Luo *et al.*
Journal of Orthopaedic Surgery and Research (2025) 20:154
https://doi.org/10.1186/s13018-025-05523-7

Journal of Orthopaedic Surgery and Research

REVIEW

Open Access

Application of an enhanced recovery after surgery care protocol in patients undergoing lumbar interbody fusion surgery: a meta-analysis

Jianghong Luo[1†], Yixin Tang[2†], Jing Cao[3†], Wei Li[1], Liu Zheng[4*] and Haomin Lin[4*]

Abstract

Background Enhanced recovery after surgery (ERAS) has been widely used in several surgical fields. This meta-analysis compared the clinical outcomes of the ERAS protocol and standard care (SC) in patients who underwent lumbar interbody fusion surgery.

Materials and methods The PubMed, Web of Science, Cochrane Library, and Embase databases were systematically searched to identify studies reporting the effects of the ERAS protocol on clinical outcomes in patients who underwent lumbar interbody fusion surgery.

Results Overall, 15 studies involving 17 865 patients were included in the final analysis. With the ERAS protocol, the length of hospitalization (SMD: −0.47, 95% CI −0.56 to −0.38), postoperative complications (OR = 0.62; 95% CI 0.50 to 0.77), operation time (SMD = −0.26; 95% CI −0.44 to −0.09), postoperative pain (SMD = −0.35; 95% CI −0.64 to −0.07) and duration of ambulation (SMD = −0.80; 95% CI −1.02 to −0.58) were significantly reduced. The rates of readmission (OR = 0.63; 95% CI 0.38 to 1.04), estimated blood loss (SMD = −0.31; 95% CI −0.69 to 0.06) and hospitalization costs (SMD: −0.56, 95% CI −1.27 to 0.14) did not significantly differ between the ERAS and SC groups.

Conclusions The present meta-analysis indicated that the ERAS protocol could be safely and feasibly implemented in the perioperative management of patients receiving lumbar interbody fusion surgery. The protocol significantly reduced the length of hospitalization, incidence of postoperative complications, operation time, duration of 1st ambulation and duration of postoperative pain. However, no differences were observed in estimated blood loss, readmission rates or hospitalization costs.

Keywords Lumbar interbody fusion surgery, Enhanced recovery after surgery, Meta-analysis, Standard care, Outcomes

†Contributed equally: Jianghong Luo, Yixin Tang, and Jing Cao.

*Correspondence:
Liu Zheng
22897021@qq.com
Haomin Lin
3273282438@qq.com
Full list of author information is available at the end of the article

Introduction

Lumbar degenerative diseases (LDDs) are the most common diseases encountered in spinal surgery; these conditions affect the quality of life of patients and cause a very serious economic burden on society [1]. Surgery is the main clinical treatment for patients with severe LDDs, among which spinal fusion is one of the most important methods [2, 3]. However, due to the long operation time of lumbar fusion, the high degree of trauma to patients and the long duration of postoperative bed rest, the postoperative recovery of patients is largely delayed; moreover, the physical and psychological burdens of patients are increased [4]. Due to the decline in physical reserve capacity and increased comorbidities in patients, the risks of perioperative complications and prolonged hospitalization need to be actively managed in clinical practice [5]. Therefore, it is urgent to explore a more optimized perioperative plan to promote postoperative rehabilitation.

Enhanced recovery after surgery (ERAS) is an evidence-based, multidisciplinary perioperative approach adopted to decrease postoperative adverse events by mitigating the stress response in patients following surgical intervention [6–9]. The proposition of ERAS has opened up a new way of thinking to solve the problem of rapid recovery of patients after various operations and to reduce the cost of treatment [10]. In fact, early clinical studies of ERAS have been carried out in European and American countries. Briefly, ERAS was first used in colorectal surgery and later in other surgical fields, such as urology, breast surgery and gynecology [10]. More importantly, the efficacy of ERAS in patients undergoing spinal surgery has also been demonstrated during the past decade. Several studies have shown that patients who undergo lumbar fusion surgery (short-segment or multilevel) can benefit from the implementation of the ERAS protocol [11–16]. Several studies have yielded inconsistent outcomes after assessing the effectiveness of this multimodal care protocol for lumbar fusion surgery for different reasons (such as hospitalization costs, postoperative pain and complications, and readmission rates) [16, 17]. Therefore, the safety and usefulness of the ERAS protocol for lumbar interbody fusion surgery are unclear.

Thus, this meta-analysis was conducted to evaluate the differences in length of stay, hospitalization costs, postoperative complications and pain, self-care ability and degree of recovery between patients treated with the ERAS protocol and those treated with the standard care (SC) plan among patients who underwent lumbar interbody fusion surgery and to provide a foundation for evidence-based clinical decision-making.

Materials and methods

We conducted and reported this study following the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines [18] and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Guidelines with the registration number [19].

Search strategy

The Pubmed, Web of Science, Cochrane Library, and Embase databases were systematically searched from inception to 01 October 2023 to identify all studies reporting the effects of the ERAS protocol on the overall clinical outcomes of lumbar interbody fusion surgery. The following search keywords or medical subject heading terms were used for all possible combinations: 'ERAS', 'ERABS', 'enhanced recovery after surgery', 'enhanced recovery after lumbar interbody fusion surgery', 'fast track', 'fusion, spinal', 'fusions, spinal', 'spinal fusions', 'spondylodesis', 'spondylosyndeses', 'spondylosyndesis' and 'spondylosyndesis'. Furthermore, the reference lists of the selected articles were manually examined to identify other relevant articles. Only studies presented in the English language were included in the study.

Inclusion and exclusion criteria

Two authors independently determined the eligibility of the articles, and any disagreements were resolved through group discussion. The inclusion criteria were as follows: published randomized controlled trials (RCTs) and retrospective cohort studies; ERAS protocols, including at least eight items from the recommended guidelines; studies comparing the influence of the ERAS protocol with that of SC on surgical outcomes in patients after lumbar interbody fusion surgery; and studies whose full texts were available. The latest and most comprehensive data were included if the same institution replicated the studies. The exclusion criteria were abstracts, reviews, case reports, and conference reports; studies without a control group; and studies without a clear description of ERAS protocol elements.

Data extraction and quality assessment

The full-text screening of the eligible studies was independently conducted by two authors, followed by data extraction based on the predefined criteria. Disagreements were resolved through a plenum consensus. The extracted data included detailed information on the study characteristics (region, study design, sample size in each arm, and follow-up time), patient baseline features (age, sex, BMI, comorbidity and type of surgery), ERAS protocol elements, and clinical outcome indictors (such as hospital length of stay, overall complications, major complications, 30-day readmission, hospitalization costs, postoperative pain, perioperative bleeding and duration of operation). The Clavien–Dindo classification was used to assess the severity of complications, with major complications being grade ≥ 3 [20].

The risk of bias of the included case–control and cohort studies was assessed independently by two authors using the Newcastle–Ottawa scale [21]. The scale awards 4 points for participant selection, 3 points for exposure or outcome, and 2 points for comparability, for a maximum total of 9 points. The quality of the studies was classified as high (7–9 points), medium (4–6 points), or low (0–3 points). The Newcastle–Ottawa Scale evaluates the risk of bias by examining the quality of a cohort study across three dimensions: selection, comparability, and outcome. Selection: This criterion evaluates the representativeness of the study subjects, the methods used for selecting these subjects, and the accuracy of the measurement techniques employed to assess exposure factors. Comparability: This aspect examines whether there are similarities between the study group and the control group, as well as whether potential confounding factors have been appropriately accounted for. Outcome: the adequacy of participant assessments, the accuracy of assessment methods, and the follow-up on outcomes. When heterogeneity is occurred, low-scoring studies will be excluded initially.

Statistical analysis

Pooled estimates for continuous and categorical variables are presented as the mean difference (MD) and odds ratio (OR), respectively, with 95% confidence intervals (CIs). We extracted the effect size reflecting the greatest degree of adjustment for potentially confounding factors when multiple effect sizes with different degrees of covariate adjustment were reported in a study. Moreover, heterogeneity between trials was assessed by the X^2 test and was expressed using the I^2 index. Significant heterogeneity was indicated when *P was* less than 0.1 or I^2 was greater than 50%. In the case of significant heterogeneity, pooled data were analyzed with a random effects model. Otherwise, the fixed-effects model was adopted. The horizontal line represents the confidence interval of the study results. The position of the square indicates the effect size, while its size reflects the weight, representing each study's contribution to the meta-analysis. The diamond shapes symbolize the overall result from merging individual studies. Solid vertical lines are employed to assess whether there is a statistically significant difference in outcomes; when horizontal lines and pooled diamond shapes from individual studies intersect with these vertical lines, it signifies no statistically significant difference between interventions. Sensitivity analyses were conducted to evaluate the stability of the results by removing each study in a single turn and determining the pooled effect size. Further subgroup analyses were performed to determine potential sources of significant heterogeneity, if necessary. Stata version 16.0 was used to conduct the meta-analysis. The asymmetry was visualized using funnel plots, and Egger's test was performed to assess publication bias.

Results

Literature search and characteristics of the studies

In total, 223 relevant citations were identified using the initial search strategy. Of those, 65 articles were excluded for duplication, and 128 were removed after screening the titles and abstracts. After a detailed full-text review and assessment, 15 articles were discarded because they did not meet the inclusion criteria. Of the 15 articles removed, 4 were reviews, 5 had no control group, and 6 lacked related data. Finally, 15 full-text articles involving 3,312 patients were included, of whom 1,543 (46.5%) were in the ERAS group and 1,769 (53.5%) were in the SC group. The results of the literature review and study selection are detailed in Fig. 1.

Table 1 lists the characteristics of the included studies. Fifteen studies involving 3,312 patients were included in the final analysis [5, 17, 22–34]. All the trials comparing the efficacy of the ERAS protocol with that of SC in patients who underwent lumbar interbody fusion surgery were well designed. Of the 15 studies, 5 studies involved elderly patients (aged greater than 50 years) [5, 24, 25, 28, 30], 6 studies involved minimally invasive surgery [22, 26–28, 32, 34], and 5 studies involved open surgery [5, 23–25, 30]. Ten studies examined transforaminal lumber interbody fusion [22–24, 26–29, 32–34], and the remaining studies involved other surgical procedures (such as posterior lumbar fusion) [5, 17, 25, 30, 31]. All the studies were retrospective cohort studies. The sample size ranged from 48 to 1060, with the study period ranging between 2017 and 2023. The ERAS and SC groups exhibited no significant differences in sex, age or BMI.

Meta-analysis results

Length of hospitalization

Ten studies [5, 17, 22–26, 29, 30, 33] involving 2010 patients reported the length of hospitalization. According to the fixed-effects model, the length of hospitalization was significantly shorter in the ERAS group (standardized mean difference (SMD): −0.47, 95% CI −0.56 to −0.38; Fig. 2). It can be concluded that the length of hospitalization was significantly reduced in the ERAS group compared to the SC group, which is clinically meaningful.

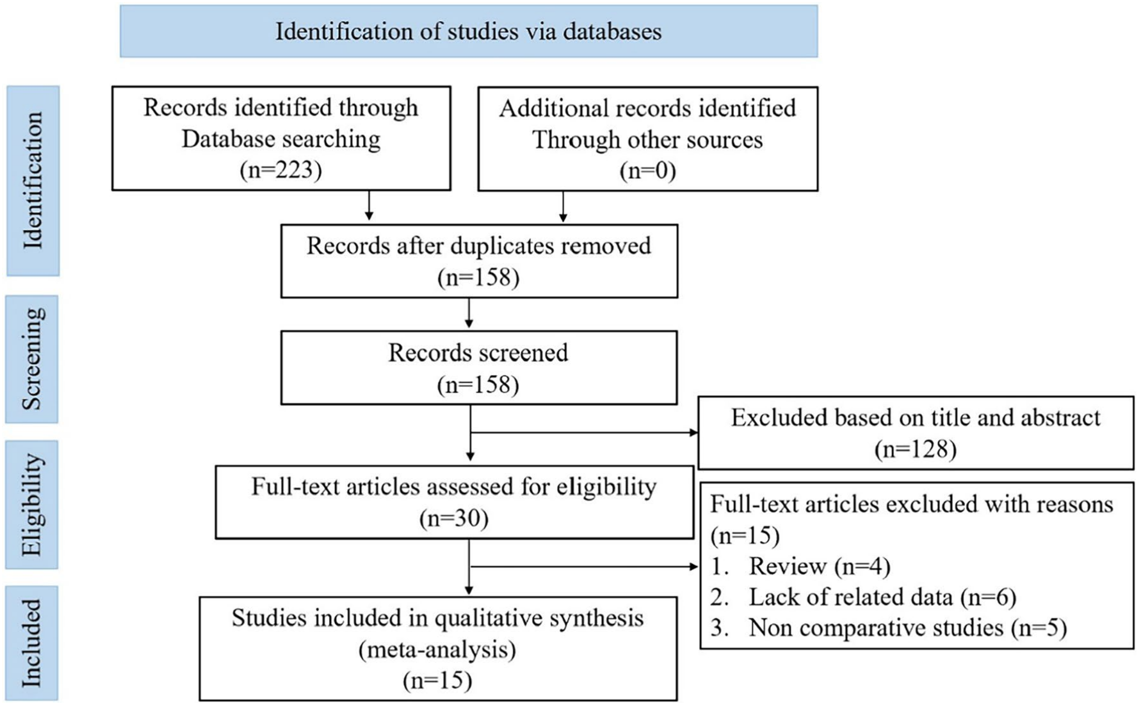

Fig. 1 Selection of studies for inclusion

The sensitivity analysis showed that the removal of any individual study had little effect on the pooled SMD, suggesting that the result was stable (Fig. 3). The sensitivity analysis figures (Fig. 3) demonstrate that the exclusion of any specific studies did not result in a statistically significant change in the overall outcome, which indicates the robustness of the results.

Postoperative complications

Eleven studies [5, 17, 22, 24, 25, 27, 29–31, 33, 34] involving 2,784 patients reported the incidence of postoperative complications. A pooled analysis with a fixed-effects model indicated that postoperative complications were significantly different between the ERAS and SC groups (OR 0.62; 95% CI 0.50 to 0.77; Fig. 4). The sensitivity analysis showed that the removal of any individual study had little effect on the pooled OR, suggesting that the results were stable (Fig. 5). The sensitivity analysis figures (Fig. 5) demonstrate that the exclusion of any specific studies did not result in a statistically significant change in the overall outcome, which indicates the robustness of the results.

Readmission

Nine studies[22–27, 30, 31, 33] involving 2,798 patients reported the rate of readmission. This rate in the ERAS group was significantly lower than that in the SC group (OR 0.47; 95% CI 0.32–0.71; Fig. 6.) According to sensitivity analyses, the removal of the trail by Wang et al. [31] had an effect on the pooled OR (Fig. 7). For readmission, the recalculated results revealed no significant change in outcome between the ERAS group and the SC group (OR 0.63; 95% CI 0.38 to 1.04; Fig. 8). Thus, this indicated that heterogeneity might have mainly come from this study [31].

Operation time

Thirteen studies [5, 17, 22–27, 30–34] with 3192 patients reported the incidence of operation time. The operation time did significantly differ between the ERAS and SC groups (SMD = −0.26; 95% CI −0.44 to −0.09; Fig. 9.) The sensitivity analysis showed that the removal of any individual study had little effect on the pooled SMD, suggesting that the result was stable (Fig. 10). The sensitivity analysis figures (Fig. 10) demonstrate that the exclusion of any specific studies did not result in a statistically significant change in the overall outcome, which indicates the robustness of the results.

Estimated blood loss

Ten studies [5, 17, 22–25, 30–33] with 2766 patients reported the incidence of estimated blood loss. According to the random effects model, the estimated blood loss volume did not significantly differ between the ERAS and SC groups (standardized mean difference (SMD) = 0.31; 95% CI − 0.69 to 0.06; Fig. 11). The sensitivity analysis showed that the removal of any individual study had little

Table 1 Characteristics of the included studies

References	Year	Region	Type of surgery	Intervention	Sample size	Age (Years)	Sex (M/F)	ERAS elements	NOS score
Sun [17]	2022	China	Lumbar fusion and internal fixation	ERAS SC	86 80	56.91 ± 11.69 58.86 ± 10.88	27/59 35/45	11	8
Li [5]	2021	China	Lumbar fusion and internal fixation	ERAS SC	60 67	73.6 ± 3.2 74.3 ± 4.2	22/38 27/40	15	7
Lu [22]	2023	China	Oblique lumbar interbody fusion	ERAS SC	62 41	57.27 ± 7.95 60.29 ± 7.58	28/34 14/27	17	8
Porche [23]	2022	America	Transforaminal	ERAS SC	57 57	66.1 ± 11.7 63.4 ± 13.3	27/30 29/28	10	7
Cui [24]	2022	China	Transforaminal	ERAS SC	64 64	79.94 ± 3.23 79.32 ± 3.21	17/47 16/48	14	8
Yuan [25]	2023	China	Posterior lumbar fusion	ERAS SC	54 54	70.1 ± 7.7 69.6 ± 8.5	12/42 12/42	12	8
Kerolus [26]	2021	America	Transforaminal	ERAS SC	87 212	62.44 ± 11.66 60.17 ± 13.21	36/51 96/116	15	8
Feng [27]	2019	China	Transforaminal	ERAS SC	44 30	61 ± 10 59 ± 9	16/28 9/21	11	8
Yang [28]	2020	China	Transforaminal	ERAS SC	51 21	70.1 ± 3.9 72.4 ± 5.4	23/28 8/13	16	8
Kalinin [29]	2021	Russia	Transforaminal	ERAS SC	24 24	58(44–69) 55(41–68)	14/10 18/11	18	6
Lu [30]	2022	China	Polysegemental lumbar Fusion	ERAS SC	46 54	79.06 ± 3.31 79.18 ± 2.67	16/30 15/39	14	7
Wang [31]	2022	China	Posterior lumbar fusion	ERAS SC	530 530	65 ± 1 64.2 ± 0.9	227/303 207/323	16	6
Chang [32]	2020	Taiwan	Transforaminal	ERAS SC	24 24	64.3 ± 11.59 60.1 ± 12.23	14/10 11/13	NA	6
Garg [33]	2021	India	Transforaminal	ERAS SC	316 496	26.4 ± 3.5 25.6 ± 3.1	174/142 264/232	20	8
Wang [34]	2017	America	Transforaminal	ERAS SC	38 15	65 ± 11 59 ± 12	21/17 5/10	NA	7

ERAS, enhanced recovery after surgery; SC, standard care; M, male; F, female; NA, not available; NOS, Newcastle–Ottawa Scale

effect on the pooled SMD, suggesting that the result was stable (Fig. 12).

Postoperative pain

Six studies [5, 22–24, 30, 33] involving 1,384 patients reported postoperative pain. According to the random effects model, postoperative pain was significantly relieved in the ERAS group (standardized mean difference (SMD) = 0.35; 95% CI 0.64 to −0.07; Fig. 13). Significant heterogeneity was observed in postoperative pain (Fig. 13, $I^2 = 85.7\%$). The sources of this heterogeneity may be attributed to variations in various surgical modalities, pain locations, and the ERAS protocol adherence.

Hospitalization costs

Only three studies [17, 27, 34] involving 293 patients reported hospitalization costs. According to the random effects model, the hospitalization costs were not significantly lower in the ERAS group (SMD: −0.56, 95% CI −1.27 to 0.14; Fig. 14). Significant heterogeneity was observed in hospitalization costs (Fig. 14, $I^2 = 79.8\%$). Disparities in health insurance coverage and costs across different regions were significant contributors to the heterogeneity observed in hospitalization costs, as we included studies from various locations (e.g., the United States, China, Europe, etc.).

1st ambulation

Three studies [23–25] with 350 patients reported the incidence of 1st ambulation. The 1st ambulation differed significantly between the ERAS and SC groups (SMD = −0.80; 95% CI −1.02 to −0.58; Fig. 15).

Subgroup analyses

To enhance the reliability of the results and further address the occurrence of heterogeneity, this study performed subgroup analyses focusing on elderly patients, open surgery, minimally invasive surgery, and various surgical types (such as posterior thoracolumbar interbody fusion and transforaminal lumbar interbody fusion).

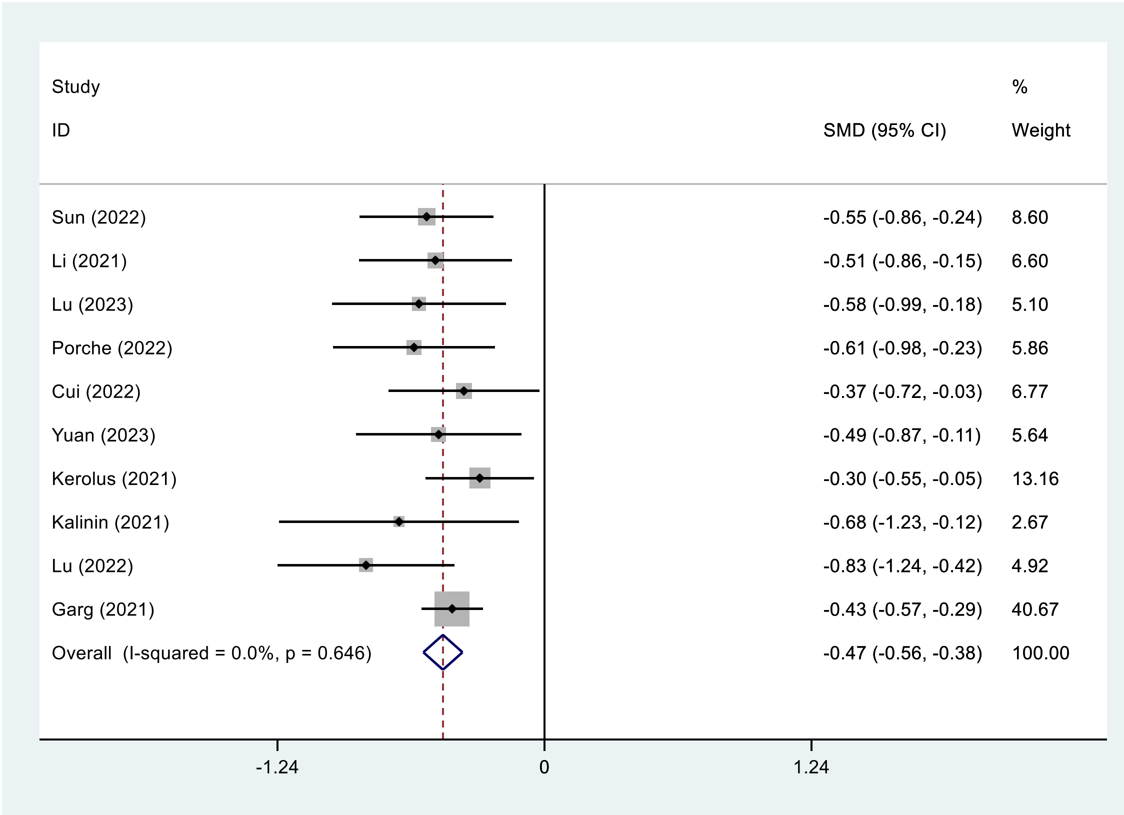

Fig. 2 Forest plot of length of hospitalization

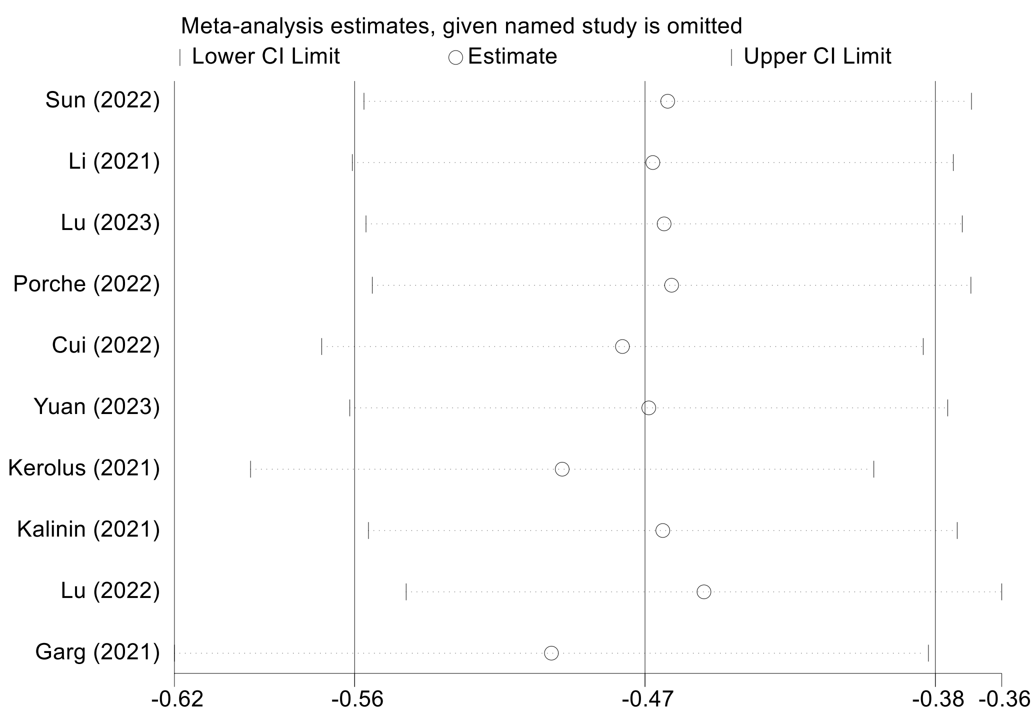

Fig. 3 Sensitivity analysis of the length of hospitalization

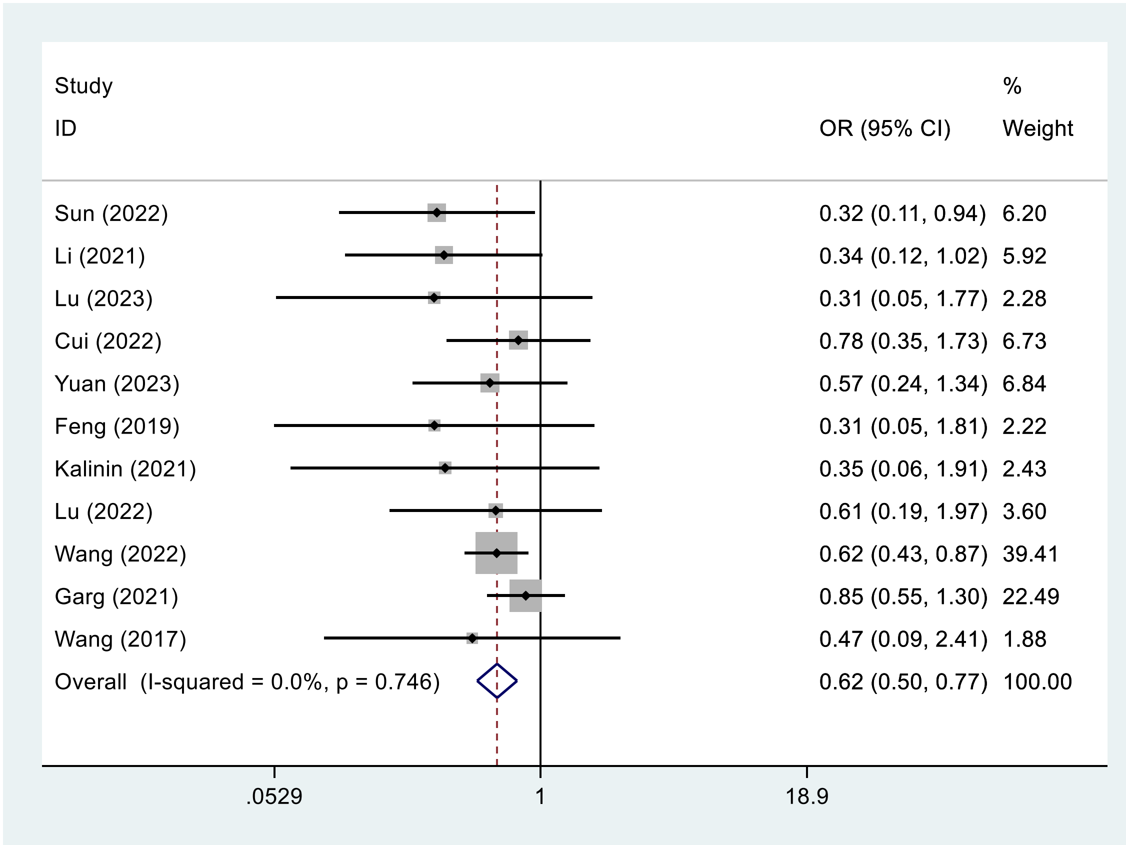

Fig. 4 Forest plot of postoperative complications

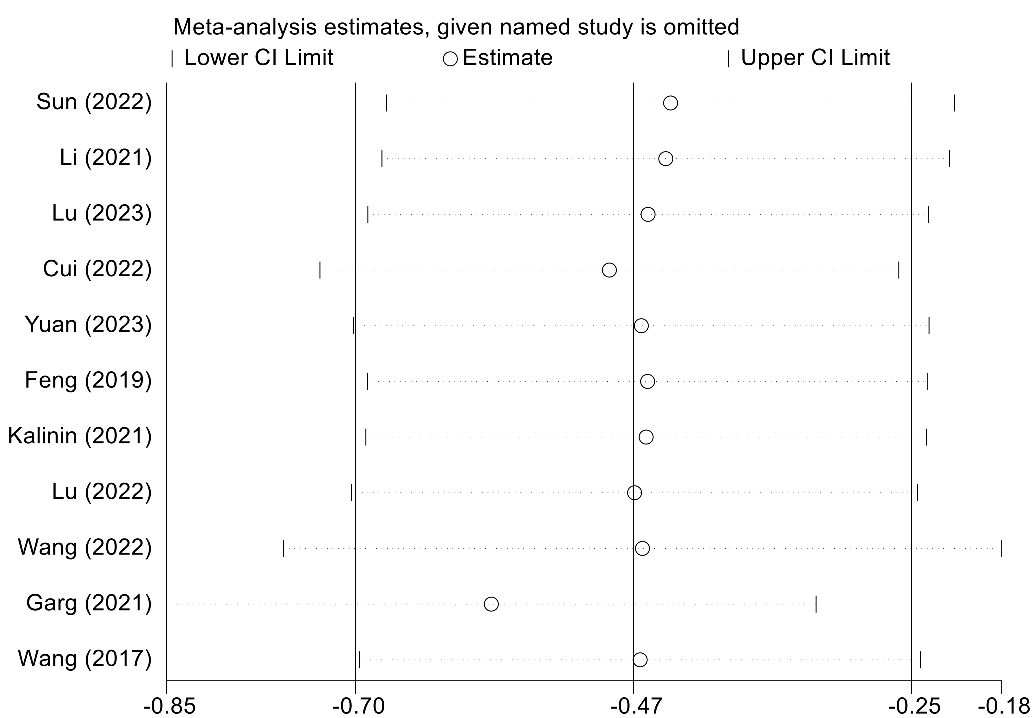

Fig. 5 Sensitivity analysis of postoperative complications

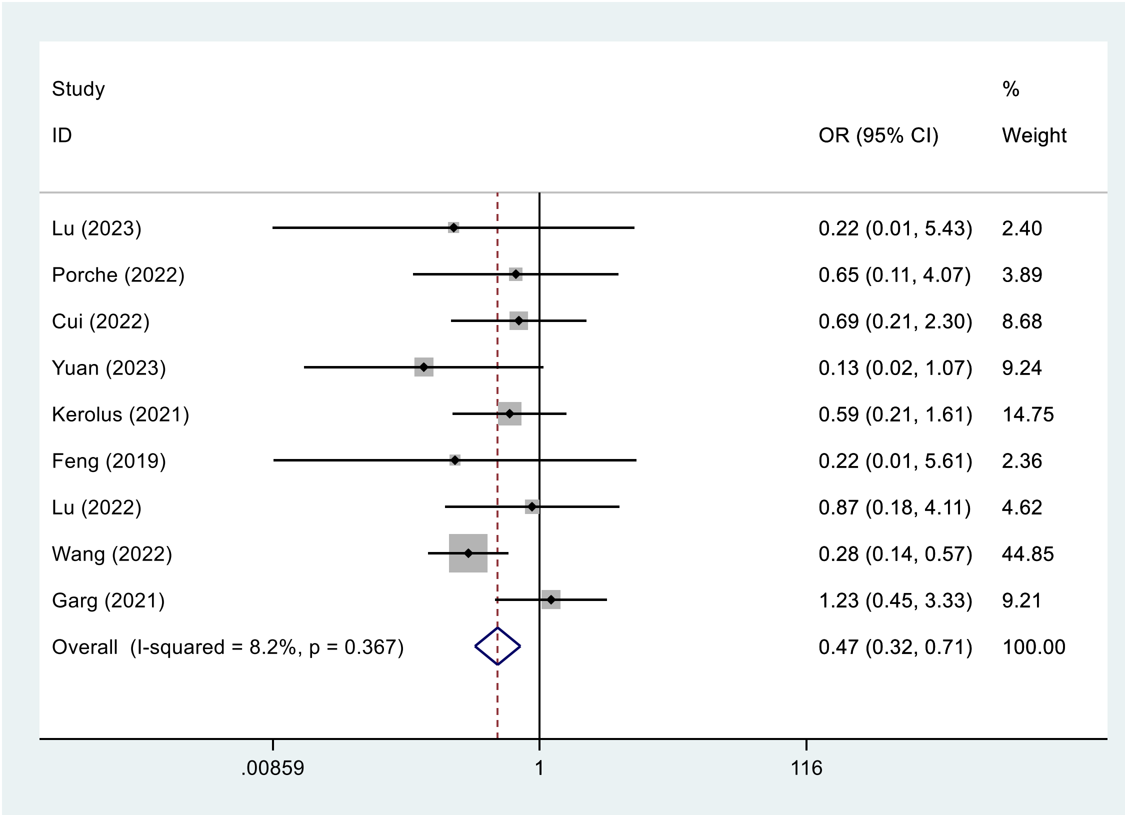

Fig. 6 Forest plot of readmission

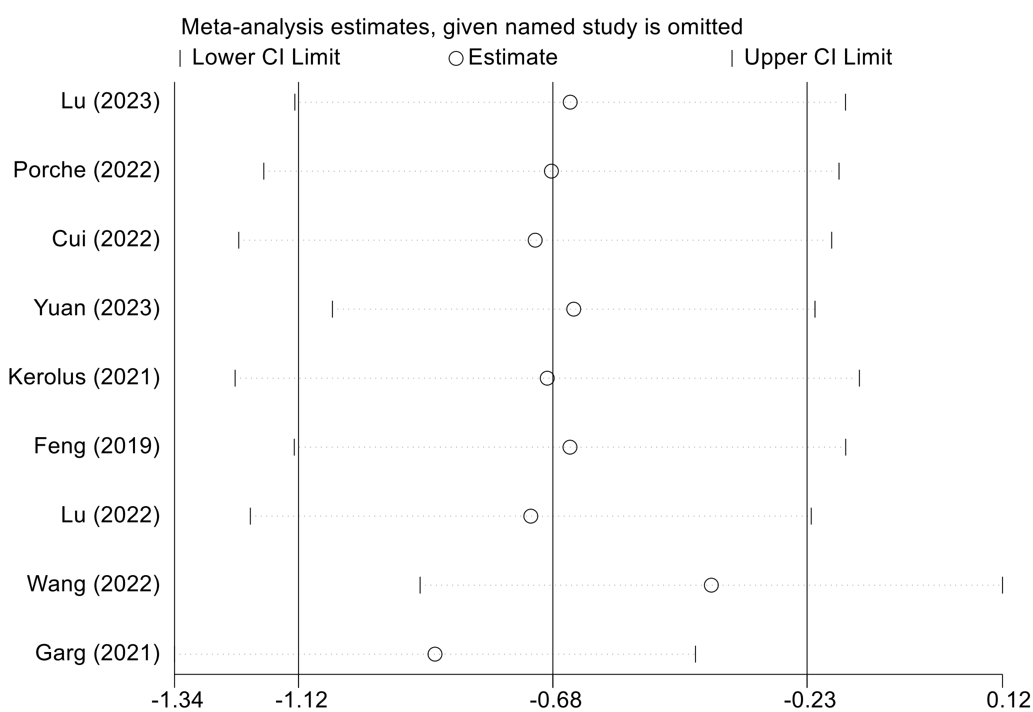

Fig. 7 Sensitivity analysis of readmission

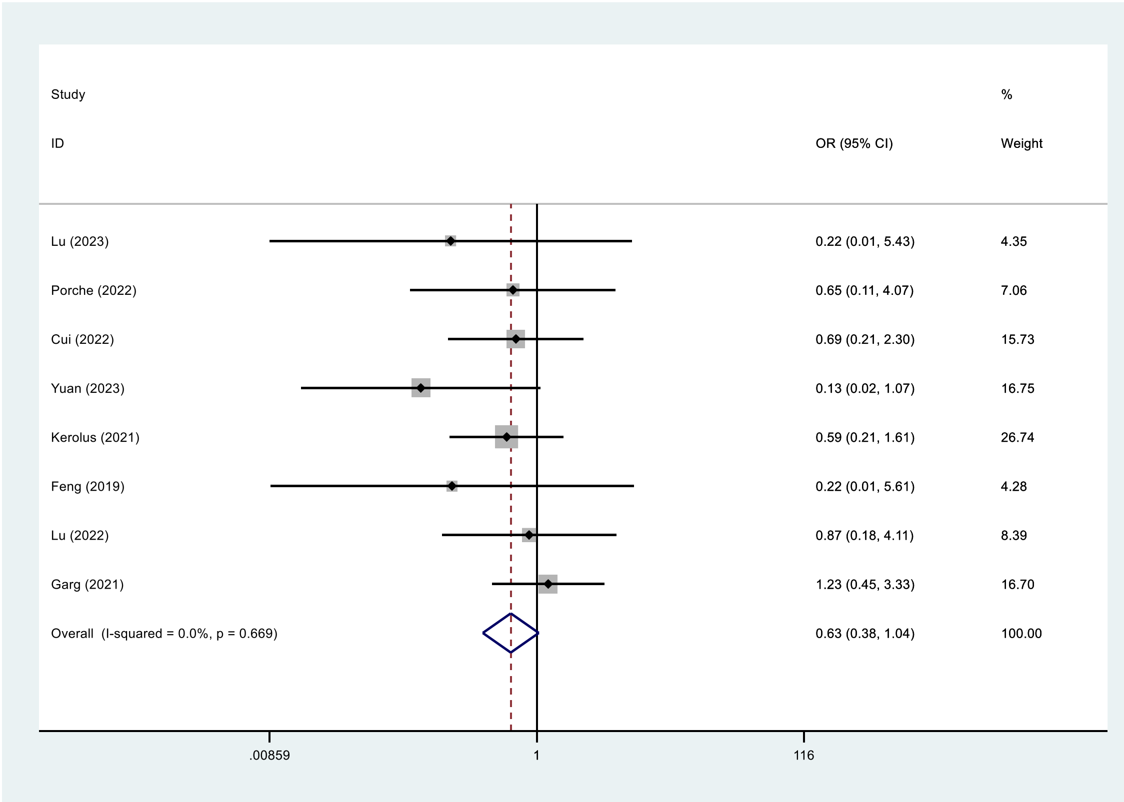

Fig. 8 Forest plot of readmission (recalculated)

The ERAS protocol significantly decreased the length of hospitalization across all subgroups, and this reduction was statistically significant. The postoperative complication rates of minimally invasive surgery (OR 0.38; 95% CI 0.12–1.26) and transforaminal lumbar interbody fusion surgery (OR 0.75; 95% CI 0.53–1.06) did not significantly differ between the two groups. The ERAS protocol did not exhibit a statistically significant advantage in readmission across all subgroups, with the exception of patients undergoing posterior thoracolumbar fusion surgery (OR 0.30; 95% CI 0.16–1.54). Meanwhile, The ERAS protocol did not exhibit a statistically significant advantage in operation time across all subgroups, with the exception of patients undergoing transforaminal lumbar interbody fusion surgery (SMD = −0.56; 95% CI −0.90 to −0.22). For patients undergoing open surgery, the implementation of the Enhanced Recovery After Surgery (ERAS) protocol resulted in a significant reduction in blood loss, demonstrating a statistically significant (SMD = −0.18; 95% CI −0.35 to −0.02). To facilitate the application of the ERAS protocol across diverse populations and surgical modalities, we conducted comprehensive subgroup analyses. The findings from this study indicate that the ERAS protocol demonstrates a positive impact on various subgroups and outcomes; however, whether these differences are statistically significant warrants further investigation. The results of our subgroup analysis provide valuable insights for selecting appropriate ERAS strategies in clinical practice (Table 2).

Publication bias

Funnel plots were used to determine potential publication bias. No significant publication bias was observed through visual inspection of the funnel plots for length of hospitalization, postoperative complications or readmission (Fig. 16). Egger's test was performed to assess publication bias, and the Egger's test yielded values of 0.069, 0.162, and 0.085 for length of hospitalization, postoperative complications and readmission, respectively (Fig. 17). The funnel plot and Egger's test indicated that the studies included in the meta-analysis were devoid of undetected cases, biases associated with small sample sizes, and the publication of negative results.

Discussion

As a concept that optimizes and integrates perioperative treatment and care, the ERAS protocol is widely used in a variety of surgical specialties worldwide [15]. Since

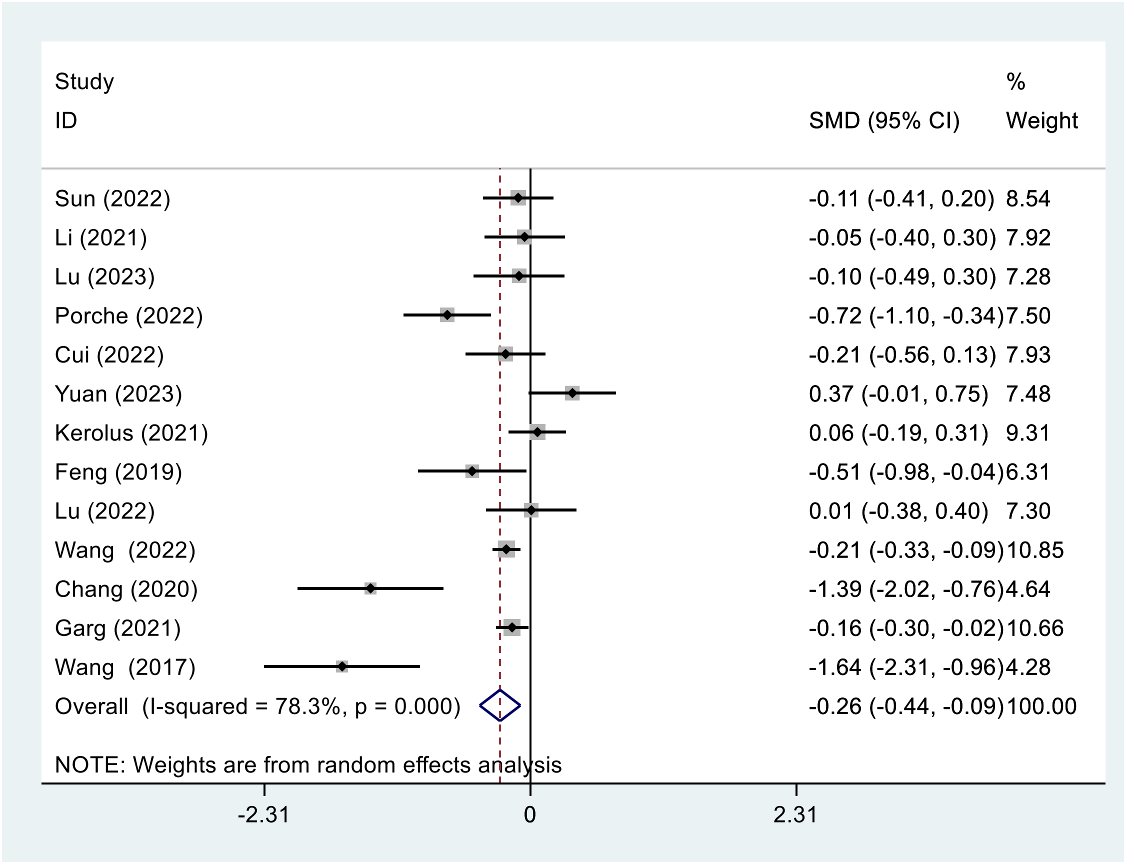

Fig. 9 Forest plot of operation time

Kehlet first proposed the ERAS protocol for patients who underwent major surgery, this protocol has been translated into many surgical fields. Moreover, corresponding evidence-based guidelines for perioperative care have been established to manage patients undergoing surgery [35, 36]. Although ERAS has been commonly used in other musculoskeletal procedures, such as total joint replacement, its use in spine surgery has been slow to develop, and research on this concept has been limited [37]. This is the first meta-analysis comparing the ERAS program with the SC program in patients who underwent lumbar interbody fusion surgery, and the findings will provide clinical theoretical support for the application of the ERAS protocol in spine surgery.

Our results revealed that the ERAS protocol, compared with the SC, significantly decreased the length of hospitalization. The same conclusion was reached in all subgroup analyses. Similarly, a previous study reported that the length of hospitalization in the ERAS cohort was significantly shorter than that in the control cohort [10]. ERAS interventions are carried out throughout the perioperative period to ensure postoperative functional recovery and early discharge, which might benefit from a well-planned preoperative examination, early postoperative diet and early postoperative functional exercise. In addition, compared with those in the SC group, patients in the ERAS group had a shorter duration to the 1st ambulation. Early ambulation is an important component of ERAS that can reduce the incidence of deep vein thrombosis, promote exhaust, shorten the length of hospitalization, and reduce mortality [38, 39]. Shortening fasting and early postoperative feeding can improve the metabolic status of patients, enhance resistance, and help patients recover their appetite and shorten the length of hospitalization [11]. The results of this study also supported the abovementioned findings.

In this study, there was a significant difference in the total incidence of complications between the ERAS and SC groups, suggesting that the ERAS care protocol may reduce the incidence of postoperative complications after lumbar interbody fusion. Early recovery of physiological function helps reduce the duration in bed, and the incidence of postoperative complications associated with the ERAS strategy substantially facilitates early recovery

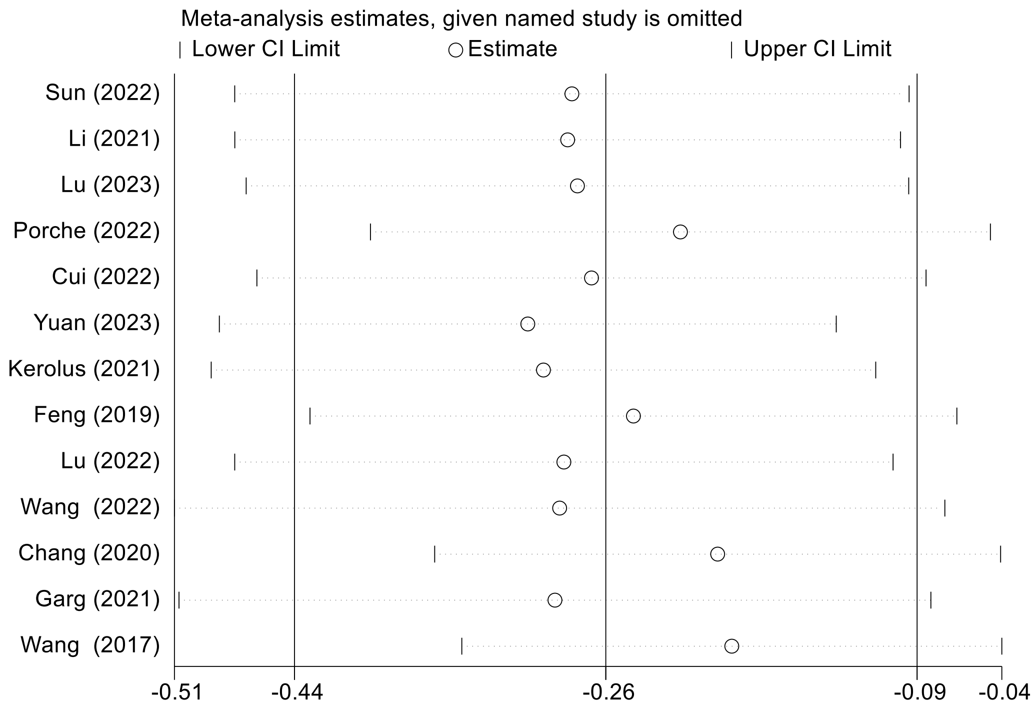

Fig. 10 Sensitivity analysis of the operation time

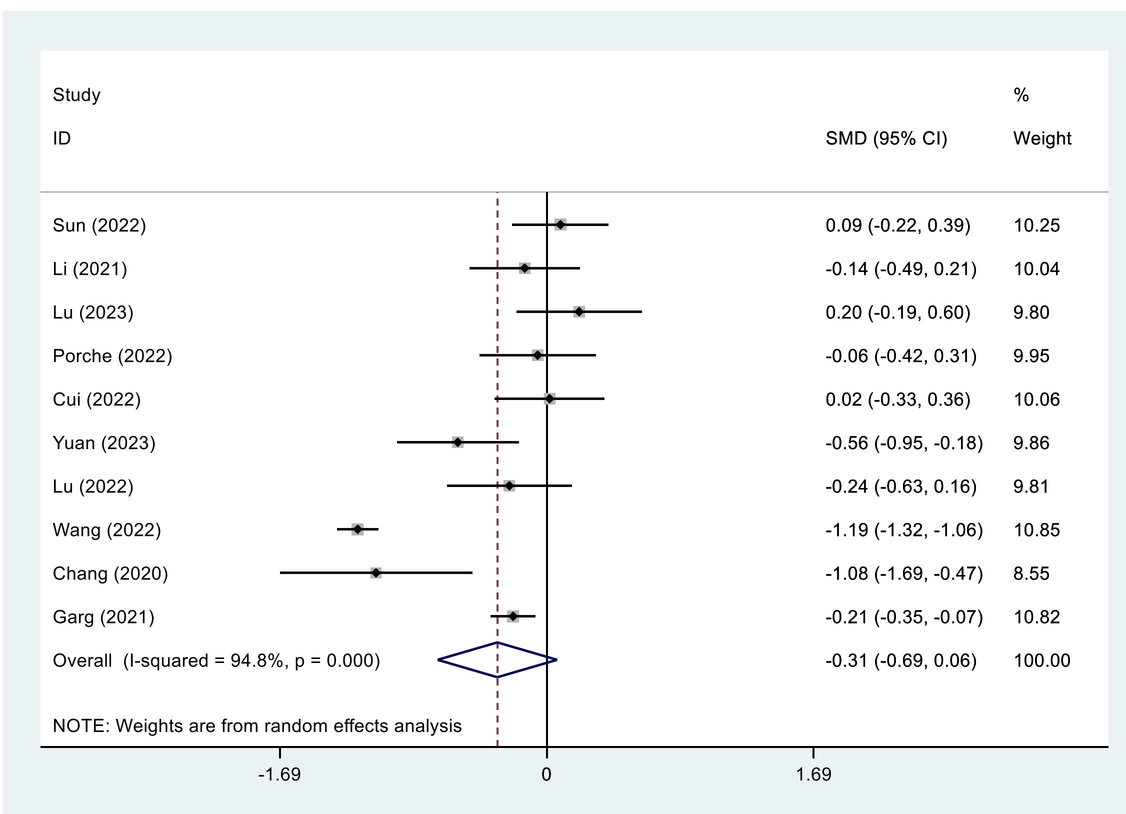

Fig. 11 Forest plot of estimated blood loss

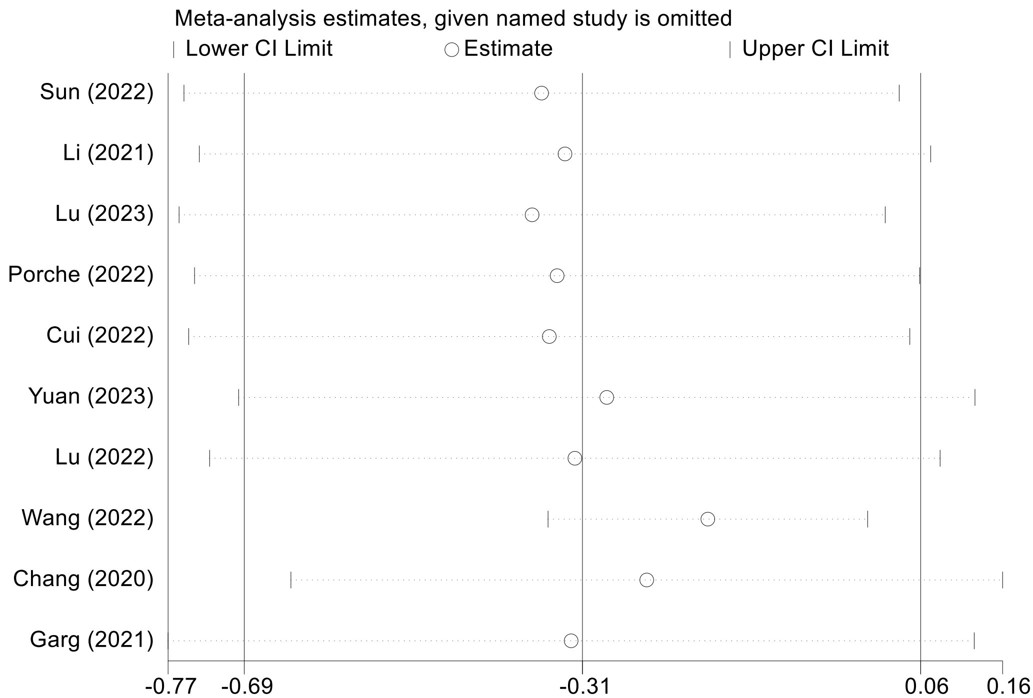

Fig. 12 Sensitivity analysis of estimated blood loss

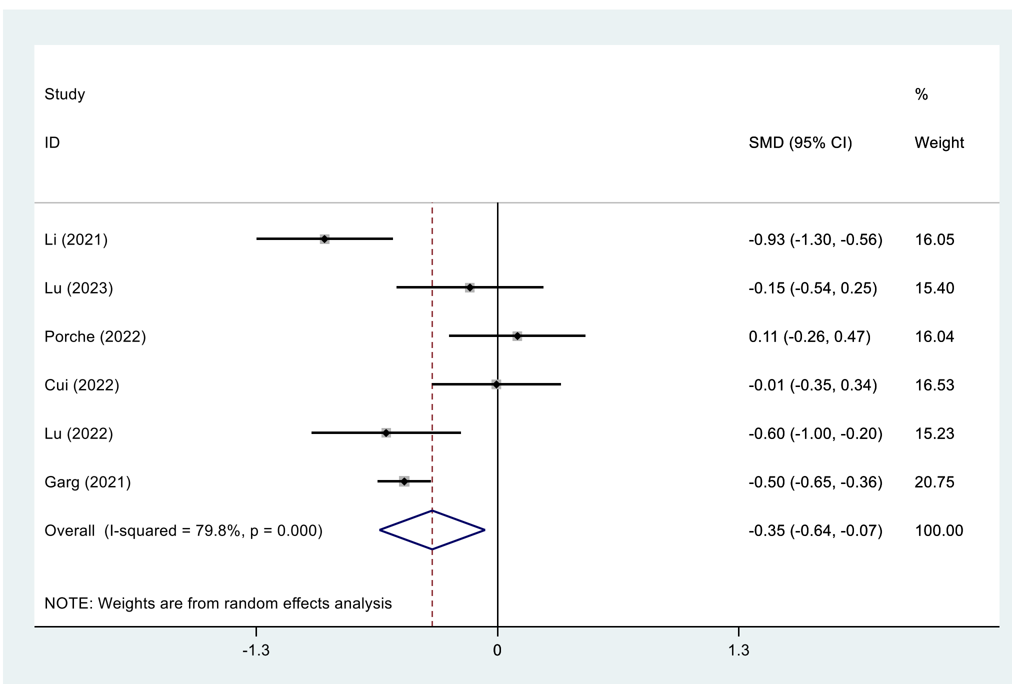

Fig. 13 Forest plot of postoperative pain

of physiological functions and reduces the incidence of postoperative complications after major spine surgery [15, 40–43]. According to the ERAS concept, early ambulation is an important process that can reduce the incidence of deep vein thrombosis, promote exhaust, shorten the length of hospitalization, and reduce

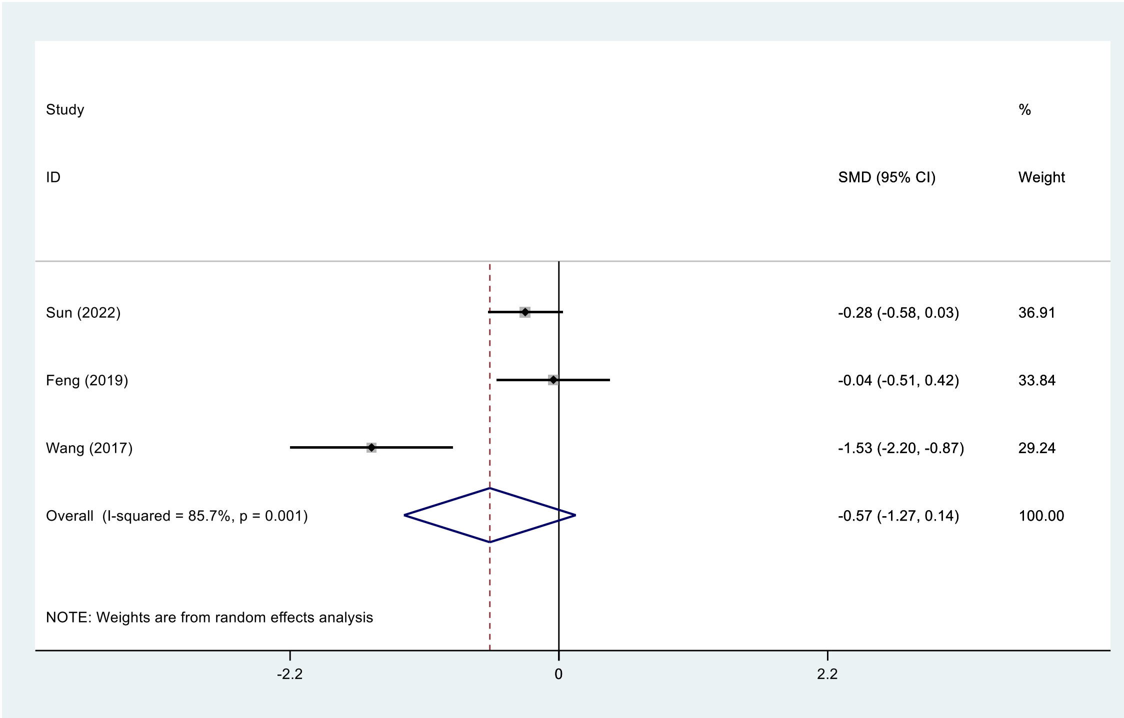

Fig. 14 Forest plot of hospitalization costs

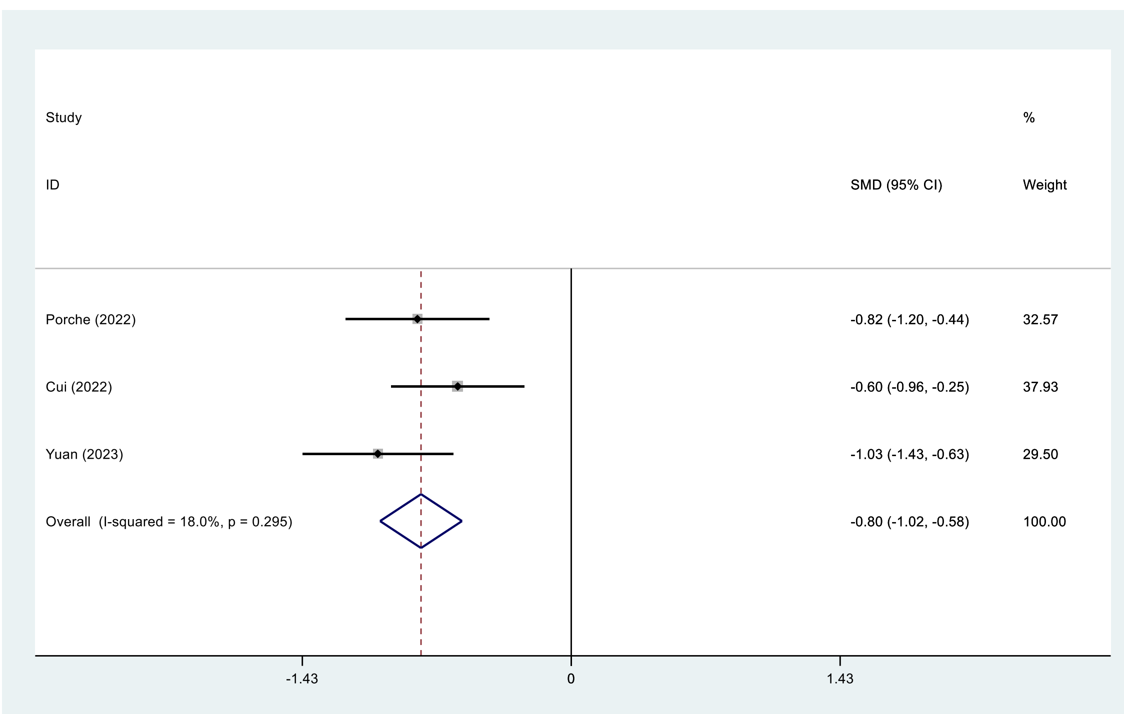

Fig. 15 Forest plot of 1st ambulation

Table 2 The results of the subgroup analyses

Outcomes	Elderly patients	Open operation	Minimally invasive surgery	Posterior thoracolumbar fusion	Transforaminal lumbar interbody fusion
Length of hospitalization (SMD; 95% CI)	−0.53 (−0.72 to −0.35)	−0.55 (−0.71 to −0.38)	NA	−0.58 (−0.74 to −0.42)	−0.42 (−0.53 to −0.31)
Postoperative complications (OR; 95% CI)	0.58 (0.36 to 0.93)	0.58 (0.36 to 0.93)	0.38 (0.12 to 1.26)	0.55 (0.41 to 0.73)	0.75 (0.53 to 1.06)
Readmission (OR; 95% CI)	0.50 (0.22 to 1.14)	0.52 (0.24 to 1.10)	0.54 (0.20 to 1.41)	0.30 (0.16 to 0.54)	0.75 (0.42 to 1.31)
Operation time (SMD; 95% CI)	0.02 (−0.22 to 0.26)	−0.12 (−0.46 to 0.22)	NA	−0.06 (−0.22 to 0.10)	−0.56 (−0.90 to −0.22)
Estimated blood loss (SMD; 95% CI)	−0.22 (−0.46 to 0.02)	−0.18 (−0.35 to −0.02)	NA	−0.32 (−0.89 to 0.26)	−0.25 (−0.55 to 0.06)
Postoperative pain (SMD; 95% CI)	−0.51 (−1.06 to 0.04)	−0.35 (−0.84 to 0.13)	NA	−0.56 (−1.02 to −0.11)	−0.16 (−0.59 to 0.27)
Hospitalization costs (SMD; 95% CI)	NA	NA	−0.77 (−2.23 to 0.69)	NA	−0.77 (−2.23 to 0.69)
1st ambulation (SMD; 95% CI)	−0.81 (−1.22 to −0.39)	−0.80 (−1.02 to −0.58)	NA	NA	−0.70 (−0.96 to −0.44)

NA, not available

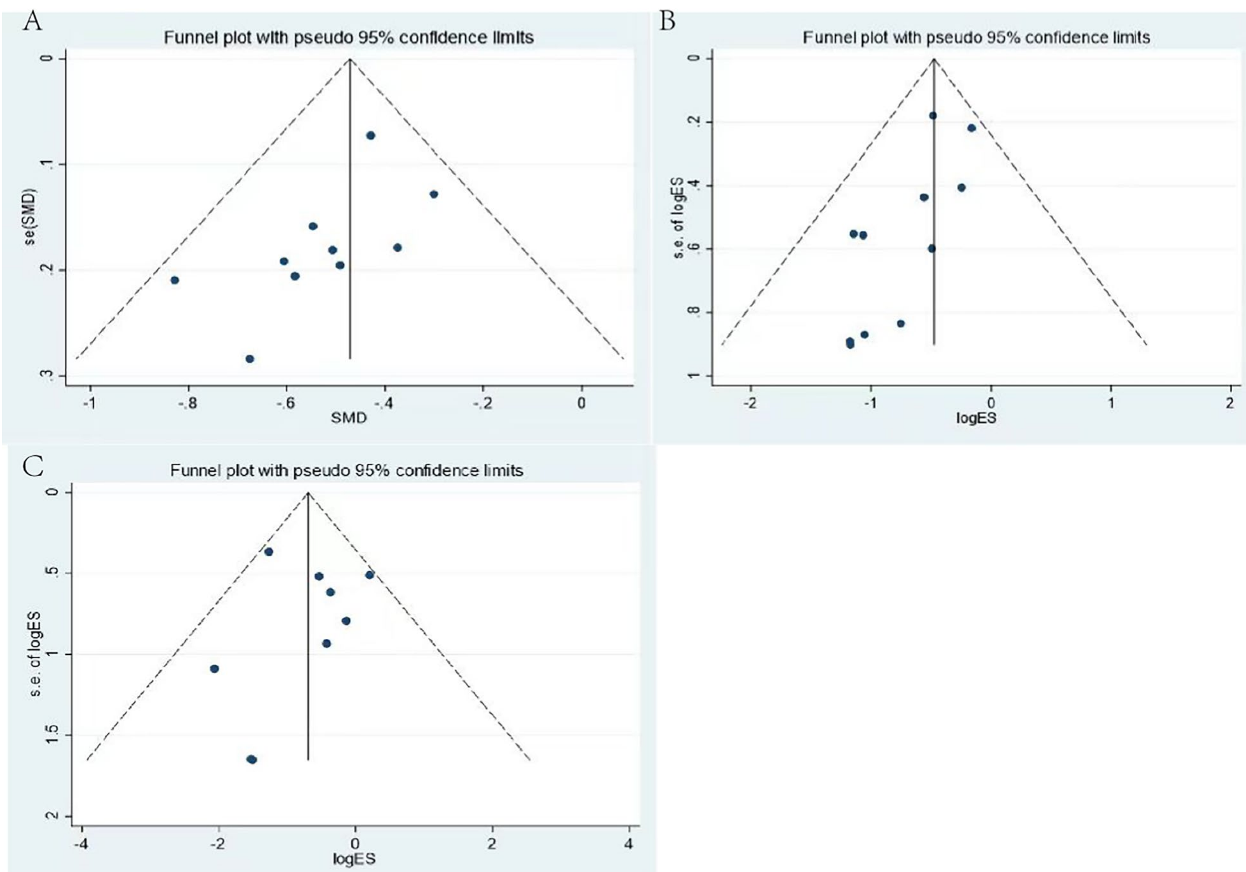

Fig. 16 Funnel plot for publication bias in the included studies

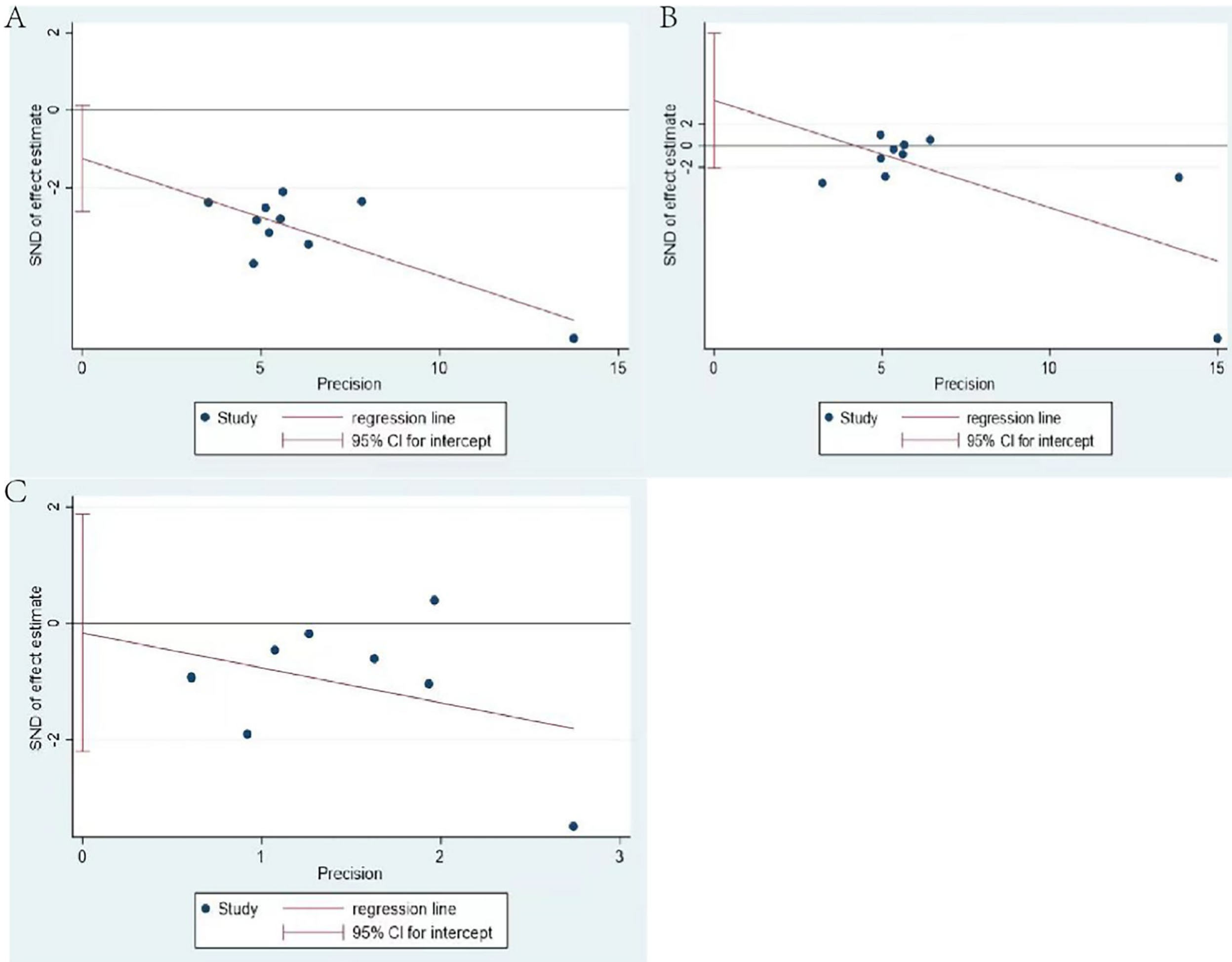

Fig. 17 Egger's test for publication bias in the included studies

mortality [38, 39]. For example, traditional fasting for 8 h before surgery and eating for 1 h day after surgery may lead to insulin resistance and metabolic stress, and metabolic stress may also increase the incidence of postoperative complications [44, 45]. Several factors contributed to the decrease in complications in previous studies. Early removal of the bladder catheter and standard antimicrobial prophylaxis reduce the risk of complications such as urinary tract infection and wound infection [46–48]. In the subgroup analysis, the pooled data revealed that the ERAS group did not have a significantly lower complication incidence than the SC group in terms of the incidence of minimally invasive surgery (OR 0.38, 95% CI 0.12 to 1.26). However, our data showed that the incidence rate of complications in the ERAS group after surgery was lower than that in the SC group; thus, we speculated that this might be related to the small sample size of this study. There was no statistically significant in postoperative complications among patients undergoing minimally invasive and transforaminal lumbar interbody fusion surgery when employing ERAS protocol. Both the ERAS protocol and minimally invasive surgical techniques are designed to minimize trauma, expedite recovery, and improve patient outcomes. According to the ERAS concept, early ambulation and a reduction in fasting duration are crucial processes that can help minimize postoperative complications. In the context of perioperative management, patients undergoing minimally invasive surgery also benefit from early ambulation and prompt initiation of feeding. Similarly, the majority of patients undergoing transforaminal lumbar interbody fusion in the studies we included chose minimally invasive surgical techniques.

Pain is the fifth most important vital sign after body temperature, pulse, respiration and blood pressure and is the main cause of medical treatment for most patients after spinal surgery. According to the study of Vilmarsson et al., painful stimulation causes sympathetic nerve reflexes and blood vessel and muscle contraction after surgery, which leads to insufficient blood supply to the surgical incision, eventually delaying wound healing and increasing the chance of infection [49]. Hence, pain relief is especially important in preventing infection in patients undergoing lumbar surgery. Effective analgesia is a critical component of the ERAS protocol. The ERAS guidelines support the use of multimodal, opioid-sparing analgesia approaches, including local anesthetics, to improve postoperative recovery [50–52]. The data in our study indicated that the visual analog scale (VAS) score in the ERAS group was significantly lower than that in the SC group. These findings indicate that the current ERAS protocol was helpful for reducing pain in the ERAS group. A previous meta-analysis compared the efficacy of ERAS for treating adolescent idiopathic scoliosis. The study concluded that, compared to the traditional care pathway, the ERAS protocol can significantly relieve postoperative pain and patient-controlled analgesia (PCA) discontinuation 0.53 days earlier ([0.4 to 0.6], $P < 0.001$) [53]. This finding is consistent with our research findings. However, there were still shortcomings in the open operation group (SMD = −0.35, 95% CI 0.84 to 0.13) and elderly patients (SMD = −0.51, 95% CI −1.06 to 0.04); although the ERAS regimen can alleviate postoperative pain, there was no significant difference compared to the SC group. This result suggested that it may be necessary to explore more suitable analgesic strategies for different populations.

The ERAS protocol significantly reduced the postoperative readmission rate of patients compared to that of patients in the SC group (OR 0.47; 95% CI 0.32 to 0.71). After excluding the heterogeneity generated by Wang et al.'s study [34], we detected no statistically significant difference in readmission rates between the two groups (OR 0.63; 95% CI 0.38 to 1.04). However, in the subsequent subgroup analysis, we found a significant difference in readmission rates between the two groups only during posterior thoracolumbar fusion surgery (OR 0.30, 95% CI 0.16 to 0.54). A previous study reported that postoperative pain is an important reason for readmission after spinal surgery [54]. In our study, we also found significant differences in postoperative pain between the two groups after posterior thoracolumbar fusion surgery (SMD = −0.56 95% CI −1.02 to −0.11).

Furthermore, the operation time in the ERAS group was significantly shorter than that in the SC group (standardized mean difference (SMD) = 0.26; 95% CI −0.44 to −0.09). However, as differences in surgical experience among surgeons cannot be ruled out, further validation is needed for this conclusion. Similarly, the estimated blood loss did significantly differ between the ERAS and SC groups during open surgery (standardized mean difference (SMD) = 0.18 95% CI −0.35 to −0.02). This may be related to the thorough preoperative evaluation and preparation conducted in the ERAS group [15]. However, this study indicated that estimated blood loss did not demonstrate statistical significance. In the ERAS group, the lower compliance with the use of hemostatic agents contributed to the lack of statistical significance in estimated blood loss. Meanwhile, patients in the non-ERAS group also received hemostatic agents during the perioperative period.

Hospitalization costs have always been a concern for patients. This study revealed that the hospitalization cost of patients in the ERAS group was lower than that of patients in the SC group. However, the hospitalization costs were not significantly lower in the ERAS group (SMD: −0.56, 95% CI −1.27 to 0.14). Similarly, a previous study indicated that the hospitalization cost of patients in the ERAS group was slightly lower than that of patients in the SC group; however, the difference was not significant (3.746 ± 0.712 vs. 3.547 ± 0.746, $P = 0.081$) [17]. Generally, a reduction in the length of hospital stay causes a significant decrease in overall hospitalization costs, although the costs of surgical and anesthesia services associated with ERAS increase accordingly [55–57]. Stone et al. 56 reported that a length of stay reduction of 0.7 days led to net institutional savings of nearly $400,000 annually [58]. Disparities in health insurance coverage and economic development across different regions resulted in hospitalization costs also lacking statistical significance. However, there were still shortcomings. Due to the limited number of studies reporting hospitalization costs, we were unable to conduct further subgroup analyses based on different countries.

High compliance with the protocol is vital to achieving ERAS. A committed ERAS team is a prerequisite for high pathway compliance. In a previous study, the ERAS group showed high compliance with patient education, antimicrobial prophylaxis, normothermia maintenance, postoperative early nutrition and mobilization, preoperative carbohydrate loading, preemptive analgesia, and postoperative multimodal analgesia. However, compliance with 3 intraoperative components was relatively low, including tranexamic acid use, local analgesia, and goal-directed fluid therapy [27]. Consequently, variations in adherence to the ERAS protocol represent a source of heterogeneity within this study. Protocol compliance is determined by care provider's awareness and preference as well as multidisciplinary communication and collaboration. The compliance with the ERAS protocol was associated with postoperative outcomes; meanwhile, due to the lack of a standardized perioperative management pathway, it was impossible to evaluate the compliance with the ERAS program for patients in the non-ERAS group; efforts are needed to maximize compliance with specific enhanced recovery pathway standards.

Nonetheless, our meta-analysis has several limitations. First, 15 studies in this review of the literature were retrospective in nature and hence prone to selection bias. Second, 11 studies compared complication rates between the ERAS and SC groups; however, the definition of this outcome measure varied between the studies. This problem was also observed when comparing readmissions between the two intervention groups, as the thresholds for reintervention may vary between centers and practices. Finally, the number of ERAS protocol elements and compliance rates varied among the included studies. This could have affected the ERAS efficacy evaluation.

Conclusions

Our study indicated that the ERAS protocol is feasible and safe for patients undergoing lumbar interbody fusion surgery. The protocol significantly reduced the length of hospitalization, incidence of postoperative complications, operation time, duration of 1st ambulation and duration of postoperative pain without increasing the estimated blood loss, readmission rate or hospitalization costs. These data can have crucial clinical implications for elevating the quality of evidence, thereby supporting protocol implementation in patients undergoing lumbar interbody fusion surgery.

Abbreviations

ERAS	Enhanced recovery after surgery
SC	Standard care
SMD	Standaed mean difference
OR	Odds ratio
LDDs	Lumbar degenerative diseases
MOOSE	Meta-analysis of Observational Studies in Epidemiology
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
RCTs	Randomized controlled trials
Cis	Confidence intervals

Acknowledgements

Not applicable.

Author contributions

HL, LZ: conception or design of the work; JL, JC, YT: data collection and quality assessment; WL: analysis and interpretation of data; HL, JL, LZ: drafting the work; HL: critical review and final approval.

Funding

This study is supported by the Sichuan Medical Research Funding Program (Q20023).

Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Orthopedics, Chengdu Sixth People's Hospital, Chengdu, Sichuan, China. [2]Department of Medical Cosmetology, Sichuan Mianyang 404 Hospital, Mianyang, Sichuan, China. [3]School of Clinic Medicine, Southwest Medical University, Luzhou, Sichuan, China. [4]Department of Hepatobiliary Pancreatic Surgery, Chengdu Sixth People's Hospital, Chengdu, Sichuan, China.

Received: 3 September 2024 Accepted: 20 January 2025
Published online: 11 February 2025

References

1. Schöller K, et al. Lumbar spinal stenosis associated with degenerative lumbar spondylolisthesis: a systematic review and meta-analysis of secondary fusion rates following open vs minimally invasive decompression. Neurosurgery. 2017;80(3):355–67.
2. Tomé-Bermejo F, Piñera AR, Alvarez-Galovich L. Osteoporosis and the management of spinal degenerative disease (I). Arch Bone Jt Surg. 2017;5(5):272–82.
3. Huang RC, et al. Advantages and disadvantages of nonfusion technology in spine surgery. Orthop Clin North Am. 2005;36(3):263–9.
4. Gerhardt J, et al. Is Eighty the new sixty? Outcomes and complications after lumbar decompression surgery in elderly patients over 80 years of age. World Neurosurg. 2018;112:e555–60.
5. Li ZE, et al. Comparative short-term outcomes of enhanced recovery after surgery (ERAS) program and non-ERAS traditional care in elderly patients undergoing lumbar arthrodesis: a retrospective study. BMC Musculoskelet Disord. 2021;22(1):283.
6. Debono B, et al. Benefits of enhanced recovery after surgery for fusion in degenerative spine surgery: impact on outcome, length of stay, and patient satisfaction. Neurosurg Focus. 2019;46(4):E6.
7. Elsarrag M, et al. Enhanced recovery after spine surgery: a systematic review. Neurosurg Focus. 2019;46(4):E3.
8. Smith J, et al. Enhanced recovery after surgery (ERAS) program for lumbar spine fusion. Perioper Med (Lond). 2019;8:4.
9. Soffin EM, et al. Design and Implementation of an Enhanced Recovery After Surgery (ERAS) program for minimally invasive lumbar decompression spine surgery: initial experience. Spine (Phila Pa 1976). 2019;44(9):E561-e570.
10. Brusko GD, et al. Reductions in length of stay, narcotics use, and pain following implementation of an enhanced recovery after surgery program for 1- to 3-level lumbar fusion surgery. Neurosurg Focus. 2019;46(4):E4.
11. Wang P, et al. Enhanced recovery after surgery (ERAS) program for elderly patients with short-level lumbar fusion. J Orthop Surg Res. 2020;15(1):299.
12. Chen J, et al. Benefits of the enhanced recovery after surgery program in short-segment posterior lumbar interbody fusion surgery. World Neurosurg. 2022;159:e303–10.
13. Porche K, et al. Enhanced recovery after surgery (ERAS) improves return of physiological function in frail patients undergoing one- to two-level TLIFs: an observational retrospective cohort study. Spine J. 2022;22(9):1513–22.
14. Dagal A, et al. Enhanced perioperative care for major spine surgery. Spine (Phila Pa). 2019;44(13):959–66.
15. Angus M, et al. The implementation of enhanced recovery after surgery (ERAS) in complex spinal surgery. J Spine Surg. 2019;5(1):116–23.
16. d'Astorg H, et al. Enhanced recovery after surgery (ERAS) protocol reduces LOS without additional adverse events in spine surgery. Orthop Traumatol Surg Res. 2020;106(6):1167–73.
17. Sun Z, Qi Y. Application of enhanced recovery after surgery care protocol in the perioperative care of patients undergoing lumbar fusion and internal fixation. J Orthop Surg Res. 2022;17(1):240.

18. Stroup DF, et al. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. JAMA. 2000;283(15):2008–12.
19. Page MJ, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Int J Surg. 2021;88: 105906.
20. Clavien PA, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg. 2009;250(2):187–96.
21. Stang A. Critical evaluation of the Newcastle–Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. Eur J Epidemiol. 2010;25(9):603–5.
22. Lu HR, et al. A new nursing pattern based on ERAS concept for patients with lumbar degenerative diseases treated with OLIF surgery: a retrospective study. Front Surg. 2023;10:1121807.
23. Porche K, et al. Enhanced recovery after surgery (ERAS) for open transforaminal lumbar interbody fusion: a retrospective propensity-matched cohort study. Spine J. 2022;22(3):399–410.
24. Cui P, et al. Comparison of perioperative outcomes in frail patients following multilevel lumbar fusion surgery with and without the implementation of the enhanced recovery after surgery protocol. Front Surg. 2022;9: 997657.
25. Yuan Y, et al. The implementation of enhanced recovery after surgery pathway in patients undergoing posterior thoracolumbar fusion for degenerative spinal deformity. BMC Musculoskelet Disord. 2023;24(1):29.
26. Kerolus MG, et al. Enhanced recovery after surgery pathway for single-level minimally invasive transforaminal lumbar interbody fusion decreases length of stay and opioid consumption. Neurosurgery. 2021;88(3):648–57.
27. Feng C, et al. Establishment and implementation of an enhanced recovery after surgery (ERAS) pathway tailored for minimally invasive transforaminal lumbar interbody fusion surgery. World Neurosurg. 2019;129:e317–23.
28. Yang Y, et al. Enhanced recovery after surgery (ERAS) pathway for microendoscopy-assisted minimally invasive transforaminal lumbar interbody fusion. Clin Neurol Neurosurg. 2020;196: 106003.
29. Kalinin AA, et al. Accelerated recovery program for patients with polysegmental degenerative lumbar spine disease. Sovrem Tekhnologii Med. 2021;13(2):74–81.
30. Cui P, et al. Patients older than 75 years undergoing polysegmental lumbar fusion surgery can also benefit from enhanced recovery after surgery program. Clin Interv Aging. 2022;17:245–52.
31. Wang S, et al. Enhanced recovery after surgery pathway: association with lower incidence of wound complications and severe hypoalbuminemia in patients undergoing posterior lumbar fusion surgery. J Orthop Surg Res. 2022;17(1):178.
32. Chang HK, et al. Less opioid consumption with enhanced recovery after surgery transforaminal lumbar interbody fusion (TLIF): a comparison to standard minimally-invasive TLIF. Neurospine. 2020;17(1):228–36.
33. Garg B, et al. Design and implementation of an enhanced recovery after surgery protocol in elective lumbar spine fusion by posterior approach: a retrospective, comparative study. Spine (Phila Pa 1976). 2021;46(12):E679-e687.
34. Wang MY, Chang HK, Grossman J. Reduced acute care costs with the ERAS® minimally invasive transforaminal lumbar interbody fusion compared with conventional minimally invasive transforaminal lumbar interbody fusion. Neurosurgery. 2018;83(4):827–34.
35. Lassen K, et al. Guidelines for perioperative care for pancreaticoduodenectomy: enhanced recovery after surgery (ERAS®) society recommendations. Clin Nutr. 2012;31(6):817–30.
36. Mortensen K, et al. Consensus guidelines for enhanced recovery after gastrectomy: enhanced recovery after surgery (ERAS®) society recommendations. Br J Surg. 2014;101(10):1209–29.
37. Huang M, et al. The University of Miami spine surgery ERAS protocol: a review of our journey. J Spine Surg. 2020;6(Suppl 1):S29-s34.
38. Aprato A, et al. No rest for elderly femur fracture patients: early surgery and early ambulation decrease mortality. J Orthop Traumatol. 2020;21(1):12.
39. Huang J, et al. Benefits of early ambulation in elderly patients undergoing lumbar decompression and fusion surgery: a prospective cohort study. Orthop Surg. 2021;13(4):1319–26.
40. Petersen PB, Jørgensen CC, Kehlet H. Delirium after fast-track hip and knee arthroplasty - a cohort study of 6331 elderly patients. Acta Anaesthesiol Scand. 2017;61(7):767–72.
41. Fineberg SJ, et al. Incidence and risk factors for postoperative delirium after lumbar spine surgery. Spine (Phila Pa 1976). 2013;38(20):1790–6.
42. Pan Z, et al. The risk factors associated with delirium after lumbar spine surgery in elderly patients. Quant Imaging Med Surg. 2019;9(4):700–10.
43. Britteon P, Cullum N, Sutton M. Association between psychological health and wound complications after surgery. Br J Surg. 2017;104(6):769–76.
44. Ljunggren S, Hahn RG, Nyström T. Insulin sensitivity and beta-cell function after carbohydrate oral loading in hip replacement surgery: a double-blind, randomised controlled clinical trial. Clin Nutr. 2014;33(3):392–8.
45. Pillinger NL, Robson JL, Kam P. Nutritional prehabilitation: physiological basis and clinical evidence. Anaesth Intensive Care. 2018;46(5):453–62.
46. Shaffer WO, et al. An evidence-based clinical guideline for antibiotic prophylaxis in spine surgery. Spine J. 2013;13(10):1387–92.
47. Kamath VH, et al. Antimicrobial prophylaxis to prevent surgical site infection in adolescent idiopathic scoliosis patients undergoing posterior spinal fusion: 2 doses versus antibiotics till drain removal. Eur Spine J. 2016;25(10):3242–8.
48. Okrainec A, et al. Compliance with urinary catheter removal guidelines leads to improved outcome in enhanced recovery after surgery patients. J Gastrointest Surg. 2017;21(8):1309–17.
49. Vilmarsson V, Schnabel K, Wikholm G. Osteoporotic sacral fracture—a painful condition, easy to miss. Sacroplasty a new treatment with quick pain relief. Lakartidningen. 2010;107(5):251–4.
50. Stenberg E, et al. Guidelines for perioperative care in bariatric surgery: enhanced recovery after surgery (ERAS) society recommendations: a 2021 update. World J Surg. 2022;46(4):729–51.
51. Bahir AW, Daxing W, Jiayu X, Bailian L, Shao G. Comparative efficacy and fusion outcomes of unilateral bi-portal endoscopic transforaminal lumbar interbody fusion versus minimally invasive transforaminal lumbar interbody fusion in treating single-segment degenerative lumbar spondylolisthesis with lumbar spinal stenosis: a two-year retrospective study. J Orthop Surg Res. 2024;19(1):835.
52. Wang W, Cui Y, Sun X, Zhang H, Yin W, Cui X, Jiao W. Transforaminalposteriorlumbar interbody fusion microscopic safe operating area: a three - dimensional model study based on computed tomography imaging. J Orthop Surg Res. 2024;19(1):342.
53. Koucheki R, et al. Comparison of interventions and outcomes of enhanced recovery after surgery: a systematic review and meta-analysis of 2456 adolescent idiopathic scoliosis cases. Eur Spine J. 2021;30(12):3457–72.
54. Cheng JS, et al. Short-term and long-term outcomes of minimally invasive and open transforaminal lumbar interbody fusions: Is there a difference? Neurosurg Focus. 2013;35(2):E6.
55. Arunakul R, Anumas S, Pattharanitima P, Susrivaraput C, Pholsawatchai W. Unilateral biportal endoscopic versus microscopic transforaminal lumbar interbody fusion for lumbar degenerative disease: a retrospective study. J Orthop Surg Res. 2024;19(1):326.
56. Guo W, Ye J, Li T, Yu Y, Fan X. Evaluation of the learning curve and complications in unilateral biportal endoscopic transforaminal lumbar interbody fusion: cumulative sum analysis and risk - adjusted cumulative sum analysis. J Orthop Surg Res. 2024;19(1):194.
57. Aleassa EM, et al. Cost-effectiveness of enhanced recovery pathway in bariatric surgery: It is not all about length of stay. Surg Obes Relat Dis. 2019;15(4):602–7.
58. Stone AB, et al. Implementation costs of an enhanced recovery after surgery program in the united states: a financial model and sensitivity analysis based on experiences at a Quaternary Academic Medical Center. J Am Coll Surg. 2016;222(3):219–25.

Publisher's Note