Selection Criteria

Inclusion Criteria

(1) Patients with DLS who had no other comorbidities that affect surgical outcome; (2) DLS were treated with single-

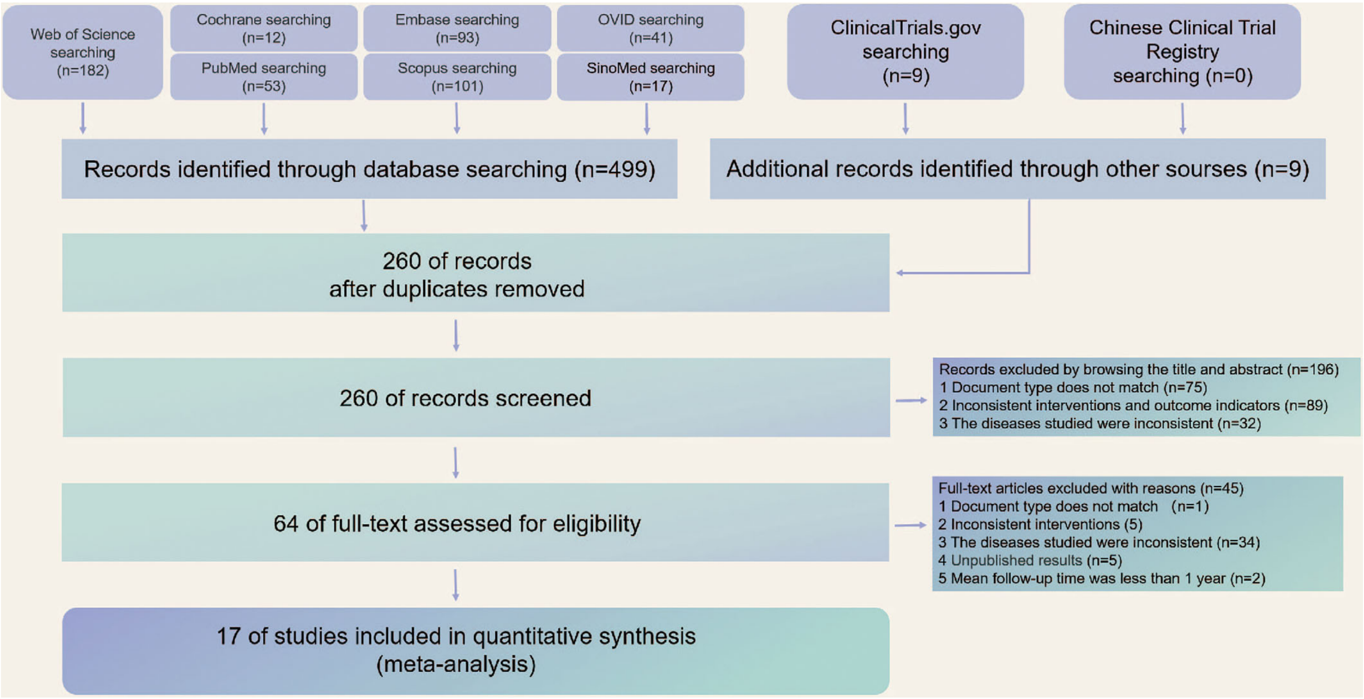


Fig. 1 PRISMA flow-chart for systematic review identifying articles reporting long-term clinical and radiographic results of oblique interbody fusion for degenerative lumbar spondylolisthesis

TABLE 1 Characteristics and MINORS score of included studies

First author	Year	Sample size	Female	No of levels treated	Age, years, Mean ± SD (range)	Level	Operation time (min)	Intraoperative blood loss (ml)	Follow-up, months, Mean ± SD (range)	MINORS score
Sato[32]	2017	20	11	20	69 ± 7.8	L2-3, L3-4, L4-5	/	/	Mean 12 (6–24)	14
Wu[33]	2019	31	22	36	60.0 ± 9.3	/	131.3 ± 14.6	163.6 ± 63.9	18.00 ± 2.87	17
Hu[12]	2020	21	12	21	Mean 64.5 (57–73)	L4-5	155	225.5	Mean 14.3 (12–18)	12
Huo[13]	2020	42	24	42	Mean 58 (37–78)	L3-4, L4-5	69.7 ± 8.7	92.6 ± 11.7	13.5 ± 1.1	13
Jin[14]	2020	32	14	32	63.9 ± 7.6	L3-4, L4-5	160.3 ± 19.7	80.0 ± 16.9	24.2 ± 7.1	17
Luo[15]	2020	128	69	/	63.75 ± 5.16	L3-4, L4-5	223.76 ± 14.19	241.78 ± 54.22	> 12	12
Qiu[16]	2020	20	5	20	50.3 ± 8.8	L1-L5	96 ± 20	61 ± 32	13.5 ± 2.3	17
Sheng[17]	2020	38	30	44	65.29 ± 8.88	L1-L5	90.79 ± 7.93	63.95 ± 23.31	> 12	16
Cho[18]	2021	28	/	49	69.7 ± 6.9	L1-L5	165.1 ± 44.4	190.6 ± 69.6	27.7 ± 21.7	18
Chung[19]	2021	52	35	56	64.6 ± 10.1	L3-4, L4-5, L5-S1	93.4 ± 30.7	83.4 ± 80.7	30.4 ± 12.9 (12–61)	12
Du[20]	2021	28	12	28	53.6 ± 6.4	L3-4, L4-5	/	/	20.3 ± 6.1	17
Han[21]	2021	28	16	28	50.4 ± 16.0	L3-4, L4-5, L5-S1	164.9 ± 56.0	142.4 ± 89.4	> 12	17
Koike[22]	2021	38	18	38	72.1 ± 11.4	L3-4, L4-5	111.9 ± 23.6	51.7 ± 37.8	18.1 ± 8.5	17
Kotani[23]	2021	92	46	93	72.0 ± 9.9	L3-4, L4-5	108 ± 22.1	51 ± 47.2	31 ± 11.5	18
Wang[24]	2021	33	21	33	62.76 ± 6.83	L2-3, L3-4, L4-5	88.91 ± 9.15	52.52 ± 14.92	> 12	17
Wu[25]	2021	33	27	36	66.9 ± 8.7	L2-3, L3-4, L4-5	199 ± 49	209 ± 99	> 12	13
Guo[26]	2022	25	/	25	56.5 ± 10.2	L3-4, L4-5, L5-S1	121.20 ± 12.01	126.20 ± 28.91	13.9 ± 1.9	17

Note: “/”means there is no relevant data.

level or multi-level OLIF; (3) studies with a mean follow-up of more than 12 months; and (4) outcome measures included clinical and imaging results.

Exclusion Criteria

(1) Multiple publication; (2) review, case reports, etc.; and (3) no sufficient data.

Literature Search Strategy

In accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (i.e., PRISMA) guidelines,[30] the PubMed, Embase, Scopus, Web of Science, Cochrane Library, ProQuest, OVID, and SinoMed databases were searched for relevant studies regardless of publication date or language. Literature sources outside these databases included ClinicalTrials.gov and the Chinese Clinical Trial Registry.

Medical Subject Headings, free terms, and the combination of the two were applied. And the search terms are as follows: Spondylolisthesis, Spondylolistheses, Spondylistheses, Olistheses, Oblique Lateral Interbody fusion, Oblique lumbar interbody Fusion, Oblique lateral lumbar interbody fusion, Retroperitoneal lumbar interbody fusion, and pre-PSOas lateral interbody Fusion, Anterior to psoas lumbar interbody fusion, Anterolateral approach to lumbar interbody fusion, OLIF, etc. The specific search strategies are outlined in Appendix S1.

Data Extraction and Quality Assessment

After eliminating duplicate studies, article titles and abstracts were reviewed and, if they fulfilled the inclusion criteria, the full text was read. If the full text met the inclusion criteria, it was included in the analysis. Study quality was evaluated using the Methodological Index for Non-randomized Studies (MINORS),[31] and studies with a total score >12 were included. Literature screening and quality Assessment were completed independently by two researchers, and any disagreements were resolved by a third researcher. The risk of bias was assessed using the Cochrane tool (ROBINS-I).

Statistical Analysis

Meta-analysis was performed using RevMan 5.4 and Stata 16.0 statistical software. And data calculation was performed by IBM SPSS Statistics 25. The statistical analyses of forest maps of single-arm data, sensitivity analysis, and publication bias were performed in Stata software while other forest maps were performed in RevMan software. Data for continuous variables are expressed as means ± standard deviation (*SD*). Our results were expressed with *MD* and 95% *CI*, and two-sided p-values with $p < 0.05$ being statistically significant. An $I^2 > 50\%$ indicated substantial heterogeneity; thus, sensitivity and subgroup analyses performed to evaluate the possible sources of the heterogeneity. And random effect would be selected if heterogeneity cannot be eliminated.

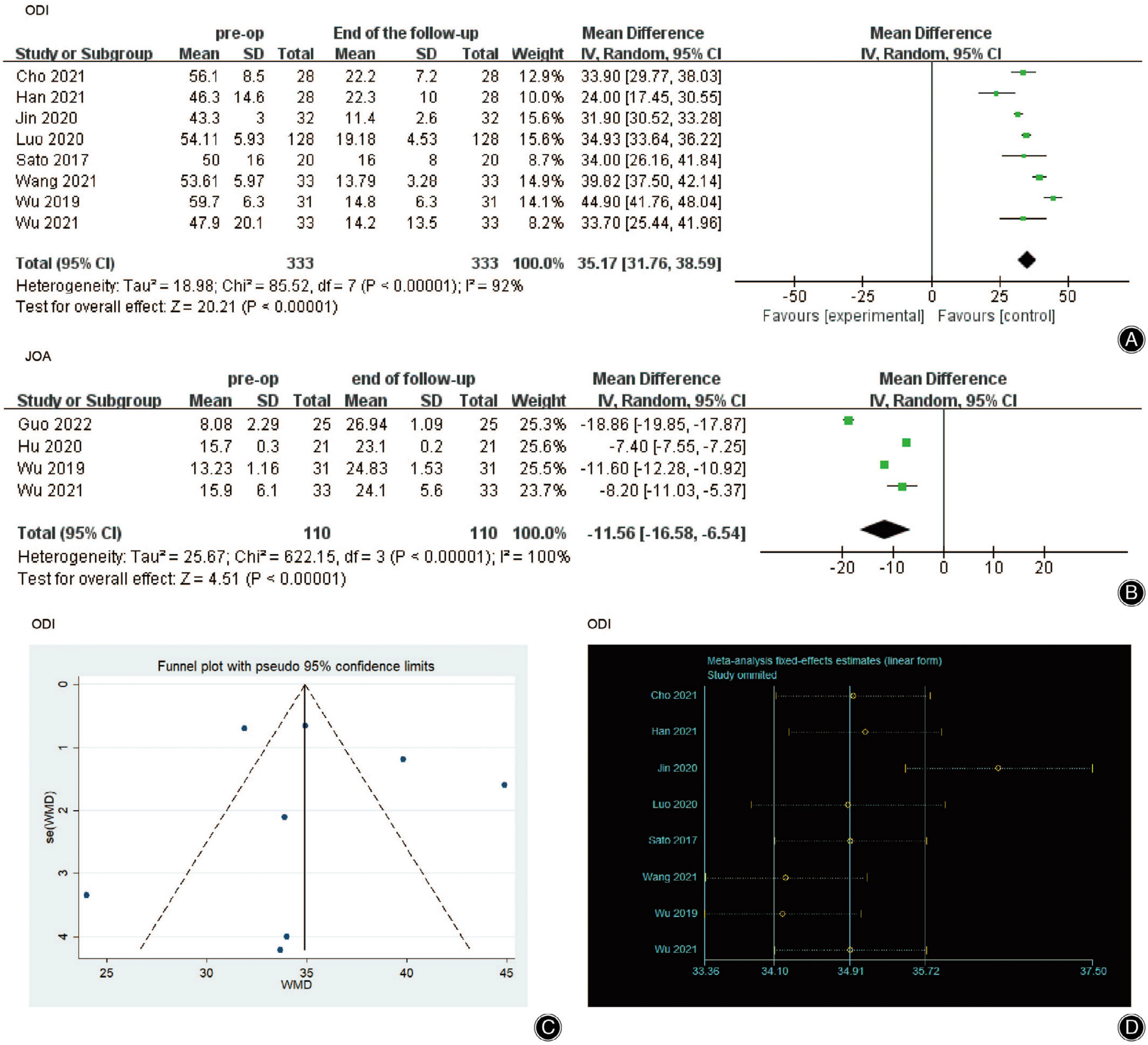
Results

Literature Search Results and Quality Evaluation

A total of 508 relevant studies were retrieved in the preliminary literature search, including 499 identified through the database search and nine additional studies identified through other sources. After reading titles and abstracts, 442 case reports, duplicate studies, and reviews were excluded. After reading the full text of the remaining 64 studies, 17 (n = 732 patients)[12–26,32,33] were ultimately included in accordance with the inclusion and exclusion criteria (Fig. 1).The MINORS score of the studies ranged from 12 to 18, with an average of 15.53, and all fulfilled the inclusion criteria (Table 1). Evaluation results according to the Robins-I tool are summarized in Table 2.

TABLE 2 Characteristics and MINORS score of included studies

Study	Confounding	Participant selection	Classification of interventions	Deviation from intended intervention	Missing data	Outcome measurements	Selective reporting	Overall
Sato[32]	Serious	Moderate	Low	Moderate	Moderate	Low	Low	Serious
Wu[33]	Moderate	Low	Low	Low	Low	Low	Low	Moderate
Hu[12]	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
Huo[13]	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
Jin[14]	Serious	Low	Low	Moderate	Low	Low	Low	Serious
Luo[15]	Moderate	Low	Moderate	Low	Low	Low	Low	Moderate
Qiu[16]	Serious	Low	Low	Low	Moderate	Low	Low	Serious
Sheng[17]	Moderate	Low	No Information	Low	Moderate	Low	Low	Moderate
Cho[18]	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate
Chung[19]	Moderate	Low	Low	Low	Low	Low	Low	Moderate
Du[20]	Moderate	Low	Low	Low	Low	Low	Low	Moderate
Han[21]	Serious	Low	Moderate	Low	Low	Low	Low	Serious
Koike[22]	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
Kotani[23]	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate
Wang[24]	Moderate	Low	Low	Low	Low	Low	Low	Moderate
Wu[25]	Moderate	Low	Moderate	No Information	Low	Low	Low	Moderate
Guo[26]	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate



ODI

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	End of the follow-up Mean	End of the follow-up SD	End of the follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Cho 2021	56.1	8.5	28	22.2	7.2	28	12.9%	33.90 [29.77, 38.03]
Han 2021	46.3	14.6	28	22.3	10	28	10.0%	24.00 [17.45, 30.55]
Jin 2020	43.3	3	32	11.4	2.6	32	15.6%	31.90 [30.52, 33.28]
Luo 2020	54.11	5.93	128	19.18	4.53	128	15.6%	34.93 [33.64, 36.22]
Sato 2017	50	16	20	16	8	20	8.7%	34.00 [26.16, 41.84]
Wang 2021	53.61	5.97	33	13.79	3.28	33	14.9%	39.82 [37.50, 42.14]
Wu 2019	59.7	6.3	31	14.8	6.3	31	14.1%	44.90 [41.76, 48.04]
Wu 2021	47.9	20.1	33	14.2	13.5	33	8.2%	33.70 [25.44, 41.96]
Total (95% CI)			**333**			**333**	**100.0%**	**35.17 [31.76, 38.59]**

Heterogeneity: Tau² = 18.98; Chi² = 85.52, df = 7 (P < 0.00001); I² = 92%
Test for overall effect: Z = 20.21 (P < 0.00001)

JOA

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Guo 2022	8.08	2.29	25	26.94	1.09	25	25.3%	-18.86 [-19.85, -17.87]
Hu 2020	15.7	0.3	21	23.1	0.2	21	25.6%	-7.40 [-7.55, -7.25]
Wu 2019	13.23	1.16	31	24.83	1.53	31	25.5%	-11.60 [-12.28, -10.92]
Wu 2021	15.9	6.1	33	24.1	5.6	33	23.7%	-8.20 [-11.03, -5.37]
Total (95% CI)			**110**			**110**	**100.0%**	**-11.56 [-16.58, -6.54]**

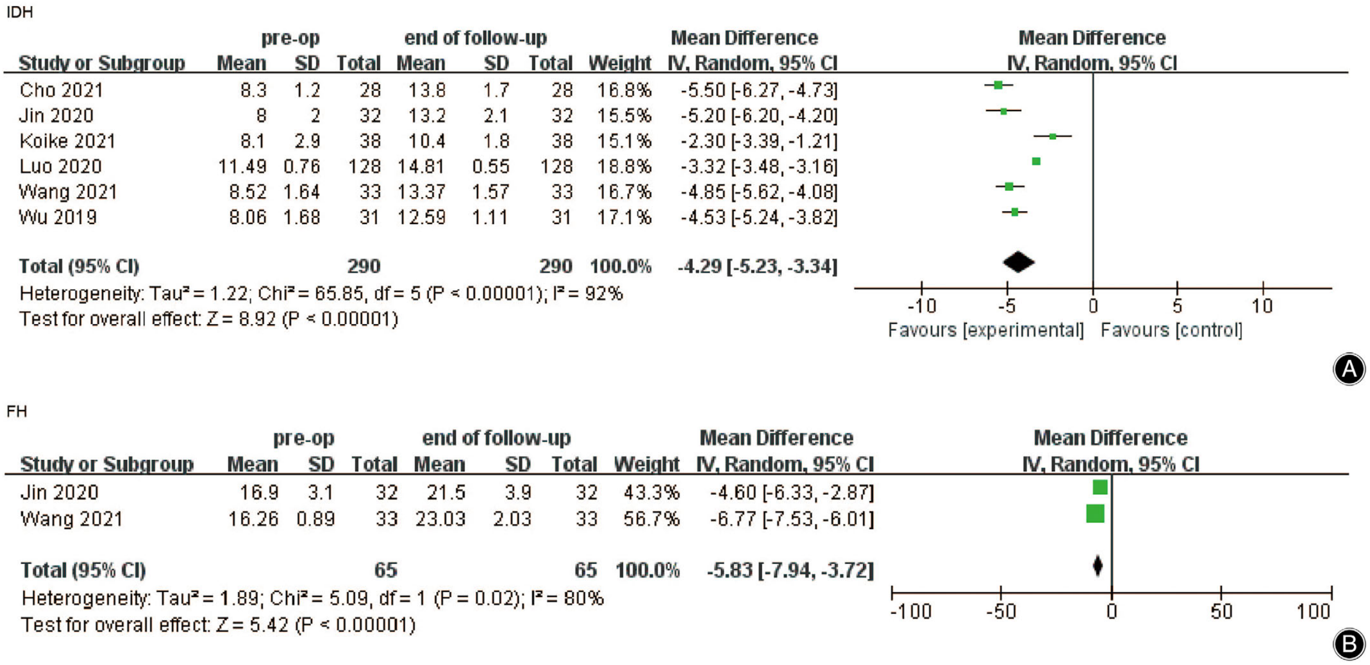
Heterogeneity: Tau² = 25.67; Chi² = 622.15, df = 3 (P < 0.00001); I² = 100%
Test for overall effect: Z = 4.51 (P < 0.00001)

Fig. 2 Forest plot of ODI score(A) and JOA score (B) before and at the end of follow-up. Funnel plot (C) of ODI score evaluating publication bias. And sensitivity analysis (D) of ODI score used to screen for literature that causes significant interference with research results

Primary Outcomes

Recovery of Lumbar Function

To evaluate lumbar function, the Japanese Orthopedic Association (JOA) and Oswestry Disability Index (ODI) scores were used in different studies. Accordingly, a meta-analysis of these two evaluation systems was performed. The ODI was used in eight studies involving 333 patients.[14,15,18,21,24,25,32,33] ODI score decreased by an average of 35.17% (95% CI 31.76%–38.59%; $I^2 = 92\%$ [random effect model]), which was statistically significant ($Z = 20.21$, $p < 0.00001$) (Fig. 2A). Five of the included studies also tested ODI immediately after surgery, with an average decrease of 29.30% (Fig. S2A). The roughly symmetrical funnel plot and Egger's test ($p = 0.764$) demonstrated no publication bias (Fig. 2C). Sensitivity analysis revealed that the study by Jin (2020) interfered with heterogeneity; however, overall, the stability remained good because the impact on clinical significance was very slight (Fig. 2D). The JOA score was applied in four



IDH

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Cho 2021	8.3	1.2	28	13.8	1.7	28	16.8%	-5.50 [-6.27, -4.73]
Jin 2020	8	2	32	13.2	2.1	32	15.5%	-5.20 [-6.20, -4.20]
Koike 2021	8.1	2.9	38	10.4	1.8	38	15.1%	-2.30 [-3.39, -1.21]
Luo 2020	11.49	0.76	128	14.81	0.55	128	18.8%	-3.32 [-3.48, -3.16]
Wang 2021	8.52	1.64	33	13.37	1.57	33	16.7%	-4.85 [-5.62, -4.08]
Wu 2019	8.06	1.68	31	12.59	1.11	31	17.1%	-4.53 [-5.24, -3.82]
Total (95% CI)			**290**			**290**	**100.0%**	**-4.29 [-5.23, -3.34]**

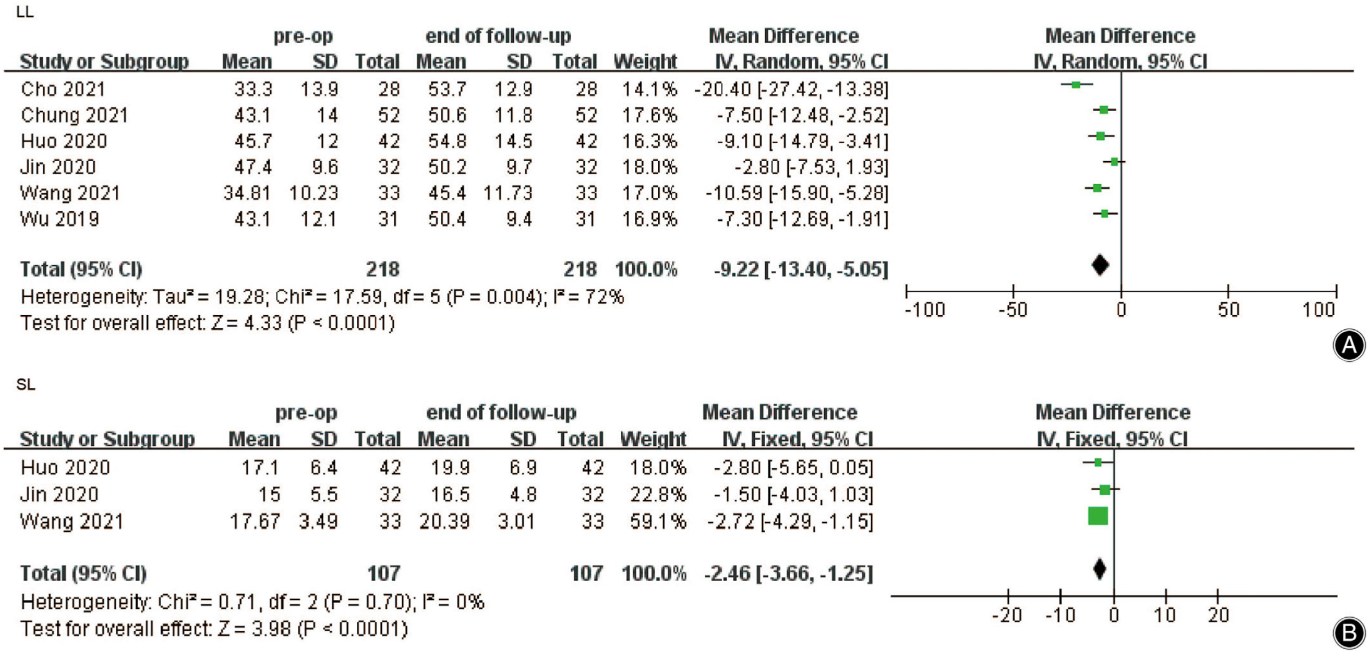
Heterogeneity: Tau² = 1.22; Chi² = 65.85, df = 5 (P < 0.00001); I² = 92%
Test for overall effect: Z = 8.92 (P < 0.00001)

FH

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Jin 2020	16.9	3.1	32	21.5	3.9	32	43.3%	-4.60 [-6.33, -2.87]
Wang 2021	16.26	0.89	33	23.03	2.03	33	56.7%	-6.77 [-7.53, -6.01]
Total (95% CI)			**65**			**65**	**100.0%**	**-5.83 [-7.94, -3.72]**

Heterogeneity: Tau² = 1.89; Chi² = 5.09, df = 1 (P = 0.02); I² = 80%
Test for overall effect: Z = 5.42 (P < 0.00001)

Fig. 3 Forest plots of IDH (A) and FH (B) of DLS patients treated with OLIF before and at the end of follow-up. IDH, intervertebral disk height; FH, foraminal height



LL

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Cho 2021	33.3	13.9	28	53.7	12.9	28	14.1%	-20.40 [-27.42, -13.38]
Chung 2021	43.1	14	52	50.6	11.8	52	17.6%	-7.50 [-12.48, -2.52]
Huo 2020	45.7	12	42	54.8	14.5	42	16.3%	-9.10 [-14.79, -3.41]
Jin 2020	47.4	9.6	32	50.2	9.7	32	18.0%	-2.80 [-7.53, 1.93]
Wang 2021	34.81	10.23	33	45.4	11.73	33	17.0%	-10.59 [-15.90, -5.28]
Wu 2019	43.1	12.1	31	50.4	9.4	31	16.9%	-7.30 [-12.69, -1.91]
Total (95% CI)			**218**			**218**	**100.0%**	**-9.22 [-13.40, -5.05]**

Heterogeneity: Tau² = 19.28; Chi² = 17.59, df = 5 (P = 0.004); I² = 72%
Test for overall effect: Z = 4.33 (P < 0.0001)

SL

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Fixed, 95% CI
Huo 2020	17.1	6.4	42	19.9	6.9	42	18.0%	-2.80 [-5.65, 0.05]
Jin 2020	15	5.5	32	16.5	4.8	32	22.8%	-1.50 [-4.03, 1.03]
Wang 2021	17.67	3.49	33	20.39	3.01	33	59.1%	-2.72 [-4.29, -1.15]
Total (95% CI)			**107**			**107**	**100.0%**	**-2.46 [-3.66, -1.25]**

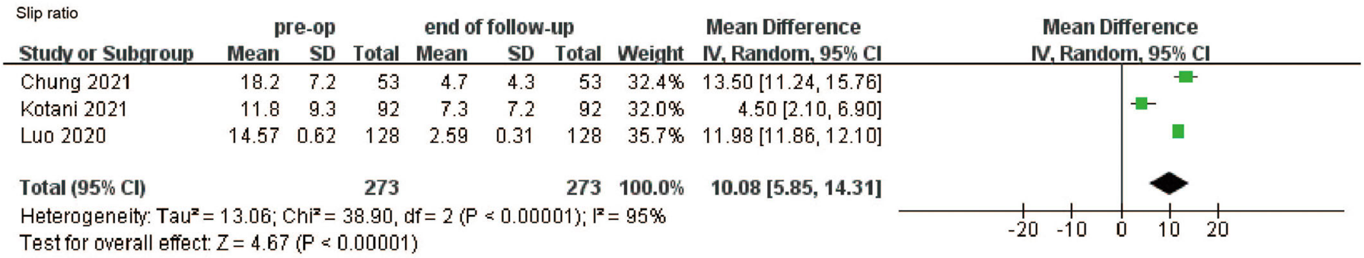
Heterogeneity: Chi² = 0.71, df = 2 (P = 0.70); I² = 0%
Test for overall effect: Z = 3.98 (P < 0.0001)

Fig. 4 Forest plots of LL (A) and SL (B) of DLS patients treated with OLIF before and at the end of follow-up. LL, lumbar lordosis; SL, segment lordosis

studies[12,25,26,33] and meta-analysis results revealed statistical significance (random effect model; MD-11.56 [95% CI −16.58 to −6.54]; $Z = 4.51$, $p < 0.00001$) (Fig. 2B).

Intervertebral Disk Height and Foraminal Height

For imaging results at the end of follow-up, six studies compared intervertebral disk height (IDH) in 290

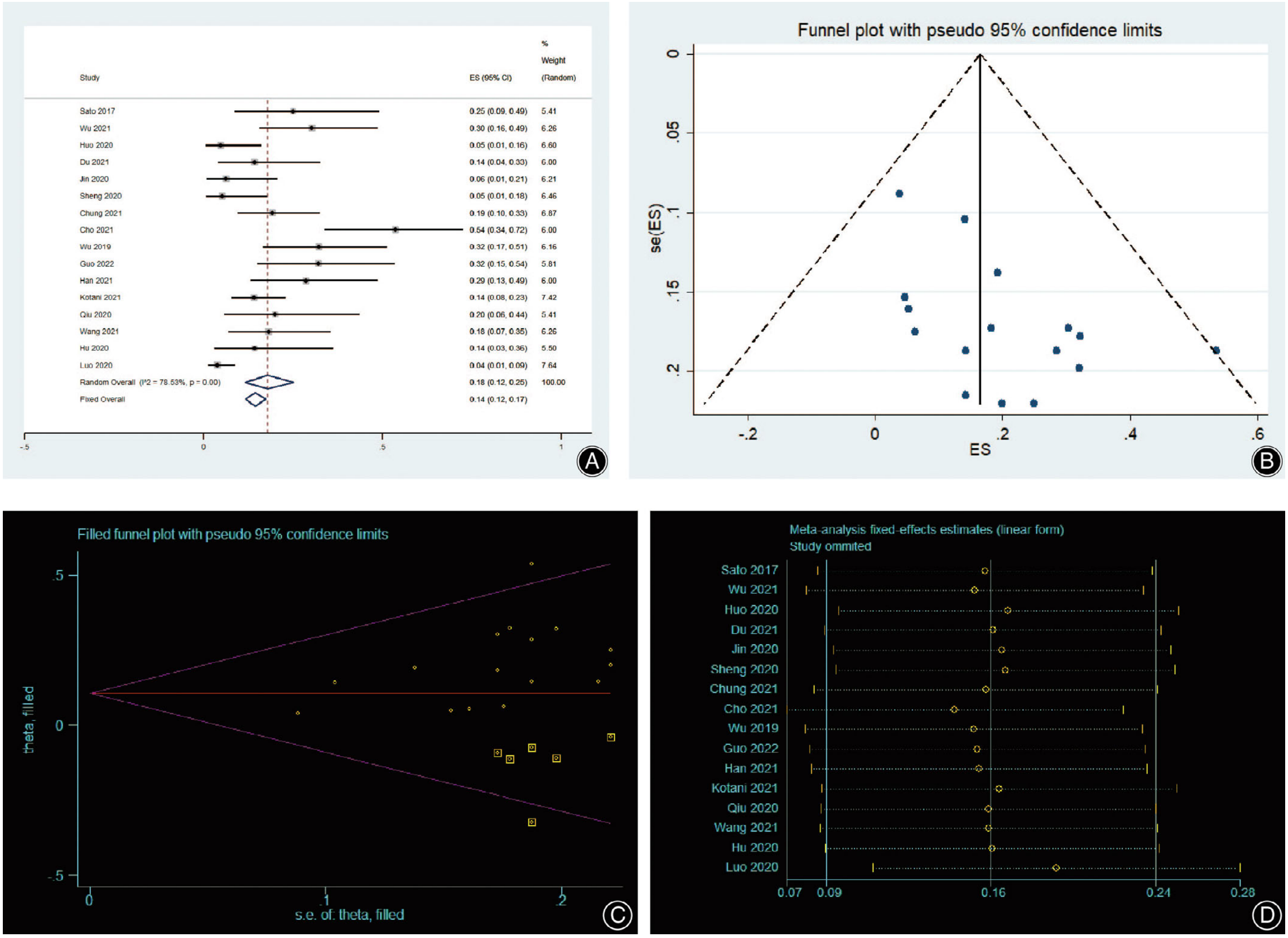


Slip ratio

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Chung 2021	18.2	7.2	53	4.7	4.3	53	32.4%	13.50 [11.24, 15.76]
Kotani 2021	11.8	9.3	92	7.3	7.2	92	32.0%	4.50 [2.10, 6.90]
Luo 2020	14.57	0.62	128	2.59	0.31	128	35.7%	11.98 [11.86, 12.10]
Total (95% CI)			273			273	100.0%	10.08 [5.85, 14.31]

Heterogeneity: Tau² = 13.06; Chi² = 38.90, df = 2 (P < 0.00001); I² = 95%
Test for overall effect: Z = 4.67 (P < 0.00001)

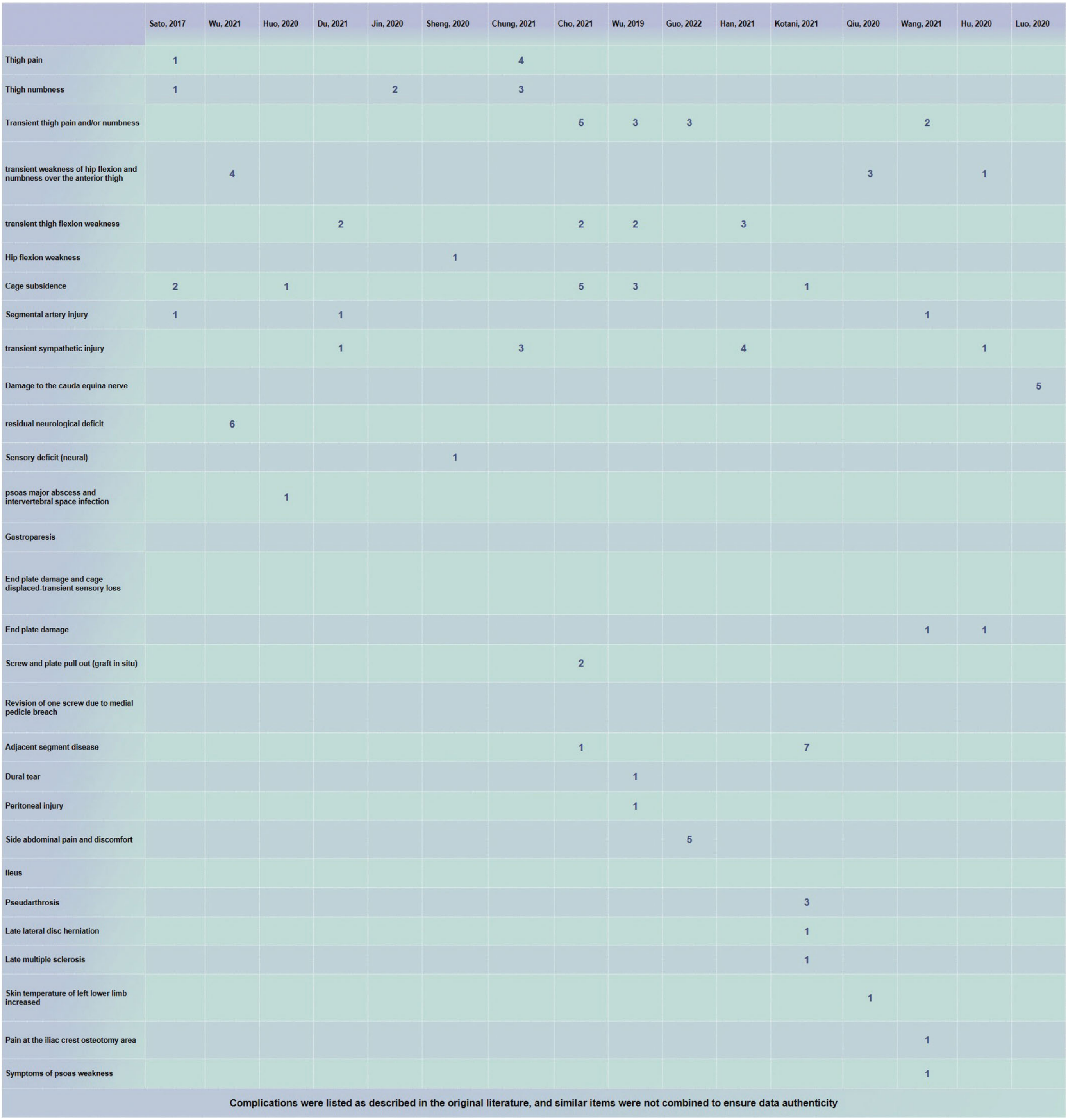
Fig. 5 Forest plot of slip ratio of DLS patients treated with OLIF before and at the end of follow-up



Study	ES (95% CI)	% Weight (Random)
Sato 2017	0.25 (0.09, 0.49)	5.41
Wu 2021	0.30 (0.16, 0.49)	6.26
Huo 2020	0.05 (0.01, 0.16)	6.60
Du 2021	0.14 (0.04, 0.33)	6.00
Jin 2020	0.06 (0.01, 0.21)	6.21
Sheng 2020	0.05 (0.01, 0.18)	6.46
Chung 2021	0.19 (0.10, 0.33)	6.87
Cho 2021	0.54 (0.34, 0.72)	6.00
Wu 2019	0.32 (0.17, 0.51)	6.16
Guo 2022	0.32 (0.15, 0.54)	5.81
Han 2021	0.29 (0.13, 0.49)	6.00
Kotani 2021	0.14 (0.08, 0.23)	7.42
Qiu 2020	0.20 (0.06, 0.44)	5.41
Wang 2021	0.18 (0.07, 0.35)	6.26
Hu 2020	0.14 (0.03, 0.36)	5.50
Luo 2020	0.04 (0.01, 0.09)	7.64
Random Overall (I^2 = 78.53%, p = 0.00)	0.18 (0.12, 0.25)	100.00
Fixed Overall	0.14 (0.12, 0.17)	

Fig. 6 Forest plot (A) of incidence of complications before and at the end of follow-up, funnel plot (B) of incidence of complications evaluating publication bias, trim and filling method (C) used to correct for publication bias and sensitivity analysis (D) used to screen for literature that causes significant interference with research results

patients.[14,15,18,22,24,33] Heterogeneity testing yielded an I^2 value of 92% and the random effect model was selected. IDH increased by an average of 4.29 mm (95% CI −5.23 to −3.34 mm; $Z = 8.92$; $p < 0.00001$) (Fig. 3A). When the time was limited to the postoperative period, IDH increased by an average of 4.47 mm (Fig. S3A). Two studies involving 65 patients addressed foraminal height (FH)[14, 24] (random effect model; MD −5.83 mm [95% CI −7.94 to −3.72 mm]; $Z = 5.42$, $p < 0.00001$) (Fig. 3B).



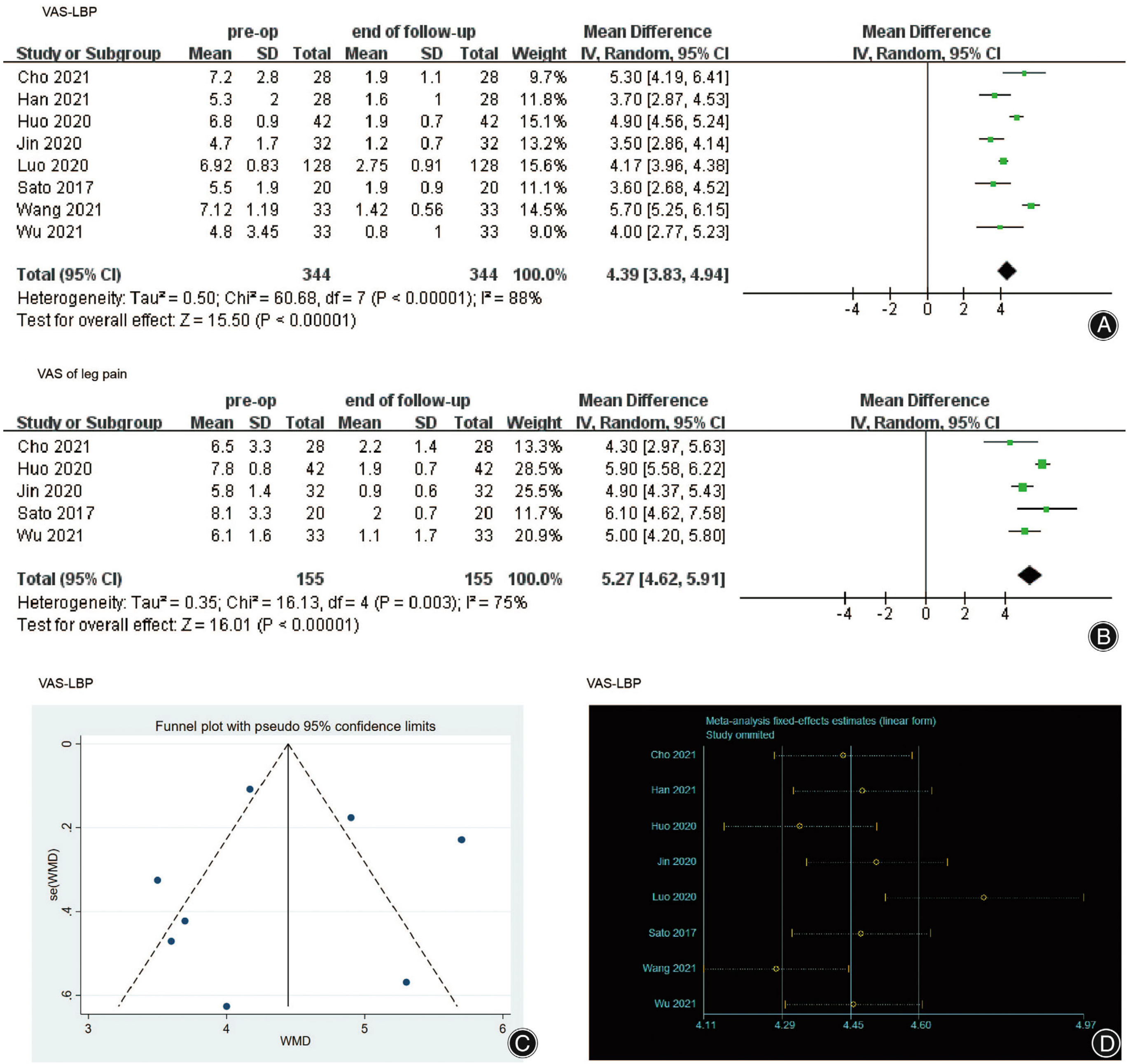
	Sato, 2017	Wu, 2021	Huo, 2020	Du, 2021	Jin, 2020	Sheng, 2020	Chung, 2021	Cho, 2021	Wu, 2019	Guo, 2022	Han, 2021	Kotani, 2021	Qiu, 2020	Wang, 2021	Hu, 2020	Luo, 2020
Thigh pain	1						4									
Thigh numbness	1				2		3									
Transient thigh pain and/or numbness								5	3	3				2		
transient weakness of hip flexion and numbness over the anterior thigh		4											3		1	
transient thigh flexion weakness				2				2	2		3					
Hip flexion weakness						1										
Cage subsidence	2		1					5	3			1				
Segmental artery injury	1			1										1		
transient sympathetic injury				1			3				4				1	
Damage to the cauda equina nerve																5
residual neurological deficit		6														
Sensory deficit (neural)						1										
psoas major abscess and intervertebral space infection			1													
Gastroparesis																
End plate damage and cage displaced-transient sensory loss																
End plate damage														1	1	
Screw and plate pull out (graft in situ)								2								
Revision of one screw due to medial pedicle breach																
Adjacent segment disease								1				7				
Dural tear									1							
Peritoneal injury									1							
Side abdominal pain and discomfort										5						
ileus																
Pseudarthrosis												3				
Late lateral disc herniation												1				
Late multiple sclerosis												1				
Skin temperature of left lower limb increased													1			
Pain at the iliac crest osteotomy area														1		
Symptoms of psoas weakness														1		

Complications were listed as described in the original literature, and similar items were not combined to ensure data authenticity

Fig. 7 Detailed complications of the included articles

Lumbar Lordosis and Segment Lordosis

Lumbar lordosis (LL) results were reported in six studies involving 218 patients.[13,14,18,19,24,33] The average improvement was 9.22° (95% CI −13.40° to −5.05°). A random effect model was selected ($I^2 = 72\%$; $Z = 4.33$, $p < 0.00001$) (Fig. 4A). Three studies compared segment lordosis (SL) in107 patients,[13,14,24] with an average improvement of 2.46° (95% CI −3.66 to −1.25°), and with statistical significance



VAS-LBP

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Cho 2021	7.2	2.8	28	1.9	1.1	28	9.7%	5.30 [4.19, 6.41]
Han 2021	5.3	2	28	1.6	1	28	11.8%	3.70 [2.87, 4.53]
Huo 2020	6.8	0.9	42	1.9	0.7	42	15.1%	4.90 [4.56, 5.24]
Jin 2020	4.7	1.7	32	1.2	0.7	32	13.2%	3.50 [2.86, 4.14]
Luo 2020	6.92	0.83	128	2.75	0.91	128	15.6%	4.17 [3.96, 4.38]
Sato 2017	5.5	1.9	20	1.9	0.9	20	11.1%	3.60 [2.68, 4.52]
Wang 2021	7.12	1.19	33	1.42	0.56	33	14.5%	5.70 [5.25, 6.15]
Wu 2021	4.8	3.45	33	0.8	1	33	9.0%	4.00 [2.77, 5.23]
Total (95% CI)			**344**			**344**	**100.0%**	**4.39 [3.83, 4.94]**

Heterogeneity: Tau² = 0.50; Chi² = 60.68, df = 7 (P < 0.00001); I² = 88%
Test for overall effect: Z = 15.50 (P < 0.00001)

VAS of leg pain

Study or Subgroup	pre-op Mean	pre-op SD	pre-op Total	end of follow-up Mean	end of follow-up SD	end of follow-up Total	Weight	Mean Difference IV, Random, 95% CI
Cho 2021	6.5	3.3	28	2.2	1.4	28	13.3%	4.30 [2.97, 5.63]
Huo 2020	7.8	0.8	42	1.9	0.7	42	28.5%	5.90 [5.58, 6.22]
Jin 2020	5.8	1.4	32	0.9	0.6	32	25.5%	4.90 [4.37, 5.43]
Sato 2017	8.1	3.3	20	2	0.7	20	11.7%	6.10 [4.62, 7.58]
Wu 2021	6.1	1.6	33	1.1	1.7	33	20.9%	5.00 [4.20, 5.80]
Total (95% CI)			**155**			**155**	**100.0%**	**5.27 [4.62, 5.91]**

Heterogeneity: Tau² = 0.35; Chi² = 16.13, df = 4 (P = 0.003); I² = 75%
Test for overall effect: Z = 16.01 (P < 0.00001)

Fig. 8 Forest plots describing the difference in VAS-LBP (A) and VAS of leg pain (B) between the end of follow-up and before surgery. Funnel plot (C) and sensitivity analysis (D) of VAS-LBP

($I^2 = 0\%$ [fixed effect model]; $Z = 3.98$, $p < 0.0001$) (Fig. 4B). On postoperative tests, the mean improvement in these two measures was 9.24° and 1.87°, respectively (Fig. S4A,B).

Slip Ratio

Three articles reported specific percentage reductions in spondylolisthesis in 273 patients at the end of follow-up.[15,19,23] Heterogeneity testing yielded an I^2 value of 95% and the random effect model was selected. Results of meta-analysis revealed statistical significance (MD 10.08% [95% CI 5.85–14.31%]; $Z = 4.67$, $p < 0.00001$) (Fig. 5). Three of the included studies also tested slip ratio immediately after surgery, and the average value was 5.69% (Fig. S5A).

Complications

The incidence of complications was statistically analyzed in 16 studies,[12–21,23–26,32,33] with a rate of 4%–54% and an overall incidence of 18% (95% CI 12%–25%) (Fig. 6A). Among them, thigh pain, numbness, and hip flexion weakness were the most common, with up to 42 cases. The funnel plot was symmetrical; however, Egger's test ($p = 0.022$) indicated slight publication bias (Fig. 6B). The "trim and fill" method revealed that six studies needed to be added to eliminate publication bias (Fig. 6C). Sensitivity analysis revealed that none of the studies significantly interfered with effect size or heterogeneity, indicating that this study had good stability (Fig. 6D, Fig. 7).

Secondary Outcomes

Basic Information and Surgical Data

Publication information (first author, publication year, etc.), baseline information (age, gender) and surgical data (L level, operation time, etc.) were collected (Table 1). According to the statistics, the mean age of the patients was 63.86 years, and the shortest mean follow-up time was 12 months.

VAS Score for LBP

Studies assessing pain using VAS-LBP score, and those including data at the end of follow-up were selected. In this study, VAS-LBP data were collected for 344 patients.[13–15,18,21,24,25,32] Heterogeneity testing yielded an I^2 value of 88% and the random effect model was applied. Results of meta-analysis revealed that differences in pre- and postoperative VAS-LBP score were statistically significant (mean difference [MD] 4.39 [95% confidence interval (CI) 3.83–4.94]; $Z = 15.50$; $p < 0.00001$) (Fig. 8A). At the time of postoperative measurement, the VAS decreased by an average of 5.58 (Fig. S6A). The funnel plot was symmetrical, and Egger's test ($p = 0.979$) revealed no publication bias (Fig. 8C). A sensitivity analysis was performed on eight studies. Only the study by Luo *et al.* introduced significant bias, largely because the sample size of that study was significantly larger than that of the other studies (Fig. 8D).

VAS Score for Leg Pain

Six studies reported VAS score for leg pain among 155 patients at the end of follow-up.[13,14,18,25,32] The mean preoperative VAS score ranged from 5.8 to 8.1. Leg pain abated and meta-analysis revealed a statistically significant difference ($I^2 = 75\%$ [random effect model]; MD = 5.27 [95% CI 4.62–5.91]; $Z = 16.01$; $p < 0.00001$) (Fig. 8B). At the time of postoperative measurement, the VAS score for leg pain decreased by an average of 5.58 (Fig. S6B).

Discussion

The choice of surgical approach for lumbar disease has long been a controversial topic. Through clinical observation, domestic and foreign investigators have found that traditional posterior lumbar interbody fusion (PLIF) surgery has disadvantages including high complication rate, large amount of blood loss, and long operative duration.[34] Currently, minimally invasive surgery has become a trend in spinal fusion,[35,36] and OLIF has emerged as a viable surgical option in recent years.

Postoperative Short- and Long-Term Efficacies

Our database search revealed that studies investigating OLIF treatment for DLS have largely been published in only the past 2 years. Most of these were retrospective in design, and most focused on the postoperative efficacy of OLIF, ignoring its long-term efficacy and safety.[16,26] However, some studies have reported that short-term clinical and radiographic outcomes after OLIF differ from long-term outcomes. For example, Jin *et al.* reported a mean postoperative ODI of 17.5 ± 3.2% and an ODI of 11.4 ± 2.6% at the end of follow-up[14]. Our study included 17 studies (all published within 5 years) on the application of OLIF for DLS, which were relatively comprehensive and had relatively consistent efficacy evaluation criteria. The study purposes were to clarify the long-term efficacies and to provide detailed data.

Pain Relief

VAS score is adopted extensively in lumbar diseases. Compared to VAS of leg pain, VAS-LBP was more commonly used, and was applied in 10 studies. In terms of the improvement of lumbago and leg pain, the postoperative low back pain and leg pain VAS score decreased by 4.55 points and 5.46 points, respectively. And compared with those before surgery, there were statistical differences ($p < 0.00001$). In addition, Han *et al.* reported a mean VAS-LBP of 2.8 ± 1.2 at 1 week postoperatively and 1.6 ± 1.0 at 3 months postoperatively.[21] This means further pain relief after long-term follow-up, which may be related to factors such as damage to the paravertebral muscles.

Clinical Function Recovery

Compared with JOA score, the ODI is more commonly used to evaluate the recovery of lumbar function and is more widely accepted. In our study, patient ODI score improved by 33.82%, and the difference was statistically significant ($p < 0.00001$). In addition, Wu *et al.* reported a mean ODI of 23.8 ± 17.6% at 3 month follow-up, which decreased to 14.2 ± 13.5% at the end of follow-up.[25] This indicates that optimal recovery of lumbar function was still not achieved 3 months after surgery. In addition, Sheng *et al.*[17] and Han *et al.*[21] evaluated patient satisfaction, with all 38 (100%) in the former study expressing satisfaction, while the satisfaction rate in the latter reached 92.60%. Jin *et al.* evaluated patients using the Short-Form-36 evaluation scale, in which the SF-36 Physical Component Summary achieved a 56.0% improvement rate, and the SF-36 Mental Component Summary achieved a 38.3% improvement rate.[14] And Koike *et al.* used JOABPEQ Effectiveness rate to evaluate efficacies, 1 year after OLIF, they also achieved positive results.[22] All these indicated that OLIF has stable long-term efficacies in DLS treatment.

Radiographic Improvement

In terms of imaging measurements, IDH increased by 4.18 mm ($p < 0.00001$) and FH increased by 4.91 mm ($p < 0.0001$) at the end of the follow-up, compared with that before surgery, with a statistically significant difference. Jin *et al.*[14] reported an increase in mean foraminal width, from 8.6 ± 1.0 mm preoperatively to 9.5 ± 0.9 mm at the end of follow-up. In addition, Luo *et al.* found that the mean spinal canal diameter increased from 8.11 to 10.86 mm and the cross-sectional area increased from 82.16 to 114.72 mm^2 after 1 year of follow-up[15]. It has been suggested that OLIF can effectively increase the height of the intervertebral space, enlarge the nerve root canal, and relieve nerve root compression after long-term follow-up. In most studies,[22] there was a slight—but not statistically or clinically significant—decrease in intervertebral height after long-term follow-up compared with short-term postoperative intervertebral height.

For DLS, it is very important to improve sagittal balance and correct LL for postoperative relief of lumbar pain and recovery of daily functions.[37] Aoki *et al.*[38] reported that the mismatch between the incident angle of the pelvis and the lordosis angle of the lumbar spine (PI-LL) after short-segment lumbar interbody fusion was significantly correlated with postoperative LBP. Hsu *et al.*[39] showed that reconstruction of LL, even in short-segment surgery, can help improve symptoms and prevent degeneration of adjacent segments. According to the results of our study, the overall LL increased by 9.22°, whereas the SL increased by 2.46° ($p < 0.00001$). Moreover, Cho *et al.*[18] reported that PI-LL mismatch exhibited marked progress, from 19.4 ± 17.6° preoperatively to 3.7 ± 11.6° at final follow-up. These results suggest that OLIF can effectively restore lumbar balance, improve LL, and restore lumbar curvature after long-term follow-up.

Vertebral Slipping

In our study, the degree of vertebral slipping after long-term follow-up was 10.45% lower than the preoperative value, a difference that was statistically significant ($p < 0.00001$). In a study by Kotani *et al.*, the degree of slippage changed from 7.3% after surgery to 7.8% 6 months after surgery, and then to 7.3% 6 months at the end of follow-up.[23] Therefore, in conclusion, OLIF had very good short- and long-term efficacy in reducing vertebral spondylolisthesis, with no significant difference between the two.

Complications

We evaluated the safety of OLIF based on the incidence of complications. Details of the cases with complications in the literature are summarized in Fig. 8. A total of 106 complications were reported in our included studies, in which pain, numbness, and hip flexion weakness on the operative side were often grouped together. In this study, the aforementioned complications were reported in 13 articles. The incidence of depression was also high, with a total of 12 cases, which may be closely related to bone mineral density among the patients. There were nine cases of sympathetic nerve injury and three cases of segmental artery injury. Cho *et al.* and Wu *et al.* studied the complication rate of PLIF and OLIF at the same time and found that the complication rate of OLIF was significantly lower than that of PLIF.[18,33] Guo *et al.* and Du *et al.* did not find that OLIF was superior to TLIF in terms of complication rate.[20,26] In particular, the reader needs to be reminded that the funnel plot for complications was basically symmetrical; however, Egger's test ($p = 0.022$) indicated slight publication bias. The main reason is that most contemporary studies investigating OLIF for DLS are retrospective in design, and the overall quality of these studies is low. Therefore, large-scale randomized controlled studies are urgently required to definitively demonstrate the safety and efficacy of OLIF.

Limitation

The data retrieval of our study was comprehensive, and the publication time of the included literature was concentrated. However, there were still some limitations. First, the number of included articles were limited. Second, most of the articles were non-randomized studies of the effects of interventions (NRSI) and large-scale randomized controlled trials were still lacking. Third, there was publication bias in some outcome measures, which may cause a certain impact on the results of systematic evaluation. However, because the population characteristics are more similar to the real world, NRSI are particularly suitable for studying long-term outcome measures and adverse effects, which is actually advantageous to our study.

Conclusion

Our study further demonstrated the long-term efficacy and safety of OLIF in the treatment of DLS, including VAS, ODI, JOA score, IDH, FH, LL, SL, slip ratio, and incidence of surgical complications. To provide a stronger basis for clinical practice, we will further compare the long-term efficacy and safety of OLIF with TLIF and other technologies in a future study. In addition, a well-designed, multicenter, randomized controlled trial with a long-term follow-up is necessary for further evaluation. In addition, through the design of this study, we found that the overall follow-up period of related studies on OLIF treatment of DLS is still short, which is a point worthy of clinical research attention and design.

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None.

Authors Contributions

Meifen Daiand Conghua Ji: Conceptualization, Methodology. Huan Ma, Fanyi Zhang and Qijie Ying: Investigation, Data Curation, Statistical analysis, Writing—Original Draft. Baoze Pan: Investigation, Data Curation. Yuting Li and Yu Cao: Editing and Revisions. Tingfei Jiang: Supervision. Conghua Ji: Funding acquisition.

Authorship Declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and that all authors are in agreement with the manuscript.

Conflicts of Interest

The author(s) declared no potential conflicts of interest.

Ethics Statement

Not needed as it is a systematic review and does not involve any patient-specific data.

Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Appendix S1 Search formulas used to obtain literature on the long-term efficacy and safety of OLIF for DLS from major databases.

Fig. S2 Forest plot of ODI (Fig. S2), IDH (**Fig. S3**), LL, SL (**Fig. S4**), slip ratio (**Fig. S5**), and VAS (**Fig. S6**) of DLS patients treated with OLIF before and after surgery.

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