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Comparing clinical and radiological outcomes between single-level OLIF and XLIF: A systematic review and meta-analysis

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ABSTRACT

Background Context: Oblique lumbar interbody fusion (OLIF) and extreme lateral interbody fusion (XLIF) are 2 popular minimally invasive spinal fusion techniques with unique approach-related complication profiles. Accordingly, patient-specific anatomical factors, such as vascular anatomy or iliac crest height, greatly influence which technique to use. Previous studies comparing these approaches do not account for the inability of XLIF to access the L5–S1 disc space and therefore do not exclude this level in their analysis. The purpose of this study was to compare radiological and clinical outcomes of these techniques in the L1–L5 region.

Methods: A query of 3 electronic databases (PubMed, CINAHL plus, and SCOPUS) was performed, without time restriction, to identify studies that evaluated outcomes of single-level OLIF and/or XLIF between L1 and L5. Based on heterogeneity, a random effects meta-analysis was performed to evaluate the pooled estimation of each variable between the groups. An overlap of 95% confidence intervals suggests no statistically significant difference at the $p<.05$ level.

Results: A total of 1,010 patients (408 OLIF, 602 XLIF) were included from 24 published studies. Improvements in disc height (OLIF: 4.2 mm; XLIF: 5.3 mm), lumbar segmental (OLIF: 2.3°; XLIF: 3.1°), and lumbar lordotic angles (OLIF: 5.3°; XLIF: 3.3°) showed no significant difference. The rate of neuropraxia was significantly greater in the XLIF group at 21.2% versus 10.9% in the OLIF group ($p<.05$). However, the rate of vascular injury was higher in the OLIF cohort at 3.2% (95% CI:1.7–6.0) as compared to 0.0 (95% CI: 0.0–1.4) in the XLIF cohort. Improvements in VAS-b (OLIF: 5.6; XLIF: 4.5) and ODI (OLIF: 37.9; XLIF: 25.6) scores were not significantly different between the 2 groups.

Conclusions: This meta-analysis demonstrates similar clinical and radiological outcomes between single-level OLIF and XLIF from L1 to L5. XLIF had significantly higher rates of neuropraxia, whereas OLIF had greater rates of vascular injury.

Background

Minimally invasive anterolateral approaches to lumbar spinal fusion have seen a dramatic increase in utilization over the past 2 decades [1]. Oblique lumbar interbody fusion (OLIF) and extreme lateral interbody fusion (XLIF) are novel techniques that provide unique advantages for accessing the lumbar spine in this fashion. Additionally, there is an established body of literature that demonstrates comparable outcomes between minimally invasive techniques and their traditional open counterparts in the treatment of degenerative thoracolumbar disease [2]. Both techniques minimize soft tissue dissection, and are associated with decreased blood loss, quicker time to ambulation, shorter hospital stays, and lower rates of infection [3–7].

Although both OLIF and XLIF have demonstrated success in the treatment of various spinal pathologies, each approach utilizes a different anatomic window to gain access to the spinal column which is largely responsible for their unique complication profiles. The extreme lateral, or "transpsoas," approach involves dissection through the psoas muscle which carries an increased risk of nerve injury due to its close proximity to the lumbar plexus. The oblique, or "anterior-to-psoas,"

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approach uses an anatomic corridor that is far enough anterior to avoid the psoas muscle thereby reducing the risk of injury to the lumbar plexus. However, because this technique utilizes a window between the prevertebral vascular structures and the psoas muscle, it carries an increased risk of vascular and sympathetic plexus injury. Accordingly, patient-specific anatomical factors play an integral role in determining which technique is preferred.

Despite the increasing popularity of both techniques, there is limited literature comparing the radiographic and patient-reported outcomes of OLIF and XLIF directly. A majority of existing comparative studies have not analyzed the 2 approaches at the same vertebral levels and were performed by a single surgeon on a small sample size that may be easily influenced by surgeon and patient specific factors (ie, body habitus) [8–10]. Additionally, the existing studies comparing OLIF and XLIF fail to appreciate the fact that OLIF can access the L5–S1 disc space whereas XLIF cannot [11]. Since it is well-established that certain pathologies have a predilection for specific intervertebral levels, and the basic biomechanics of the lumbar spine change dramatically at the lumbo-sacral interface, any comparisons between the OLIF and XLIF approaches must analyze the same region of the lumbar spine for precise analysis. These limitations make it difficult to reliably draw conclusions about the potential differences in outcomes between the 2 techniques. Therefore, the purpose of this study is to compare the clinical and radiological outcomes of single-level OLIF and XLIF in the L1–L5 region through a systematic review and meta-analysis.

Materials and methods

Search strategy

This study was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A systematic search of 3 electronic databases (PubMed, CINAHL plus, and SCOPUS) was conducted to identify studies that evaluated outcomes of single-level OLIF or XLIF between the levels L1–L5. No time restriction was implemented for this meta-analysis. All published studies were evaluated using the Boolean search string: “lateral lumbar interbody fusion[title]” OR “XLIF[title]” OR “extreme lateral interbody fusion[title]” OR “XLIF[title]” OR “direct lateral interbody fusion[title]” OR “DLIF[title]” OR “direct lumbar interbody fusion[title]” OR “transpsoas[title]” OR “oblique lumbar interbody fusion[title]” OR “oblique lateral lumbar interbody fusion[title]” OR “OLIF[title]” OR “anterior to psoas[title].”

Study selection

Studies were considered eligible for inclusion if they met the following criteria: (1) prospective or retrospective, (2) patients at least 18 years of age, (3) sample size greater than 10 patients, (4) containing data on single-level lumbar fusion performed utilizing an oblique or lateral approach between L1 and L5, (5) contained data on demographic variables, clinical outcomes, radiological outcomes, perioperative data or complications related to single-level fusion. Studies were excluded from the analysis if they met any of the following criteria: (1) included data involving the L5–S1 level, (2) were not published in English, (3) had a sample size less than 10, (4) were case reports, animal or cadaveric studies. The initial query yielded 2,150 results through the above databases. After removing duplicates and applying inclusion and exclusion criteria, 24 studies were included in the final analysis (Fig. 1) [12–35].

Data extraction

Two reviewers (N.P. and D.C.) independently evaluated both the abstracts and titles for identification of articles relevant to the meta-analysis. Full texts of each study were obtained, and their respective reference lists were thoroughly reviewed for any studies that may be worthy of addition to the meta-analysis. If any discrepancies were encountered, with respect to inclusion of a particular study, a senior author would review the article for consideration (A.E.). Data regarding study type, type of surgical technique, levels operated on, sample size and patient demographics were collected. Perioperative outcomes and postoperative complications including rates of neurological injury, vascular injury, pseudarthrosis, subsidence, and reoperation were obtained from all studies.

Radiographic outcomes including both pre- and postoperative measurements for anterior disc height (ADH), lumbar lordosis angle (LLA), and lumbar segmental angle (LSA) were recorded. Lastly, pre- and postoperative measurements for patient reported outcome measures based on Visual Analogue Scale for back (VAS-b) pain and Oswestry Disability Index (ODI) scores were independently collected from each study. Improvements in radiographic and patient-reported outcome measures were using measures provided at final follow-up with a minimum requirement of 1 year postoperatively.

Quality assessment

The methodological qualities of the included studies were assessed using the Newcastle-Ottawa scale [36]. The scale is comprised of 3 domains including selection, comparability of groups, and assessment of outcomes. The quality assessment of each study was determined through overall scores which were categorized as low (0–3), moderate (4–6), or high (7–9). Scores were determined independently by the aforementioned reviewers and any discrepancies were addressed by the senior author.

Bias assessment

The presence of publication bias was investigated through the use of funnel plots. Funnel plots were generated for primary and secondary outcomes including improvements in radiographic and clinical outcome scores. These scatter plots depicted the treatment effects estimated from individual studies against a measure of the study size. In the absence of bias, the plot will resemble an inverted funnel, as smaller studies scatter widely at the bottom, and larger studies demonstrate less variation and consolidate towards the mean.

Statistical analysis

Meta-analysis was conducted on outcome data from the 24 studies. Based on heterogeneity, random effects models of meta-analysis were used to estimate the pooled estimates and the 95% confidence intervals. Heterogeneity within all included studies in this meta-analysis was assessed using Cochran’s Q test – a chi-square-based test. A p value of $<.05$ was used for statistical significance. Although the Cochran’s Q test resulted in values that describe qualitative information concerning the presence of heterogeneity, I^2 statistics index was used to quantify the amount of heterogeneity for each study group. This was calculated as the percentage of total variability in a set of effect sizes attributable to true heterogeneity. Forest plots were created to estimate the pooled proportions or pooled means with 95% confidence interval (CI).

To compare the differences in outcome data between patients who underwent OLIF compared to those who underwent XLIF, we conducted a meta-analysis within these groups separately to get the pooled estimations. Overlap of the 95% CI of the 2 groups suggests no statistically significant difference at the $p<.05$ level.

The weighted mean values were calculated by the equation $W = \frac{\sum_{i=1}^{2k} N_i * M_i}{\sum_{i=1}^{2k} N_i}$, where k is the number of studies with eligible outcome estimates for both OLIF and XLIF groups, N_i is the sample size in the i^{th} study for the OLIF or XLIF group, and M_i is the mean or proportion of the outcome in the i^{th} study for the corresponding group. Statistical analyses were performed using statistical software R version 4.0.4.

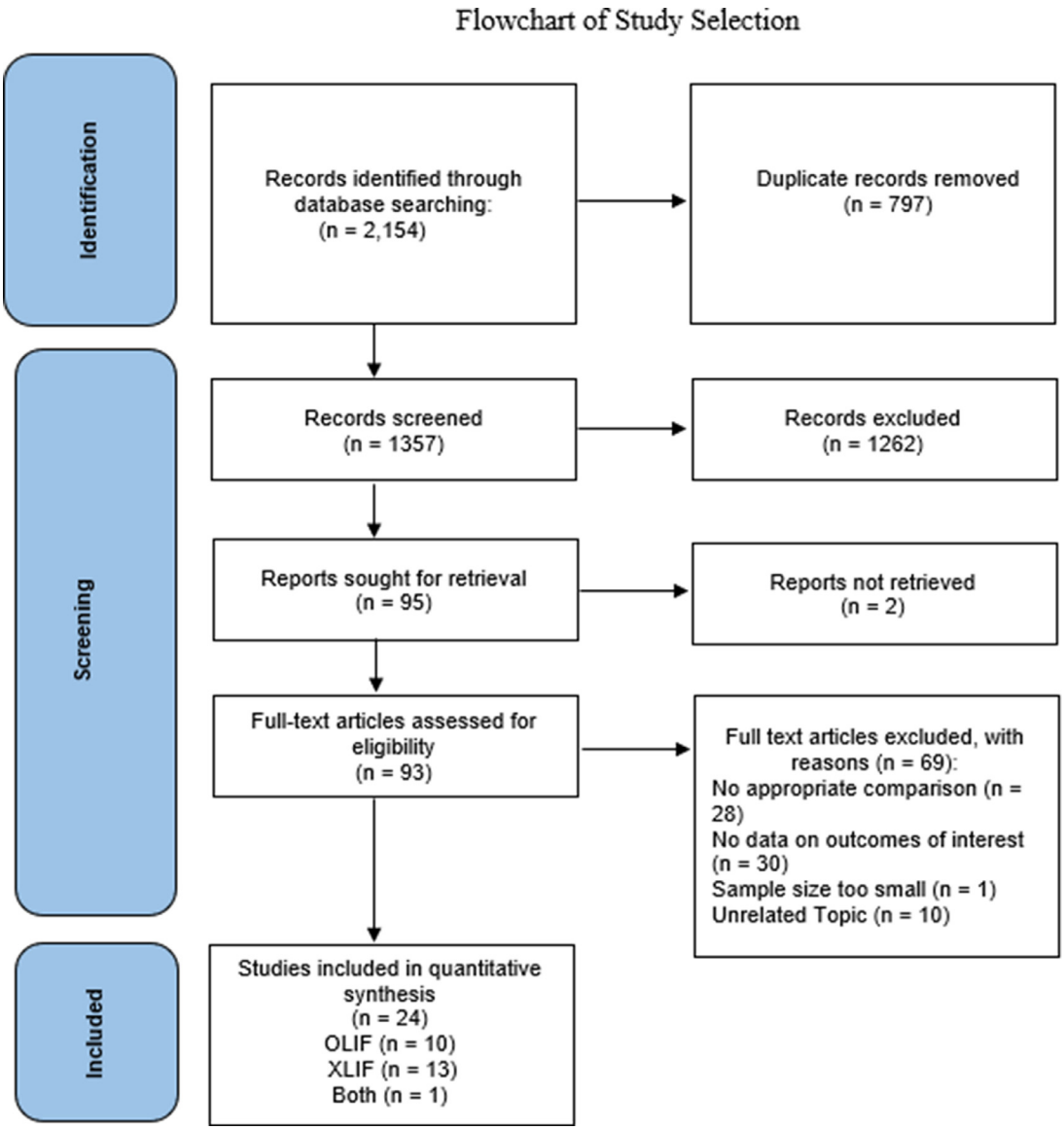

Fig. 1. Flowchart of study selection. OLIF, oblique lumbar interbody fusion; XLIF, extreme lateral interbody fusion.

Results

Study selection

A total of 2,154 studies were search searched, and 797 duplicates were excluded (Fig. 1). Upon screening for eligibility and requesting reports for retrieval, 93 full-text articles were obtained for thorough reading and review. Of these, 28 articles were removed due to inappropriate comparisons, 30 were removed as they did not provide outcomes of interest as described specifically for single-level fusions, 10 were unrelated to our topic at hand, and 1 had an inadequately small sample size. Subsequently, we had 24 total studies included for quantitative synthesis of which 19 were retrospective cohort studies, 3 were prospective observational studies and 2 were randomized controlled trials.

Quality assessment

Assessment of risk of bias using the Newcastle-Ottawa scale showed that almost all studies had a high-quality assessment score (7–9) with one study having a moderate quality score of 6 (Table 1). The most commonly cited reasons for loss of points were due to diminished comparability of the cohorts and limitations in regard to achieving adequate follow-up time. All studies had a level of evidence of 2 or 3 (Table 2).

Description of study

A total of 1,010 patients from 24 comparative studies (14 XLIF, 11 OLIF) were included in our analysis. The study population had an average age of 62.2 years and a body mass index (BMI) of 24.86. Differences in patient demographics between the 2 groups are illustrated in Table 3. A total of 408 patients with an average age of 60.8 years (I^2=88%, 95% CI: 57.9–63.8) and average BMI of 23.98 kg/m^2 (I^2=77%, 95% CI: 23.39–24.57) at the time of operation were included in the OLIF group (Figs. 2A and 3A). The XLIF group was comprised of 602 patients with an average age of 61.3 years (I^2=93%, 95% CI: 58.2–64.3) and BMI of 25.6 kg/m^2 (I^2=89%, 95% CI:24.4–26.8) (Figs 2B and 3B). There were no significant differences in demographic characteristics between the 2 groups.

Perioperative data

Differences in perioperative data between the 2 groups are reported in Table 4. Pooled analysis of 8 OLIF studies revealed that the mean

Table 1
Newcastle-Ottawa scale quality assessment scores for included studies

Studies	Selection				Comparability	Exposure			Total quality score
Author, year	Representativeness of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design/analysis	Assessment of outcome	Was follow-up long enough for outcome to occur	Adequacy of follow up of cohorts	
OLIF Studies									
Yingsakmongkol et al. [14]	1	1	1	1	2	1	1	1	9
Han et al., 2021 [12]	1	1	1	1	1	1	1	1	8
Takaoka et al., 2021[13]	1	1	1	1	1	1	1	1	8
Hung et al., 2021[24]	1	0	1	1	1	1	1	1	7
Du et al., 2021 [29]	1	1	1	1	0	1	1	1	7
Li et al., 2021 [30]	1	1	1	1	1	1	1	1	8
He et al., 2020 [31]	1	1	1	1	0	1	1	1	7
Wen et al., 2019 [32]	1	1	1	1	1	1	1	1	8
Lin et al., 2018 [33]	1	1	1	1	0	1	1	1	7
Heo & Kim, 2017 [34]	1	1	1	1	2	1	1	1	
Sato et al., 2015 [35]	1	1	1	1	1	1	0	1	7
XLIF studies									
Yingsakmongkol et al., 2022 [14]	1	1	1	1	2	1	1	1	9
Li et al., 2021 [15]	1	0	1	0	2	1	1	1	7
Hiyama et al., 2021 [27]	1	1	1	1	2	1	1	1	9
Jung et al., 2021 [28]	1	1	1	1	2	1	1	1	9
Saadeh et al., 2019 [22]	1	1	1	1	2	1	0	1	8
Ahlquist et al., 2018 [16]	1	1	1	1	2	1	0	1	8
Verla et al., 20 [17]	1	1	1	1	2	1	0	1	8
Du et al., 201 [19]	1	1	1	1	1	1	1	1	8
Rhee et al., 2015 [23]	1	1	1	1	2	1	1	1	9
Ahmadian et al., 2013 [18]	1	1	1	1	1	1	1	1	8
Pimenta et al., 2013 [25]	1	1	1	1	0	1	1	0	6
Kepler et al., 2011 [20]	1	1	1	1	2	1	1	0	8
Malham et al., 2012 [21]	1	1	1	1	2	1	1	1	9
Marchi et al., 2012 [26]	1	1	1	1	2	1	1	1	9

OLIF= oblique lateral interbody fusion; XLIF= extreme lateral interbody fusion.

Table 2
Characteristics of Included Studies.

Study	Sample size	Study type	Levels	Subjects (n, mean age, M:F)	Age (years)	Level Of evidence
OLIF Studies (n = 408)	408					
Yingsakmongkol et al. [14]	30	Retrospective	L4–L5	30, 63.0y 27/73	63.0	III
Han et al. [12]	28	Retrospective	L3–L5	28, 50.4y, 43/57	50.4	III
Takaoka et al. [13]	66	Retrospective	L3–L5	66, 66.0y, 42/58	66.0	III
Hung et al. [24]	21	Retrospective	L2–L5	21, 62.33y, 48/52	62.33	III
Du et al. [29]	29	Retrospective	L3–L5	57/43	53.6	III
Li et al. [30]	28	Retrospective	L3–L5	25/75	57.5	III
He et al. [31]	41	Retrospective	L4–L5	27/73	61.0	III
	32	Retrospective	L4–L5	31/69	59.8	III
Wen et al, 2019 [32]	36	Retrospective	L3–L5	36/64	56.9	III
	38	Retrospective	L3–L5	40/60	58.9	III
Lin et al. [33]	25	Retrospective	L4–L5	32/68	64.0	III
Heo & Kim [34]	14	Retrospective	L2–L5	50/50	66.3	III
Sato et al. [35]	20	Retrospective	L3–L5	45/55	69.0	III
XLIF Studies	602					
Yingsakmongkol et al. [14]	30	Retrospective	L4–L5	27/73	63.53	III
Li et al., 2021[23]	54	Prospective observational	L3–L5	35/65	60.3	II
	41	Prospective observational	L3–L5	49/51	57.9	II
Hiyama et al. [27]	80	Retrospective	L1–L5	60/40	71.6	III
Jung et al. [28]	31	Retrospective	L2–L5	100/0	66.8	III
	92	Retrospective	L1–L5	0/100	64.4	III
Saadeh et al. [22]	20	Retrospective	L2–L5	35/65	62.0	III
Ahlquist et al. [16]	23	Retrospective	L2–L5	-	-	III
Verla et al. [17]	17	Retrospective	L1–L5	59/51	56.1	III
Du et al. [19]	20	Retrospective	L1–L5	40/60	63.2	III
Rhee et al. [23]	38	Retrospective	L2–L5	47/53	-	III
Ahmadian et al. [18]	31	Retrospective	L4–L5	29/71	61.5	III
Pimenta et al. [25]	15	Prospective RCT	L4–L5	27/73	49.1	II
	15	Prospective RCT	L4–L5	47/53	45.7	II
Kepler et al. [20]	13	Retrospective	L3–L5	39/61	-	III
Malham et al. [21]	30	Retrospective	L1–L5	33/67	62.7	III
Marchi et al. [26]	52	Prospective observational	L1–L5	27/73	67.6	II

RCT, Randomized control trial; OLIF, oblique lateral interbody fusion; XLIF, extreme lateral interbody fusion.

Table 3
Age and BMI of OLIF and XLIF Cohorts.

Variable	OLIF Value	OLIF 95% CI	XLIF value	XLIF 95% CI
Age (years)	60.80	[57.85 – 63.76]	61.25	[58.24 – 64.27]
BMI (kg/m2)	23.98	[23.39 – 24.57]	25.61	[24.40 – 26.81]

BMI, body mass index; OLIF, oblique lateral interbody fusion; XLIF, extreme lateral interbody fusion; CI, confidence interval.

Table 4
Perioperative Outcomes and Postoperative Complications for OLIF and XLIF cohorts

Parameter	OLIF	OLIF 95% CI	XLIF	XLIF 95% CI	Conclusion
Perioperative outcomes					
EBL (mL)	87.7	[80.0–95.4]	92.9	[66.4–119.2]	Overlap
Operative time (min)	125.8	[104.3–147.2]	129.5	[106.7–152.3]	Overlap
Postoperative complications (%)					
Neuropraxia rate	10.9	[8.1–14.4]	21.2	[17.8–25.0]	No overlap*
Vascular injury	3.2	[1.7–6.0]	0	[0.0–1.4]	No overlap*
Pseudarthrosis rate	6.1	[3.8–9.6]	6.0	[3.7–9.7]	Overlap
Subsidence rate	18.9	[15.0–23.6]	14.3	[11.1–18.3]	Overlap
Reoperation rate	1.8	[0.5–5.0]	7.2	[4.6 –10.3]	Overlap

EBL, Estimated blood loss; CI, confidence interval
* indicates significance at p<.05.

blood loss for the group was 87.7 mL (I^2=90%, 95% CI: 80.0–95.4) as shown in Fig. 4A. 9 XLIF studies were included in the analysis and demonstrated a mean blood loss of 92.79 mL (I^2=99%, 95% CI: 66.4–119.2) (Fig. 4B). The average operative time of the OLIF group was 125.8 minutes (I^2=100%, 95% CI: 104.3–147.2) and 129.5 minutes (I^2=99%, 95% CI: 106.7–152.3) for the XLIF group (Figs. 5A and 5B). No significant differences were observed between the 2 groups regarding blood loss or operative time.

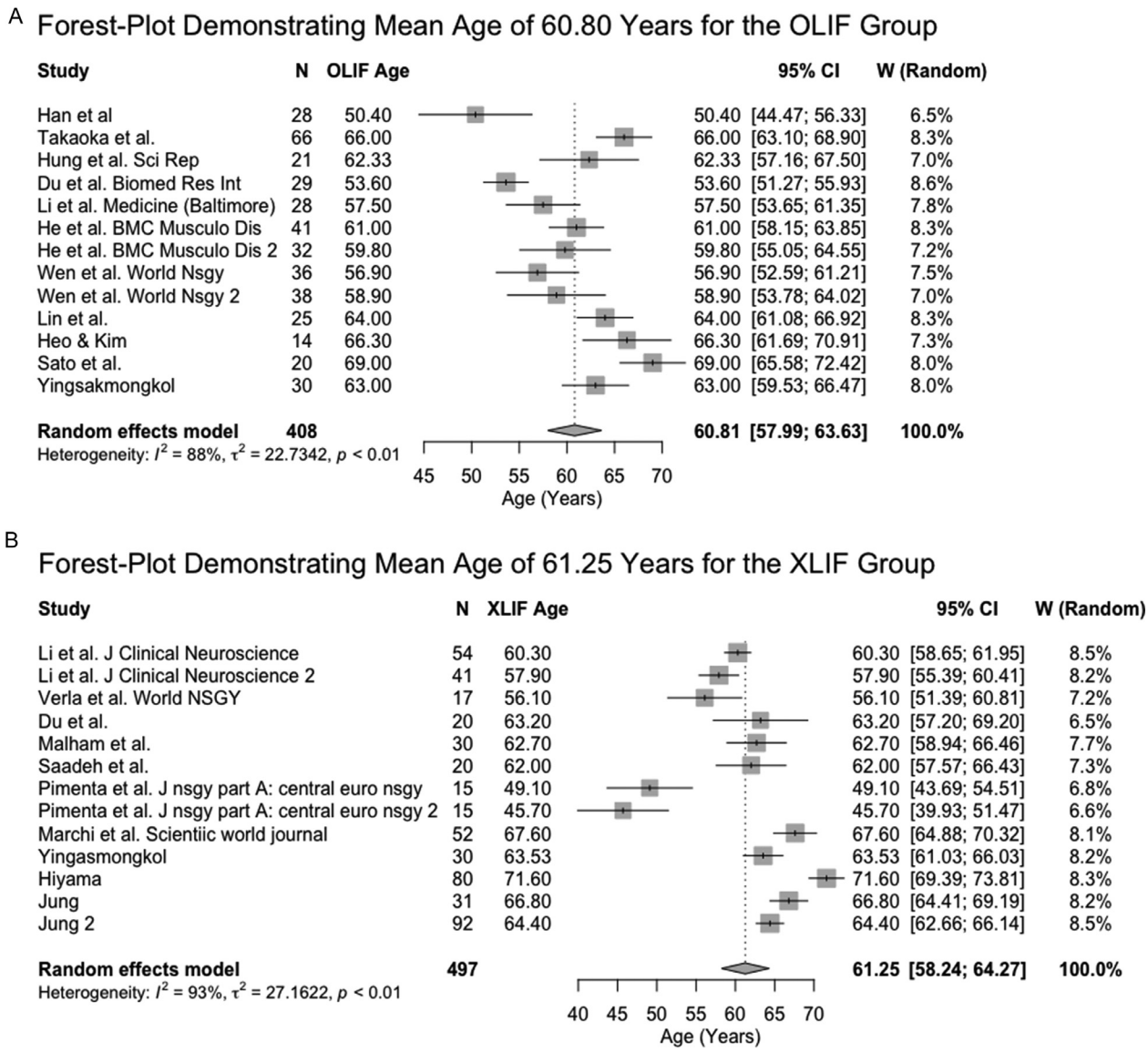

Fig. 2. A. Forest-plot demonstrating mean age, confidence intervals and heterogeneity present in the OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval. B. Forest-plot demonstrating mean age, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval.

Table 5
Changes in VAS-back and ODI Scores of OLIF and XLIF groups.

	OLIF Value	OLIF 95%CI	XLIF Value	XLIF 95%CI	Conclusion
VAS-back					
Preop	6.8	[5.8–7.8]	7.5	[6.8–8.2]	Overlap
Postop	1.25	[0.2–2.3]	2.9	[1.7–4.1]	Overlap
Change	-5.6	[-7.5 to -3.6]	-4.5	[-5.9 to -3.1]	Overlap
ODI					
Preop	53.2	[46.7–59.6]	50.1	[48.9–51.2]	Overlap
Postop	14.9	[6.4–23.3]	23.8	[8.4–39.3]	Overlap
Change	-37.9	[-44.4 to 31.5]	-25.6	[-43.0 to -8.6]	Overlap

OLIF, oblique lumbar interbody fusion; XLIF, extreme lateral interbody fusion; VAS, visual analog scale; ODI, Oswestry disability index; CI, confidence interval.

Patient-reported outcomes

Patient-reported functional outcome, including the visual analog scale for back (Vas-b) pain and the ODI, scores are recorded in Table 5. Final follow-up measurements presented in studies were used as our postoperative data points if they were at least 1 year after the index procedures. Pooled-analysis for VAS-b scores were based on 5 OLIF studies and 6 XLIF studies. The baseline mean VAS-b scores for the OLIF group were 6.8 (I^2=95%, 95% CI: 5.82–7.8) before surgery and 1.25 (I^2=99%, 95% CI: 0.2–2.3) at final follow-up. The XLIF group had mean VAS-b score of 7.5 (I^2=82%, 95% CI: 6.8–8.2) preoperatively and 2.9 (I^2=95%, 95% CI: 1.7–4.1) at final follow-up. Both groups demonstrated significant postoperative reduction in VAS-b scores. The mean improvement in the VAS-b score for the OLIF group was 5.6 (I^2=99%, 95% CI:

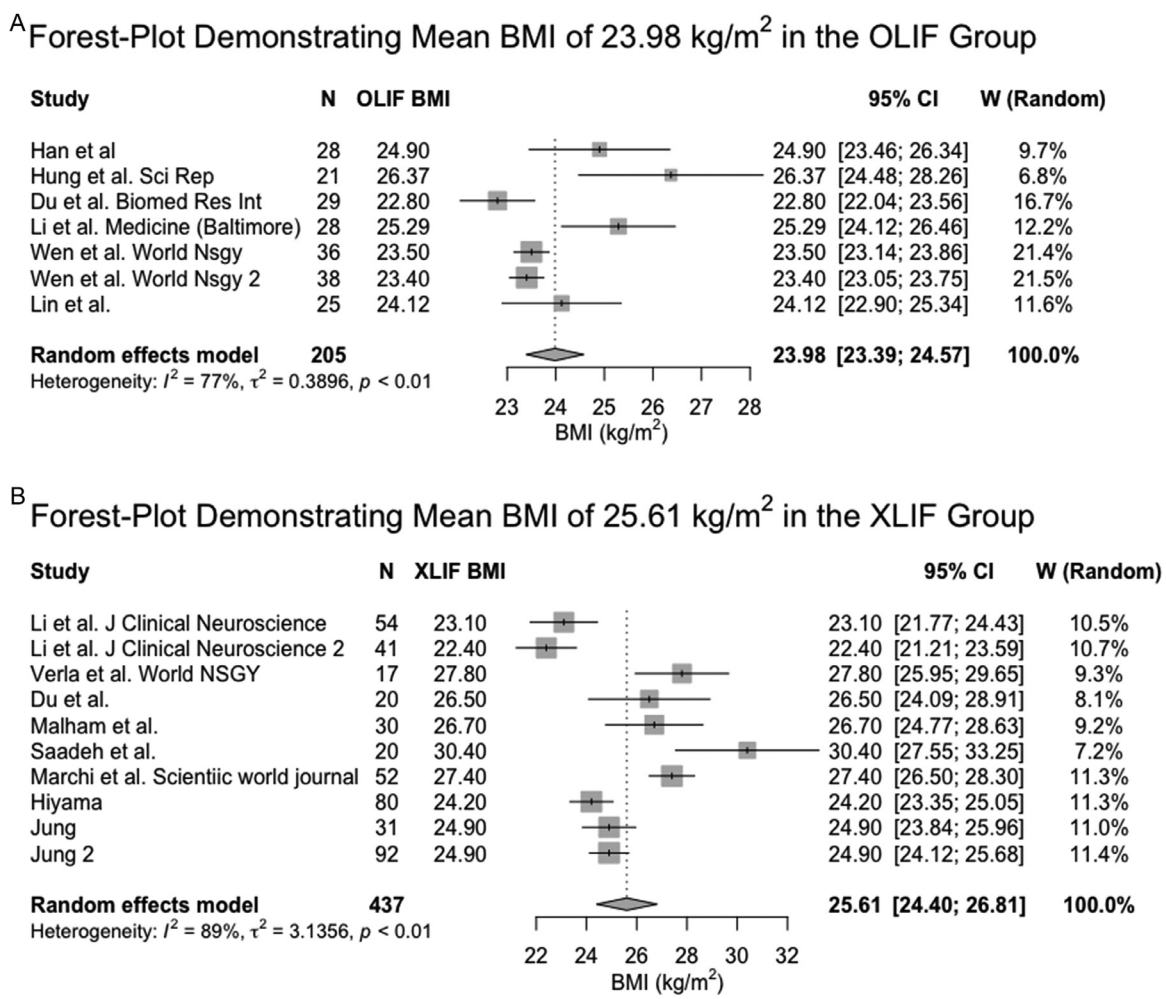

Fig. 3. A. Forest-plot demonstrating mean BMI, confidence intervals and heterogeneity present in the OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval. B. Forest-plot demonstrating mean BMI, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval.

3.6–7.5) and 4.5 (I^2=97%, 95% CI: 3.1–5.9) in the XLIF group (Figs 6A and 6B). No significant differences were observed between the 2 groups in regards to mean improvement in VAS-b scores.

Pooled analysis for ODI values was based on 6 OLIF studies and 4 XLIF. The mean preoperative ODI value for the OLIF group was 53.2 (I^2=96%, 95% CI: 46.7–59.6) and improved to 14.9 (I^2=0.0%, 95% CI: 6.4–23.3) at final follow-up. The mean ODI score for the XLIF group was 50.1 (I^2=100%, 95% CI: 48.9–51.2) preoperatively and 14.9 (I^2=98%, 95% CI: 6.4–23.3) at final follow-up. Both groups demonstrated a significant improvement in ODI scores at final follow-up compared to preoperative measurements. Pooled analysis determined that the mean improvement in ODI scores was 37.9 (95% CI: 31.5–44.4) and 25.6 (95% CI: 8.6–43.0) for the OLIF and XLIF groups, respectively (Figs. 7A and 7B). These differences were not found to be statistically significant.

Radiographic outcomes

Radiographic outcomes including postoperative disc height and lordosis correction were recorded in Table 6. Pooled-analysis of 6 OLIF studies and 4 XLIF studies were used to assess for meaningful differences in disc height restoration. Final ADH were 12.0 mm (I^2=98%, 95% CI: 10.4–13.6) and 12.4 mm (I^2=97%, 95% CI: 10.0–14.9) for the OLIF and XLIF groups respectively and demonstrated no significant differences. Similarly, changes in ADH were 4.2 mm (I^2=99%, 95% CI: 2.4–6.0) and 5.3 mm (I^2=96%, 95% CI: 3.5–7.1) for the OLIF and XLIF groups respectively and were not found to be significantly different (Figs. 8A and 8B). Lordosis correction was assess-based on improvements in LSA and LLA from 5 OLIF studies and 4 XLIF studies. Final LSA (OLIF: 12.3 degrees [I^2=89%, 95% CI: 9.3 – 15.2]; XLIF: 14.1 degrees [I^2=83%, 95% CI: 11.5 – 16.7]) and LLA (OLIF: 35.6 degrees [I^2=83%, 95% CI: 30.9 – 40.5]; XLIF: 43.5 degrees [I^2=97%, 95% CI: 31.3 – 55.7]) showed no significant differences between the 2 groups. LLA improved by a mean of 5.3 degrees (I^2=87%, 95% CI: 0.1–10.5) in the OLIF group and 3.3 degrees (I^2=64%, 95% CI: 0.5–6.1) in the XLIF group (Figs. 9A and 9B). LSA improved by a mean of 2.3 degrees (I^2=0%, 95% CI: 1.1 – 3.5) in the OLIF group and 3.1 degrees (I^2=89%, 95% CI: 0.6–5.6) in XLIF group (Figs. 10A and 10B). No significant differences were observed in terms of lordosis correction between the 2 groups.

Complication related outcomes

Rates of postoperative complications in both cohorts are recorded in Table 4. Analysis based on complication rates obtained from the studies demonstrated that the XLIF group has a significantly higher rate of neuropraxia at 21.2% (95% CI: 17.8–25.0) compared to the OLIF group at 10.9% (95% CI: 8.1–14.4). The rate of vascular injuries was significantly greater in the OLIF group as compared to the XLIF group at 3.2% (95% CI: 1.7–6.0) and 0.0% (95% CI: 0.0–1.4) respectively. The proportion of patients in the OLIF group who experienced pseudoarthrosis follow-

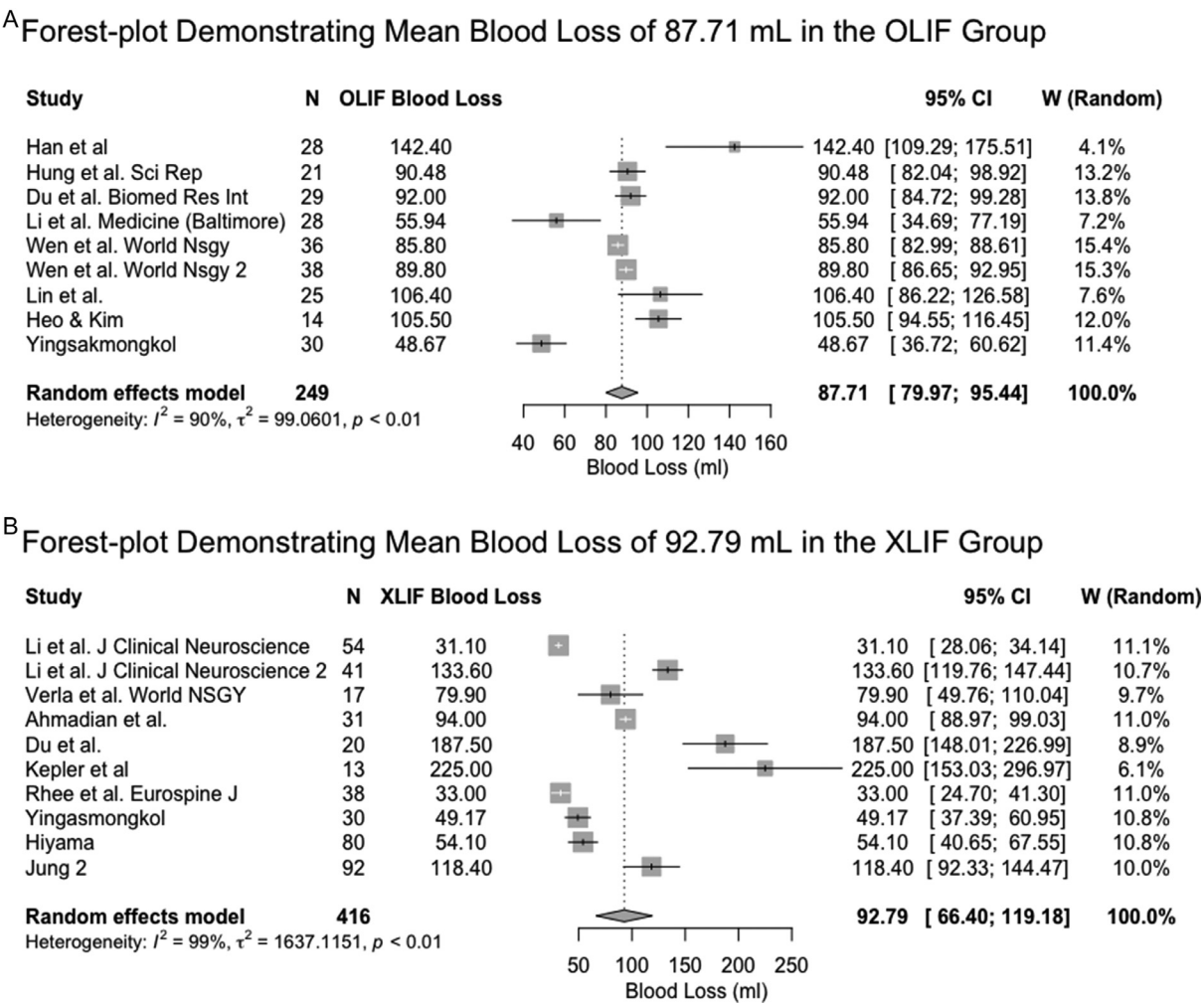

Fig. 4. A. Forest-plot demonstrating mean blood loss, confidence intervals and heterogeneity present in the OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval. B.Forest-plot demonstrating mean blood loss, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval.

Table 6
Changes in ADH, LSA, LLA in OLIF and XLIF groups

	OLIF Value	OLIF 95%CI	XLIF Value	XLIF 95%CI	Conclusion
ADH (mm)					
Preop	7.8	[6.5–9.1]	7.1	[5.0–9.2]	Overlap
Postop	12.0	[10.4–13.6]	12.4	[10.0–14.9]	Overlap
Change	4.2	[2.4–6.0]	5.3	[3.5–7.1]	Overlap
LSA (degrees)					
Preop	10.1	[6.9–13.4]	10.9	[8.2–13.6]	Overlap
Postop	12.3	[9.3–15.2]	14.1	[11.5–16.7]	Overlap
Change	2.3	[1.1 – 3.5]	3.1	[0.6–5.6]	Overlap
LLA (degrees)					
Preop	30.6	[24.2–37.0]	40.1	[30.5–49.6]	Overlap
Postop	35.7	[30.9–40.5]	43.5	[31.3–55.7]	Overlap
Change	5.3	[0.1–10.5]	3.3	[0.5–6.1]	Overlap

OLIF, oblique lumbar interbody fusion; XLIF, extreme lateral interbody fusion; ADH, anterior disc height; LSA, lumbar segmental angle; LLA, lumbar lordosis angle; CI, confidence interval.

ing the procedure was found to be 6.1% (95% CI: 3.8–9.6). This was comparable to the rate of pseudoarthrosis observed in the XLIF group found to be 6.0% (95% CI: 3.7–9.7). Similarly, the rates of subsidence were also comparable between the OLIF and XLIF groups at 18.9% (95% CI: 15.0–23.6) and 14.3% (11.1–18.3) respectively. The rate of reoperation the XLIF group was higher than that of the OLIF group, 7.2% (95% CI: 4.6–10.3) and 1.8% (95% CI: 0.5–5.0) respectively, however, these differences were not found to be significant.

Risk of bias

Publication bias was evaluated using funnel plots for primary and secondary outcomes. Funnel plots were generated for studies including data on specific radiographic outcomes, such as mean improvements in ADH (Fig. 11) and LLA (Fig. 12). Clinical outcome measures, such as mean improvements in ODI (Fig. 13) and VAS-b (Fig. 14) scores, were similarly assessed. Funnel plots for ADH and VAS ef-

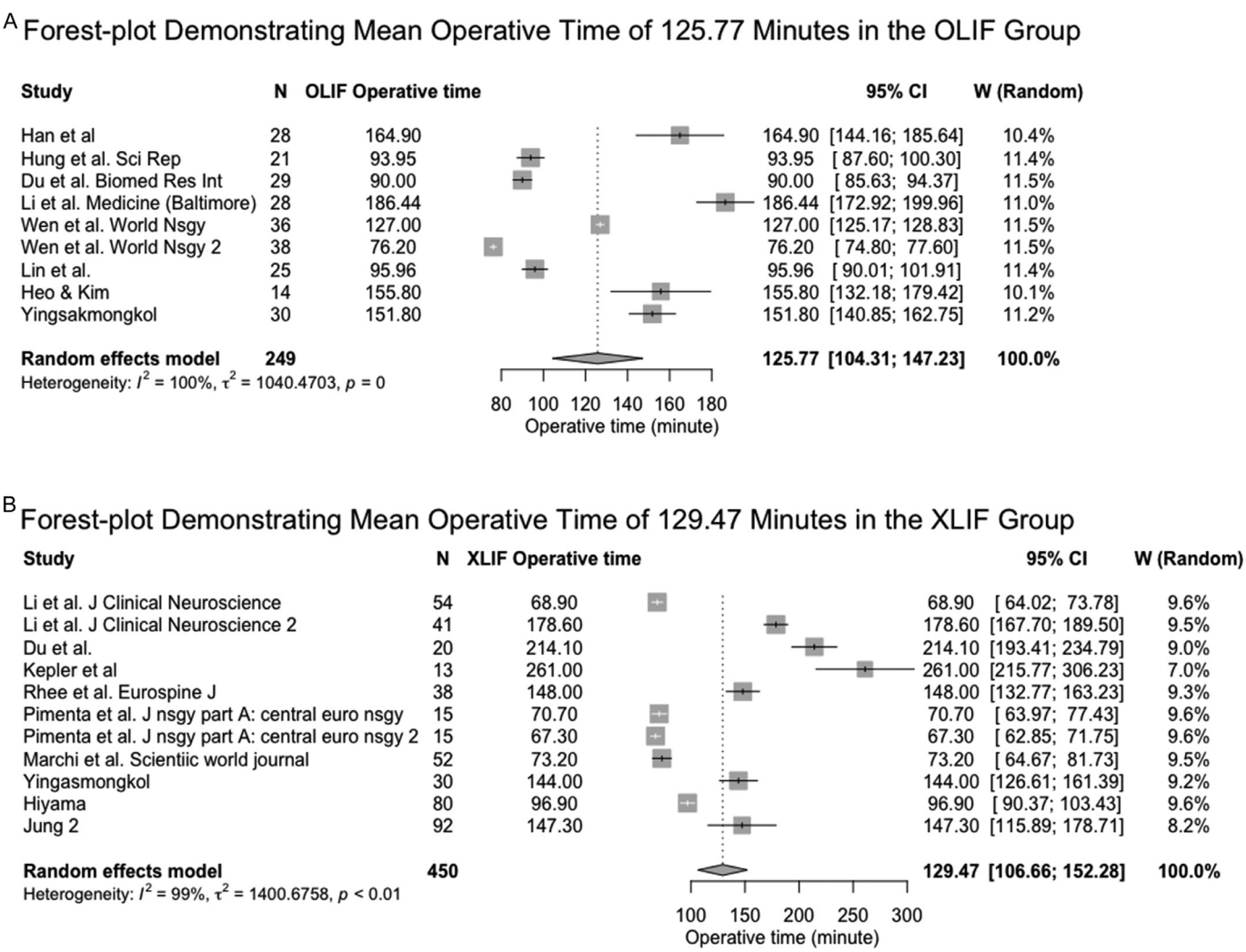

Fig. 5. A. Forest-plot demonstrating mean operative time, confidence intervals and heterogeneity present in the OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval. B. Forest-plot demonstrating mean operative time, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval.

fect size estimates demonstrate that a few studies fell outside of the funnel indicating larger studies did not provide more accurate estimates as expected. As a result, we should interpret the conclusion for ADH and VAS with caution with the limitation of publication bias. For LLA and ODI effect sizes, almost all studies followed the inverted funnel shape indicating minimal or no publication bias present for these measurements.

Discussion

The advent of OLIF and XLIF for lumbar interbody arthrodesis has offered surgeons minimally invasive methods of obtaining excellent clinical and radiographic outcomes. Studies have highlighted that their unique anatomic windows correlate with the variations in postoperative complications observed. Walker et al conducted a meta-analysis consisting of 20 studies assessing postoperative complications in 6,481 patients undergoing either single or multilevel OLIF or XLIF. Their results demonstrated that although both procedures had low rates of major complications, the “transpsoas” approach possessed a greater risk of permanent motor injury while the “anterior to psoas” approach led to increased rates of major vessel injury [11]. However, their study included both single and multi-level arthrodesis and did not account for the limitations encountered at the L5 – S1 disc level. The variability in OLIF techniques implemented by surgeons when accessing the L5–S1 level may influence postoperative findings. Additionally, there are significant differences in surgical outcomes when assessing single and multi-level procedures. Our meta-analysis is the first of its kind to account for these limitations and compare outcomes of single level OLIF and XLIF at the L1–L5 levels.

Our study found no significant differences between the 2 cohorts in terms of average blood loss and operative time. Our results are consistent with a majority of the studies comparing both single and multilevel fusions that demonstrated no significant differences in perioperative outcomes [8,9,14,37]. These findings may be attributable to the fact that OLIF and XLIF are similar anterolateral techniques that both involve dissection through the retroperitoneal space to gain access to the vertebral disc. The increased operative time observed in the XLIF cohort in the present study may be related to differences in patient positioning for both techniques. Additionally, all studies mentioned a subsequent repositioning of patients to perform percutaneous posterior instrumentation following the first part of the procedure which may influence the operative time. Walker et al found that XLIF had a significantly higher operative time (XLIF: 203.6 minutes, OLIF: 120.5 minutes, p<.001), but no differences in blood loss [11]. The authors suggested that this variation may be the result of a higher number of levels being treated in the XLIF group relative to the OLIF group (2.3 vs. 1.8), as well as the increased time necessary to set up intraoperative neuromonitoring or fluoroscopy for XLIF [11].

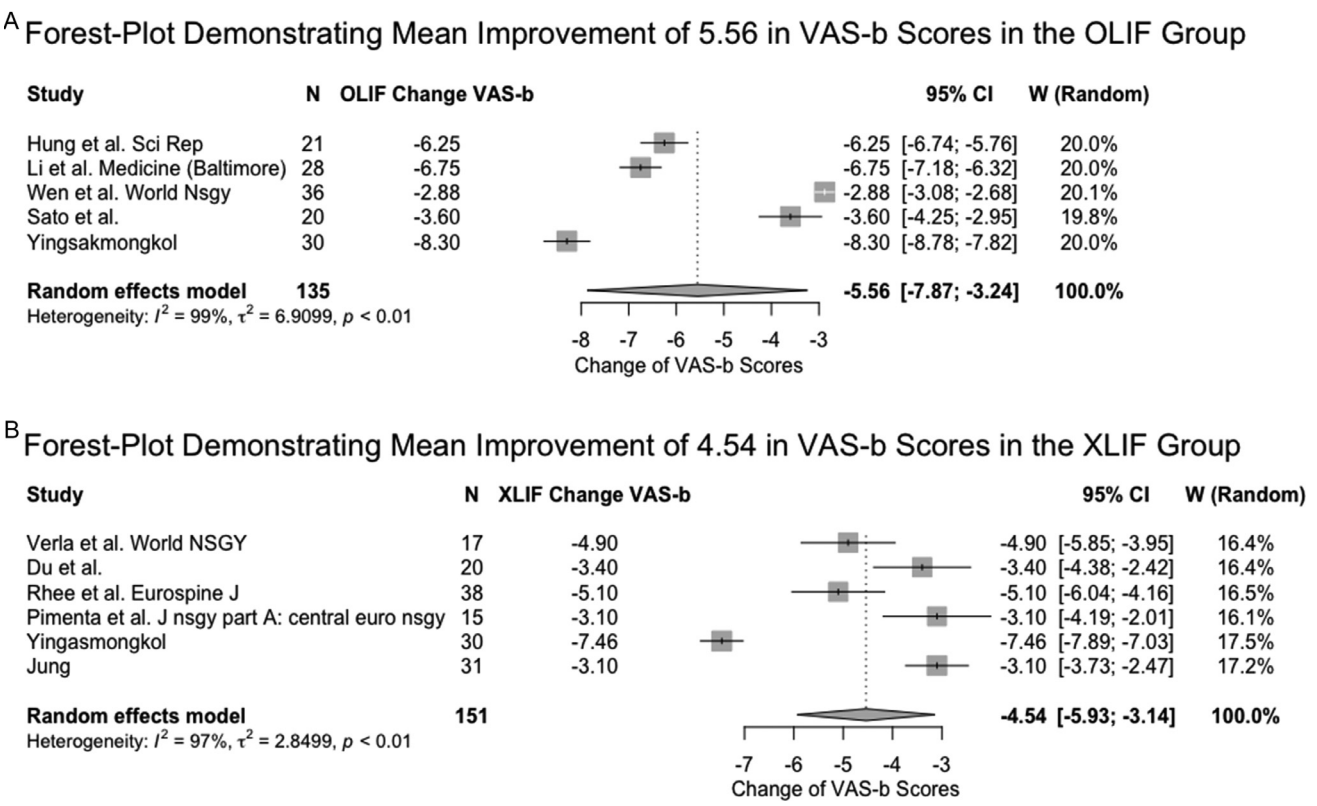

Fig. 6. A. Forest-plot demonstrating mean VAS-b score improvement, confidence intervals and heterogeneity present in the OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval; VAS-b= visual analogue scale for back pain scores. B. Forest-plot demonstrating mean VAS-b score improvement, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval; VAS-b= visual analogue scale for back pain scores.

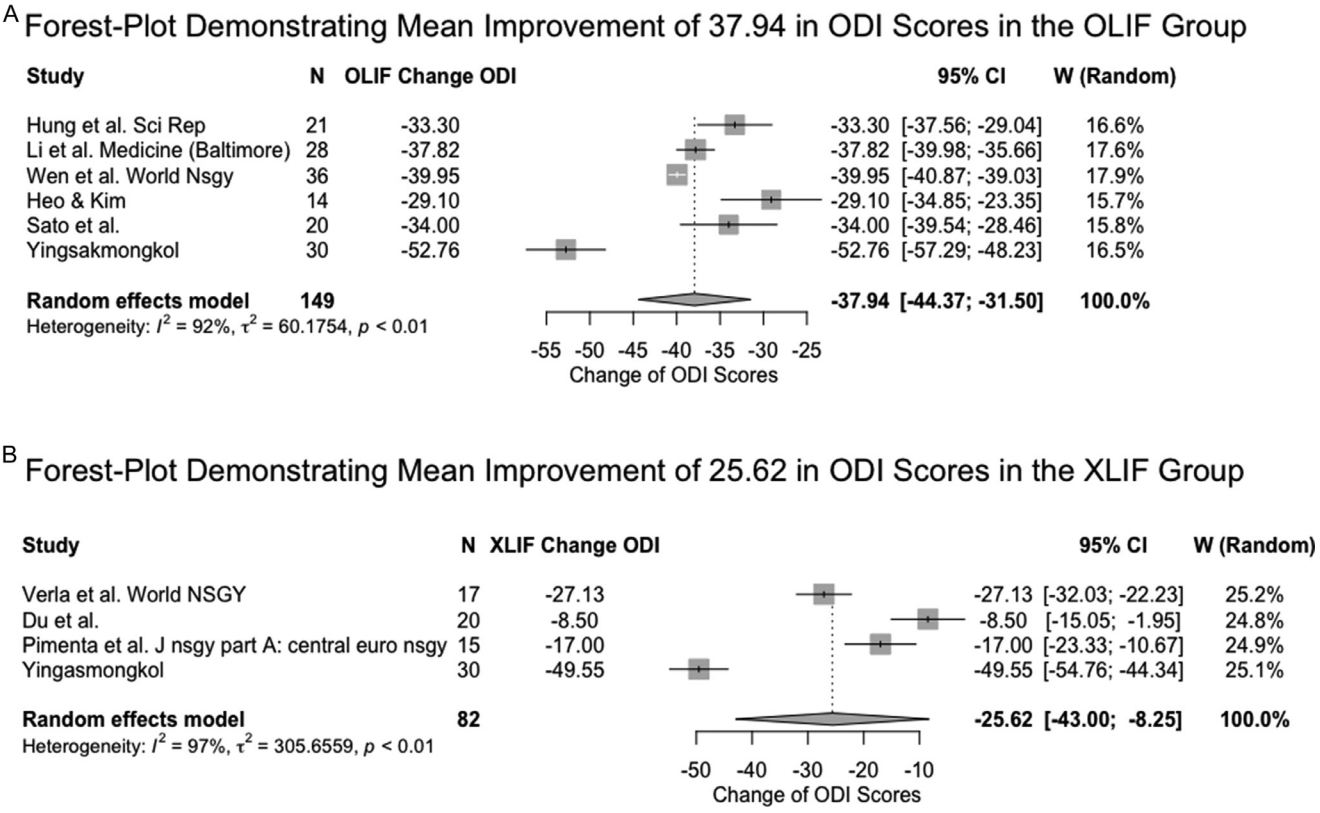

Fig. 7. A. Forest-plot demonstrating mean ODI score improvement, confidence intervals and heterogeneity present in the OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval; ODI= oswestry disability index. B. Forest-plot demonstrating mean ODI score improvement, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval; ODI= oswestry disability index. B.

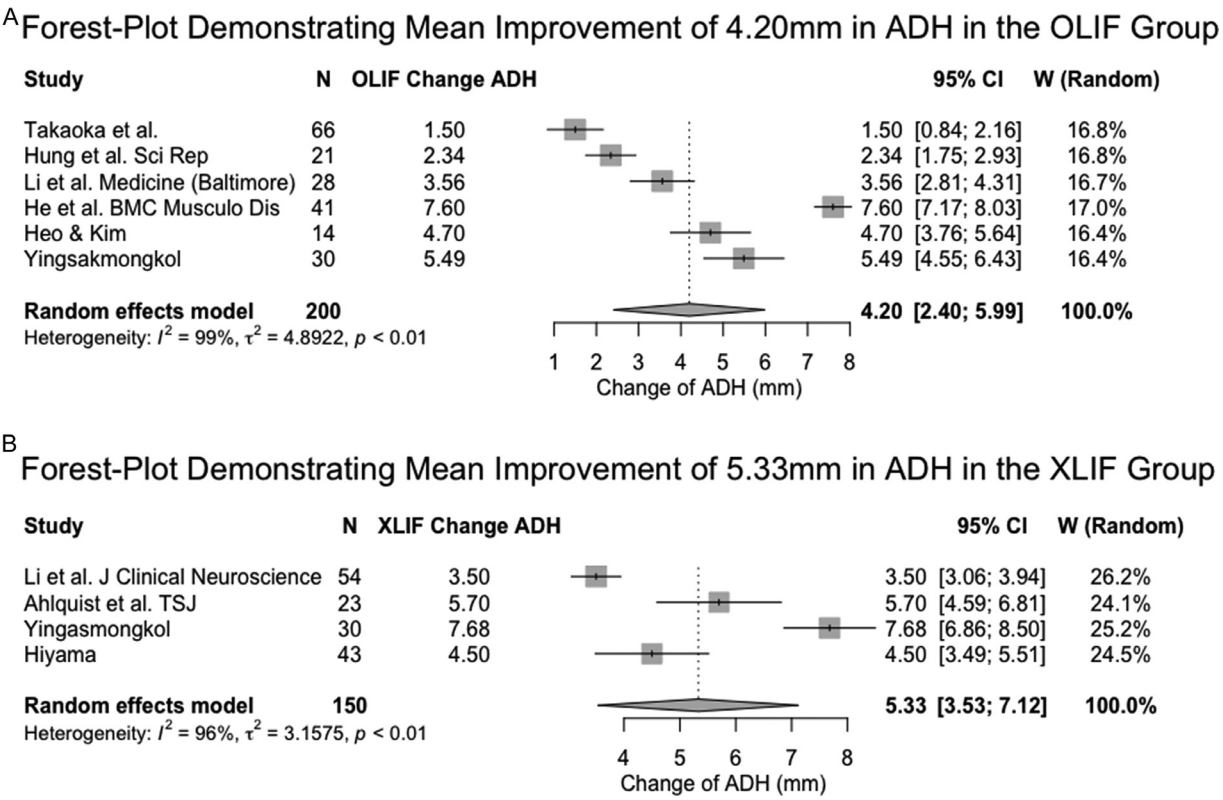

Fig. 8. A. Forest-plot demonstrating mean ADH improvement, confidence intervals and heterogeneity present in the OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval; ADH= anterior disc height. B. Forest-plot demonstrating mean ADH improvement, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval; ADH= anterior disc height.

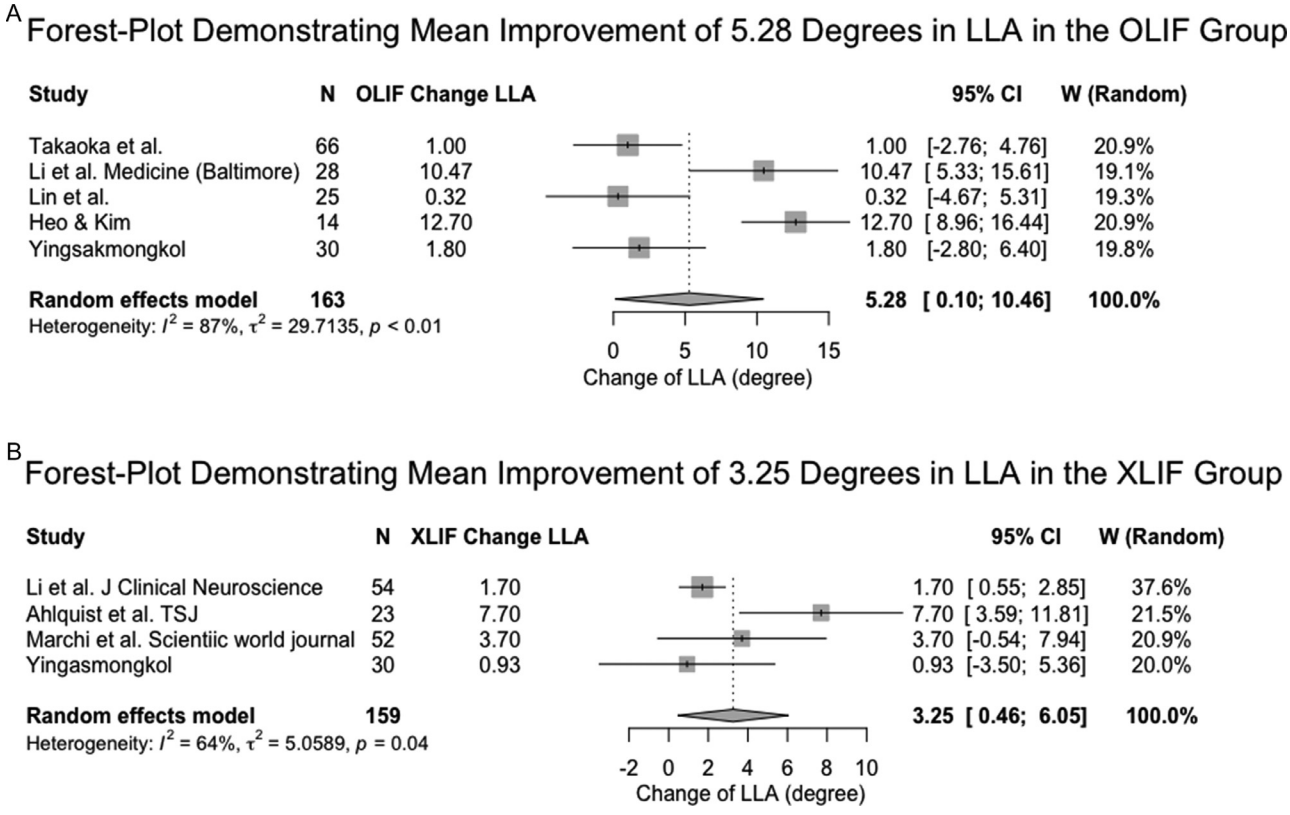

Fig. 9. A. Forest-plot demonstrating mean LLA improvement, confidence intervals and heterogeneity present OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval; LLA= lumbar lordosis angle. B. Forest-plot demonstrating mean LLA improvement, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval; LLA= lumbar lordosis angle.

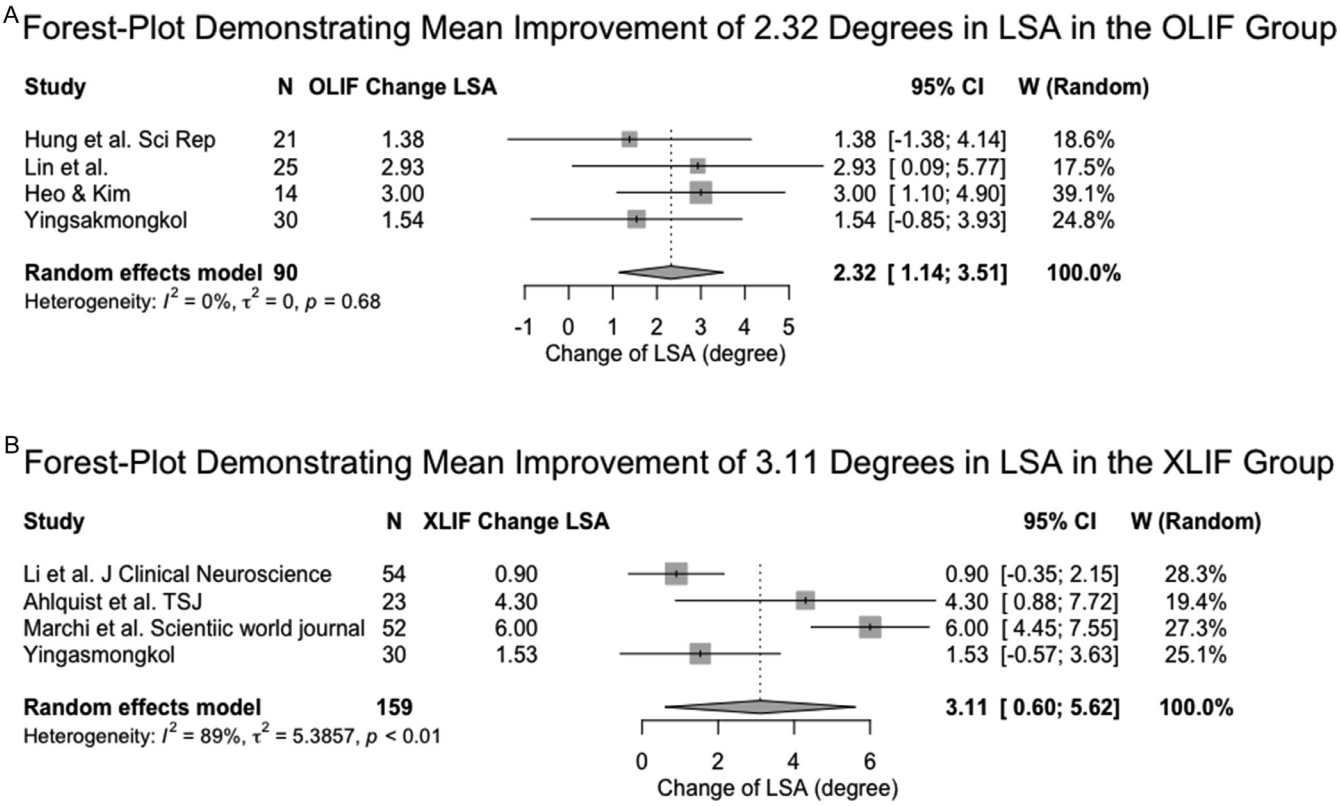

Fig. 10. A. Forest-plot demonstrating mean LSA improvement, confidence intervals and heterogeneity present in OLIF cohort. OLIF= oblique lumbar interbody fusion; CI= confidence interval; LSA= lumbar segmental angle. B. Forest-plot demonstrating mean LSA improvement, confidence intervals and heterogeneity present in the XLIF cohort. XLIF= extreme lateral interbody fusion; CI= confidence interval; LSA= lumbar segmental angle.

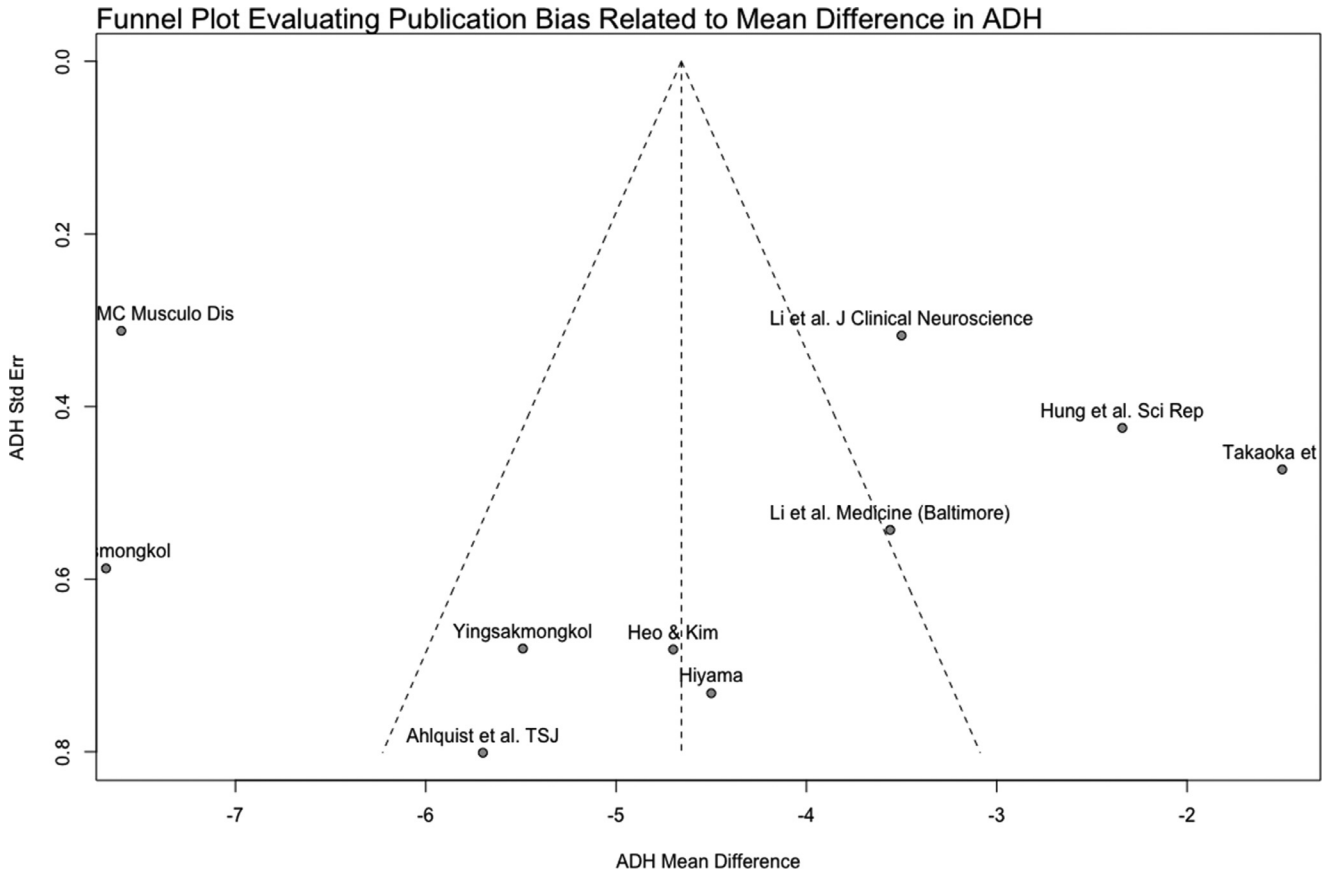

Fig. 11. Funnel plot evaluating publication bias related to mean difference in ADH. ADH, anterior disc height.

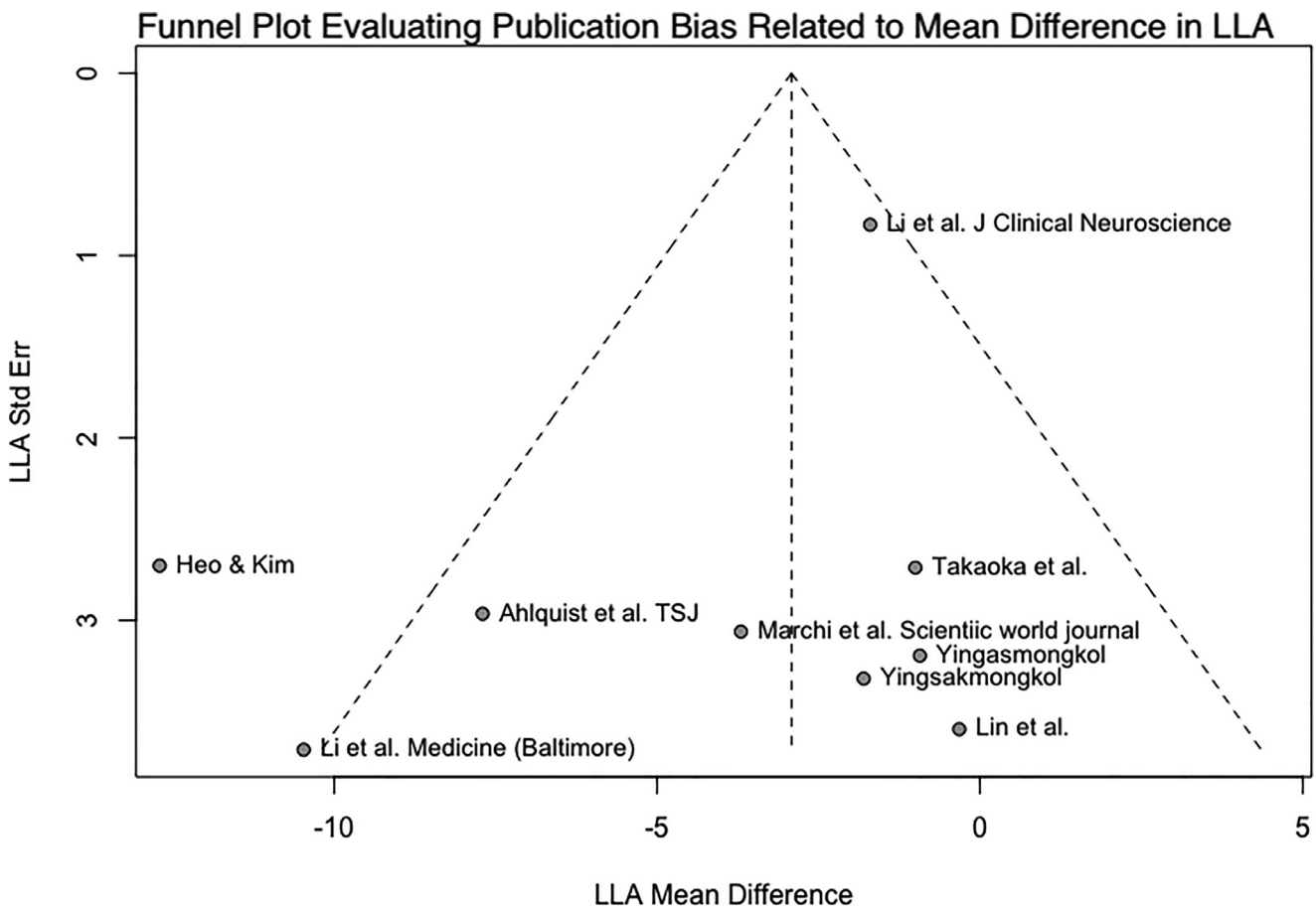

Fig. 12. Funnel plot evaluating publication bias related to mean difference in LLA. LLA, lumbar lordosis angle.

As expected, differences in complication rates were observed between the 2 groups. The "transpsoas" approach involves dissection through the psoas muscle which has been shown to increase the likelihood of lumbar plexus injury and psoas weakness with an incidence ranging from 0.7% to 30% [2,11,21,37]. OLIF utilizes a more anterior approach which correlates to relatively lower rates of reported neuropraxia but increased rates of vascular injury and sympathetic dysfunction [2,11,37,38]. Similarly, our results demonstrated a significantly higher rate in neuropraxia in the XLIF cohort (21.2% vs. 10.9%) and significantly higher rates of vascular injury in the OLIF cohort (3.2% vs. 0.0%).

Differences in rates of pseudoarthrosis, subsidence or reoperation between the 2 groups were not found to be significant. Riccardi et al conducted a meta-analysis of 3 randomized control trials comparing single and multilevel OLIF and XLIF and found no differences in rates of revision surgery or subsidence [37]. Walker et al. [11] also found rates of both subsidence and pseudoarthrosis to be comparable . Li et al. [39] conducted a meta-analysis pooling data from 56 studies involving 2,852 patients that underwent single or multilevel OLIF and XLIF and observed a higher rate of cage subsidence in the OLIF group. The authors attributed their findings to a more limited discectomy corridor in the OLIF approach, as compared to the XLIF approach, contributing to placement of smaller interbody grafts.

Regarding clinical outcomes, we found that both approaches showed significant improvement in postoperative VAS-b and ODI scores These findings were consistent with the literature demonstrating the efficacy of both procedures in the treatment of lumbar pathologies [8,37,39]. Additionally, our study found no significant differences in the mean change in score improvement between the 2 groups. These findings are consistent with several studies analyzing clinical outcomes of both single and multilevel OLIF and XLIF procedures restricted to the L1 – L5 region [9,14,37]. However, Li et al. [39] found that OLIF provided slightly better outcomes in terms of improvements in ODI and VAS scores at long-term follow-up. They attributed these differences to complications related to psoas muscle injury during the XLIF approach.

Our analysis found that both OLIF and XLIF were effective for improving disc height and restoring lordosis. Both approaches enable the surgeon to insert larger cages into the disc space and have demonstrated key advantages over more posterior approaches. Our findings are consistent with the existing studies analyzing changes in disc height [14,39]. Additionally, no significant differences were observed between the 2 groups in regards to lordosis correction as measured by the LSA and LLA. Although the current data is limited, 2 single-institution studies similarly found no differences in lordosis improvement between OLIF and XLIF as measured by changes in LLA [8,14]. Disc height is the most important factor influencing lordosis correction [40]. Therefore, the comparable improvements in lordosis between the 2 groups are consistent with the similarities observed with respect to disc height.

Given the similarities in radiographic and clinical outcomes observed between the OLIF and XLIF cohorts, the optimal anterolateral approach to the lumbar spine is dependent upon the risk of neurovascular injury which is heavily influenced by each patient's individualized anatomy. Studies have highlighted the importance of preoperative MRIs in examining psoas muscle morphology to assess the position of the lumbar plexus. A teardrop, or "mickey mouse," psoas morphology at L4–L5, is characterized by anterior migration of the lumbar plexus and posterolateral migration of the iliac vasculature. These findings may be associated with an increased risk of neurovascular injury when using an XLIF approach, thus favoring an OLIF in these patients. However, isolated posteriorly positioned iliac vessels may lead to an increased risk

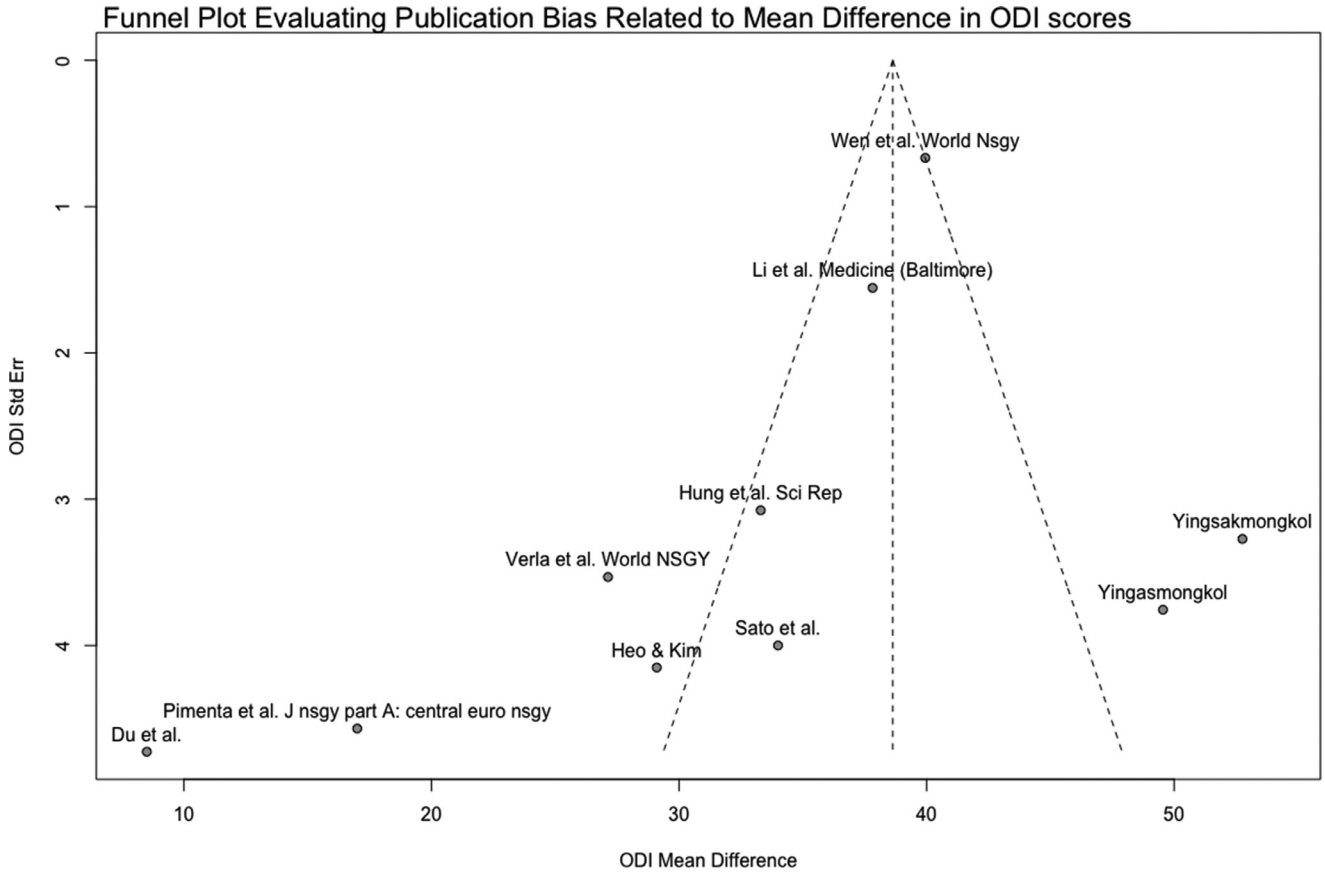

Fig. 13. Funnel plot evaluating publication bias related to mean difference in ODI scores. ODI, oswestry disability index.

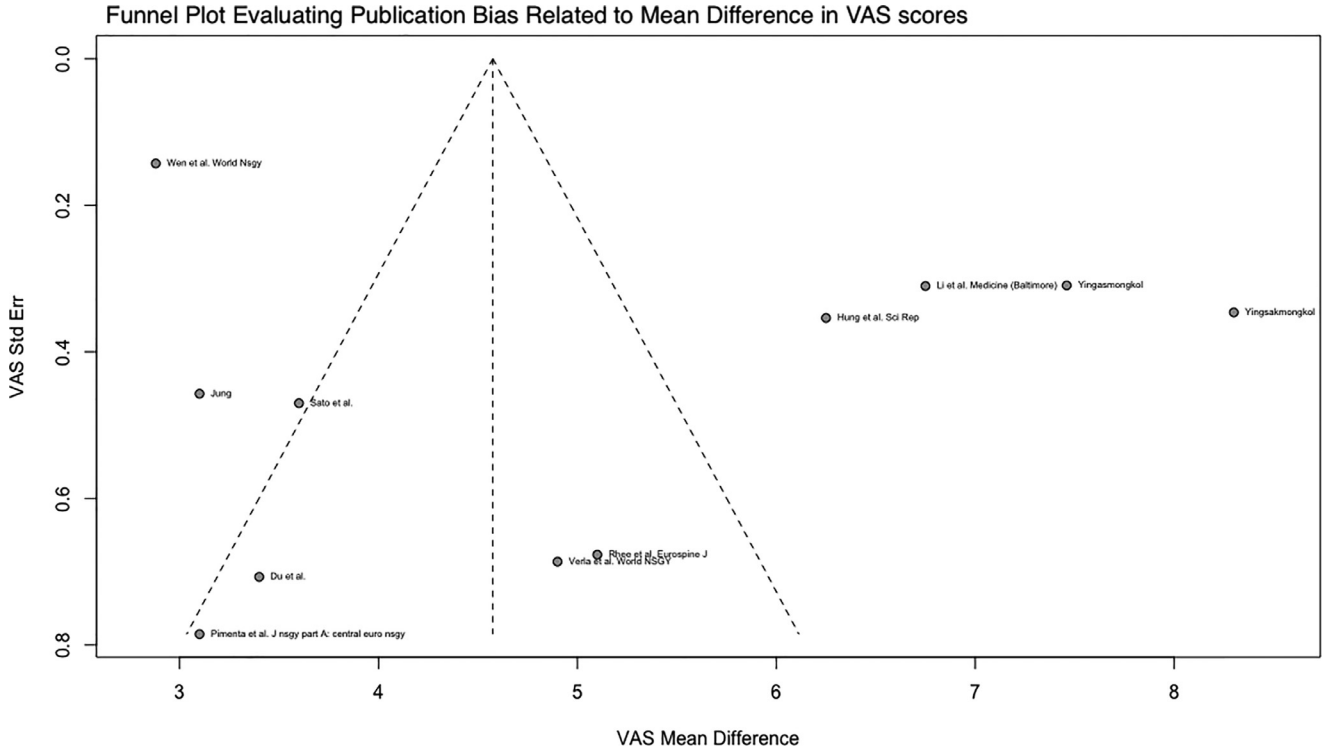

Fig. 14. Funnel plot evaluating publication bias related to mean difference in VAS scores. VAS, visual analog scale.

of vascular injury during an OLIF as the anatomic window between the psoas and the vasculature becomes narrower. Therefore, we recommend prioritizing preoperative imaging when selecting the anterolateral procedure that provides patients with the best outcomes and lowest risk of complications.

To the best of our knowledge, this meta-analysis comprises the largest current collective patient cohort in which perioperative, radiographic, and clinical outcomes of single-level OLIF and XLIF have been reported. This study has several key strengths including a greater statistical power by performing a meta-analysis, pooling, and comparing heterogenous data from a large sample of studies. Nonetheless, several limitations do exist in this study. First, because only studies published in English were used, there may be potential for language bias. Furthermore, most studies were retrospective studies with incomplete reporting. The exclusion of studies involving both single and multilevel fusion which failed to report data introduces an element of selection bias and limits the generalizability of this meta-analysis. Additionally, we should interpret the conclusions derived from data regarding certain variables (ADH and VAS) with caution given the presence of publication bias as indicated by the funnel plots.

Furthermore, the sample of patients in each group varied across studies, which introduces extraneous factors, such as graft material, indications for surgery, specific levels operated on, and surgical experience, into the final analysis. Additionally, we were unable to expand our analysis to other approach-related complications commonly encountered following these two approaches due to a limited number of the included studies reporting data on these findings. Lastly, it is well established that XLIF has the highest risk of neural injury at the L4/L5 level. Therefore, it was difficult to accurately compare the rates of neural injury without being able to discern the fraction of cases performed at the L4/L5 level in each cohort. However, the authors are currently working on a prospective study comparing these two fusion techniques specifically at the L4/L5 level to account for these limitations.

Conclusion

This meta-analysis demonstrates similar perioperative, clinical, and radiological outcomes between OLIF and XLIF for the treatment of single-level lumbar pathology between L1 and L5. XLIF had significantly higher rates of approach-related transient neuropraxia, whereas OLIF had significantly greater rates of vascular injury. However, overall complication and reoperation rates were similar between the 2 groups. Likewise, improvement in disc height and lordosis correction did not differ between the two groups suggesting equivocal potential to correct spinal deformity at these levels.

Declarations of competing interests

Dr. Emami receives grants/research support from NuVasive. Dr. Faloon receives grant and research support from Stryker Spine and Centinel Spine. Dr. Hwang is a consultant for Stryker Spine. None of these are applicable to the current study. For the remaining authors, none were declared.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2023.100216.

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