Systematic Review

Comparative Efficacy of Interlocking Intramedullary Nails and Percutaneous Plate Implantation in the Treatment of Femoral Shaft Fractures: A Meta-Analysis

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AIM: Interlocking intramedullary nailing and percutaneous plate implantation are commonly used techniques in the treatment of femoral shaft fractures. This study aimed to determine the most appropriate and effective treatment strategy between interlocking intramedullary nails and percutaneous plate implantation by analyzing and summarizing the available evidence.
METHODS: Relevant articles published from the date of database construction in PubMed, Embase, Web of Science, and Cochrane to 2024 were searched and downloaded according to PRISMA 2020. These studies were screened following pre-established inclusion criteria, and the data were extracted. Methodological quality assessment for retrospective studies was performed using the Newcastle-Ottawa Scale, whereas Review Manager Software was used for methodological quality assessment of randomized controlled trials (RCTs) and statistical analysis.
RESULTS: Only 13 studies containing 1061 patients were included in the meta-analysis. Femoral shaft fractures treated with interlocking intramedullary nailing had shorter operative and fluoroscopic time and less estimated blood loss. Pediatric patients treated with interlocking intramedullary nails had less estimated blood loss and shorter healing time. Interlocking intramedullary nailing group in the retrospective study was associated with shorter operative time and less blood loss, whereas, in the randomized controlled trial (RCT) study, it was associated with less blood loss and shorter healing time.
CONCLUSIONS: Interlocking intramedullary nailing is more advantageous in treating femoral shaft fractures and is a more appropriate option for treating femoral shaft fractures in pediatric patients.
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Keywords: interlocking intramedullary nail; percutaneous plate implantation; femoral shaft fracture; meta-analysis; femoral fracture

Introduction

The femur is the longest and the strongest tubular bone in the human body. The femoral shaft is the diaphysis, extending from 2–5 cm below the trochanter to 2–5 cm above the femoral condyle. Femoral shaft fractures are frequently encountered in clinical practice. High-energy traumas are considered the primary cause of these fractures and require intensive care and effective treatment to recover [1]. Improper treatment of such fractures leads to adverse complications such as infection, limb length discrepancy, angular malalignment, nonunion, and femoral head necrosis, with high mortality and disability rates [2, 3, 4]. Surgical treatments for femoral shaft fractures are broadly categorized into external and internal fixation techniques. External fixation is associated with potential complications, including pin tract infections, loosening of fixation pins, and nerve damage [5, 6]; therefore, it is not considered the effective and widely preferred treatment modality.

In contrast, internal fixation offers a wide range of applications with robust stability and early functional exercise after surgery [7]. Interlocking intramedullary nailing and percutaneous plate implantation are the two commonly used internal fixation techniques in clinical practice [8]. Nevertheless, assessing the efficacy of these two therapies and determining the appropriate patient population have been challenging.

In recent years, intramedullary nailing technology has been developed rapidly. Among the numerous available instruments for this technique, interlocking intramedullary nails are the most frequently applied because they offer certain advantages, including reduced surgical damage, reliable fixation, faster healing, and fewer adverse impacts. For successful and effective outcomes through the intramedullary nailing technique, achieving and maintaining proper alignment of the fractured bone during reaming and nail insertion are crucial. Additionally, prior health conditions of every patient, such as obesity and age, must be considered during treatment. Generally, this treatment modality is more often applied to patients with an age above 10 years and weighing over 49 kilograms (kg) [9]. Unfortunately, ischemic necro-

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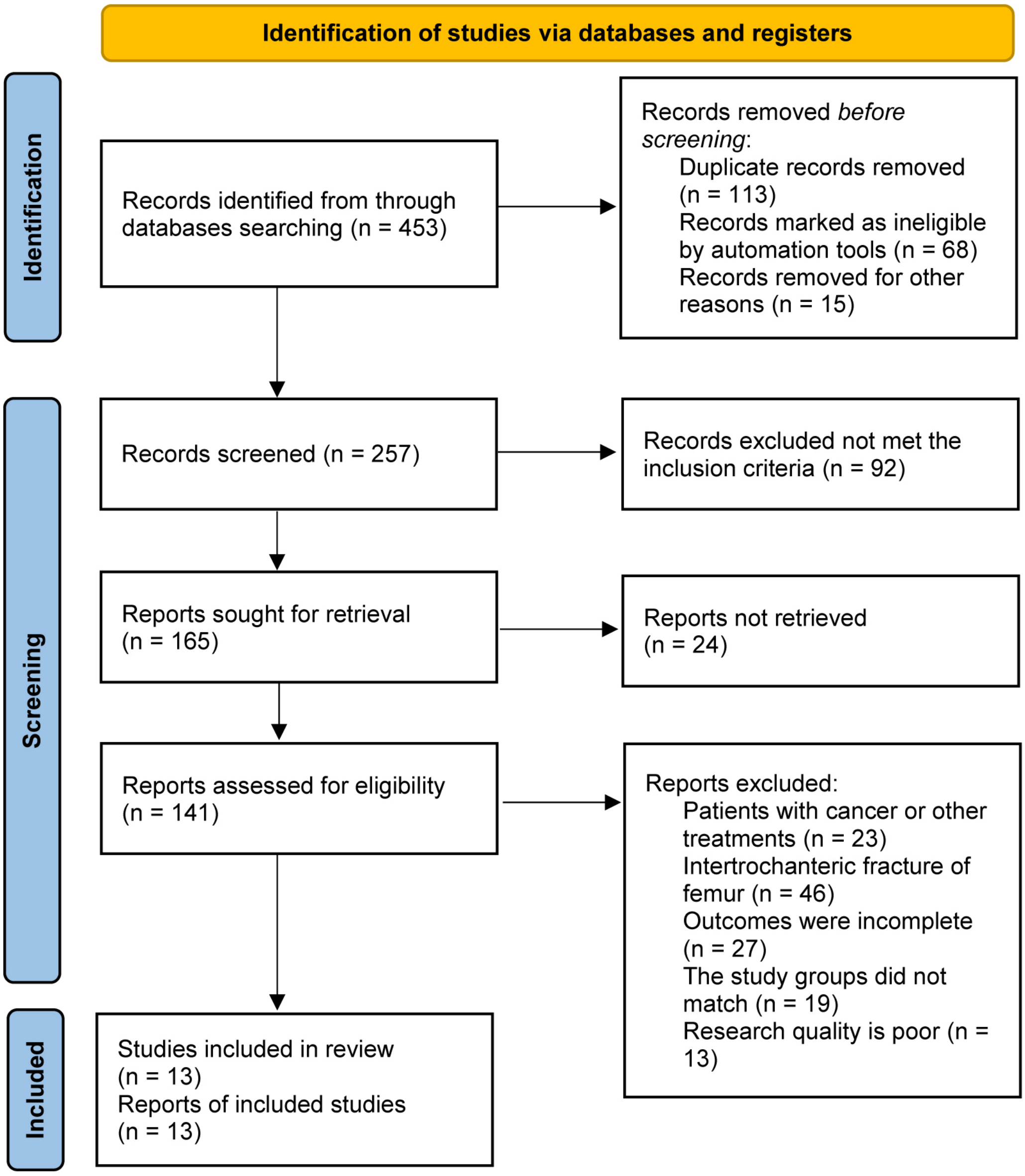

Fig. 1. A flowchart of the literature searching and screening.

sis of the femoral head was identified in children treated with intramedullary nail fixation. This complication is associated with damage to the medial femoral artery near the pyriform fossa during nail insertion.

Meanwhile, the incidence of other complications, such as hip valgus deformity and femoral neck stenosis, has also gradually increased [10, 11]. The need for marrow expansion in many patients has also led to marrow deformation and even more serious sequelae. Although plate fixation is considered appropriate and beneficial under certain conditions that could outperform other fixation techniques, it also has limitations, such as large surgical incisions, enhanced local trauma, significant local blood flow destruction, and non-union of fractures [12]. Additionally, percutaneous plate implantation is an eccentric fixation, which is biomechanically unstable and can lead to nail or plate breakage under improper and inadequate care. The risks and complications regarding this strategy could be even more significant in younger patients [13].

In the current meta-analysis, the data from the studies comparing the efficacy of interlocking intramedullary nailing and percutaneous plate implantation have been combined to understand their existing potential and provide reliable recommendations for clinical treatment protocols in treating femoral shaft fractures.

Methods

Search Strategy

Databases like PubMed, Embase, Web of Science, Cochrane, and others were systematically searched following the PICOS search strategy [14]. The search keywords “femoral shaft fracture”, “interlocking intramedullary nail”,

Table 1. Characteristics of the included studies.

Study	Year	Design	Treatment	Gender (female:male)	Mean age	Sample size	Complication (n)	LLD (cm)	Outcomes
Allen *et al.* [17]	2018	RCS	interlocking intramedullary nails	14:36	9	50	NA	NA	Operative time, estimated blood loss, fluoroscopy time, length of stay, excellent rate
			percutaneous plate implantation	6:9	8	15	NA	NA	
Howard *et al.* [29]	2024	RCS	interlocking intramedullary nails	3.03:1	64.2	93	4%	NA	Length of stay
			percutaneous plate implantation	2.82:1	70.1	100	8.60%	NA	
Rollo *et al.* [20]	2019	RCS	interlocking intramedullary nails	4:11	42.67	15	NA	NA	Operative time, estimated blood loss, healing time
			percutaneous plate implantation	4:11	42.84	15	NA	NA	
Li *et al.* [22]	2020	RCS	interlocking intramedullary nails	32:45	8.1	77	1	NA	Operative time, estimated blood loss, fluoroscopy time, length of stay
			percutaneous plate implantation	19:26	8	45	1	NA	
Meccariello *et al.* [24]	2021	RCS	interlocking intramedullary nails	22:8	42.67	30	NA	NA	Operative time, estimated blood loss, healing time
			percutaneous plate implantation	20:10	42.84	30	NA	NA	
Luo *et al.* [18]	2019	RCS	interlocking intramedullary nails	16:35	5.9	29	NA	1.4 ± 3.66	Operative time, estimated blood loss, length of stay, healing time
			percutaneous plate implantation			22	NA	1.5 ± 2.02	
Milligan *et al.* [23]	2019	RCS	interlocking intramedullary nails	4:10	9.7	14	4	NA	Length of stay, excellent rate
			percutaneous plate implantation	3:11	7.7	14	1	NA	
Ocalan *et al.* [19]	2019	RCS	interlocking intramedullary nails	9:19	48	28	4	NA	Operative time, length of stay
			percutaneous plate implantation	39:30	35.3	69	19	NA	
Xu *et al.* [25]	2021	RCS	interlocking intramedullary nails	31:59	53.3	90	NA	NA	Operative time, estimated blood loss, length of stay
			percutaneous plate implantation	13:28	55	41	NA	NA	
Al-Doori *et al.* [28]	2024	RCT	interlocking intramedullary nails	7:9	7.1	16	5	5	Operative time, estimated blood loss, healing time, excellent rate
			percutaneous plate implantation	6:10	7.8	16	5	2	
Ekwunife *et al.* [26]	2022	RCT	interlocking intramedullary nails	5:21	18–85	26	2	3	Excellent rate
			percutaneous plate implantation	11:15		26	1	5	
El-Adly *et al.* [27]	2021	RCT	interlocking intramedullary nails	3:22	7.96	25	8	1.25 ± 0.4	Operative time, estimated blood loss, fluoroscopy time, length of stay, healing time, excellent rate
			percutaneous plate implantation	7:18	8.28	25	2	0.75 ± 0.1	
Wang *et al.* [21]	2019	RCT	interlocking intramedullary nails	22:38	10.36	60	5	NA	Operative time, estimated blood loss, length of stay, healing time, Excellent rate
			percutaneous plate implantation	24:36	6.55	60	6	NA	

LLD, limb length discrepancy; NA, not available; RCS, retrospective cohort study; RCT, randomized controlled trial.

Table 2. The Newcastle-Ottawa Scale (NOS) evaluation scores for retrospective studies.

Authors	Year	Selection	Comparability	Outcome	NOS score
Allen *et al*. [17]	2018	3	2	2	7
Howard *et al*. [29]	2024	3	1	1	5
Rollo *et al*. [20]	2019	3	1	2	6
Li *et al*. [22]	2020	3	2	2	7
Meccariello *et al*. [24]	2021	4	1	2	7
Luo *et al*. [18]	2019	4	2	2	8
Milligan *et al*. [23]	2019	3	1	1	5
Ocalan *et al*. [19]	2019	3	2	1	6
Xu *et al*. [25]	2021	3	2	2	7

"intramedullary nail", "percutaneous plate implantation", "plate", and "plating" were used. Relevant articles published from the date of database construction to May 30, 2024 were searched and downloaded. For subsequent analysis, the articles were selected following the PRISMA 2020 protocol (**Supplementary Material**), with two reviewers considering and confirming the final inclusion of the papers. In case of disagreement between the two reviewers on the inclusion of the literature, a third reviewer had to confirm the inclusion. Finally, the reference lists of the included papers were manually searched to ensure the inclusion of all eligible studies.

Inclusion and Exclusion Criteria

The inclusion criteria for the literature were as follows: (1) studies targeting femoral shaft fractures; (2) intervention strategies involved interlocking medullary nailing and percutaneous plate placement; (3) retrospective studies and randomized controlled trials (RCTs); (4) studies where at least one of the post-treatment outcomes such as duration of the surgery and fluoroscopy, estimated blood loss, length of hospital stay, healing time, and excellent rating, would have been provided or calculated as the outcomes for each study. However, the exclusion criteria included (1) studies with incomplete data regarding the selected outcomes; (2) studies with single-arm trials; (3) studies with false, fake, incomplete, and unavailable data; (4) low-quality literature; (5) studies with animal subjects; (6) studies with fractures due to cancer, knee arthroplasty, or other similar causes; (7) studies published in pathology report format or treatment guideline format; (8) studies in which valid data were not extracted from published results, hindering the objective assessment of treatment efficacy.

Data Extraction and Risk of Bias Assessment

Data from all eligible trials were extracted independently by 2 reviewers and subsequently cross-checked. Study profiles (authors, year, intervention, sample size), baseline information (age, sex, study type, and complications), and mean and standard deviation (SD) of outcome indicators were extracted. The disagreement regarding the extraction of the eligible data was settled by the third independent researcher. The quality of the included studies was assessed by three independent reviewers using the Newcastle-Ottawa Scale (NOS) score for retrospective studies and the Cochrane Randomised Trial Risk of Bias Assessment for RCTs [15, 16]. The methodological quality assessment of RCTs was performed using Review Manager Software (version 5.3, Cochrane RevMan, London, UK). For each comparison, the risk of bias was examined using funnel plots where asymmetry in plotting indicates a greater risk of bias. Points outside the confidence interval indicate the presence of heterogeneity.

Statistical Analysis

Review Manager Software (version 5.3, Cochrane RevMan, London, UK) was used for meta-analysis. The extracted data were divided into subgroups based on age (adults and children) and study type (retrospective studies and RCTs). For each outcome indicator, heterogeneity analysis was performed using the results of the I^2 test. Total heterogeneity was calculated by combining the heterogeneity of subgroups. The heterogeneity with a value of $I^2 \geq 50\%$ was considered to be large and a random effects model was used for subsequent analyses. Whereas the heterogeneity with a value of $I^2 \leq 50\%$ was considered small, and a fixed-effects model was used for further analysis. The Stata Software (version 12, Stata Corp., Lakeway Drive, TX, USA) was used to perform subgroup regression analyses to analyze sources of heterogeneity. For continuous variables, if the measurement units of the outcome indicators were the same, the weighted mean difference (MD) coefficient was used as the final indicator. On the contrary, the standardized mean difference (SMD) coefficient was used as the final indicator. For dichotomous variables, odds ratio (OR) was used as the final indicator. The 95% confidence interval (CI) was used to evaluate the confidence level of the results. The difference at a p-value < 0.05 was considered statistically significant. Finally, forest plots and funnel plots were used to visualize the outcomes.

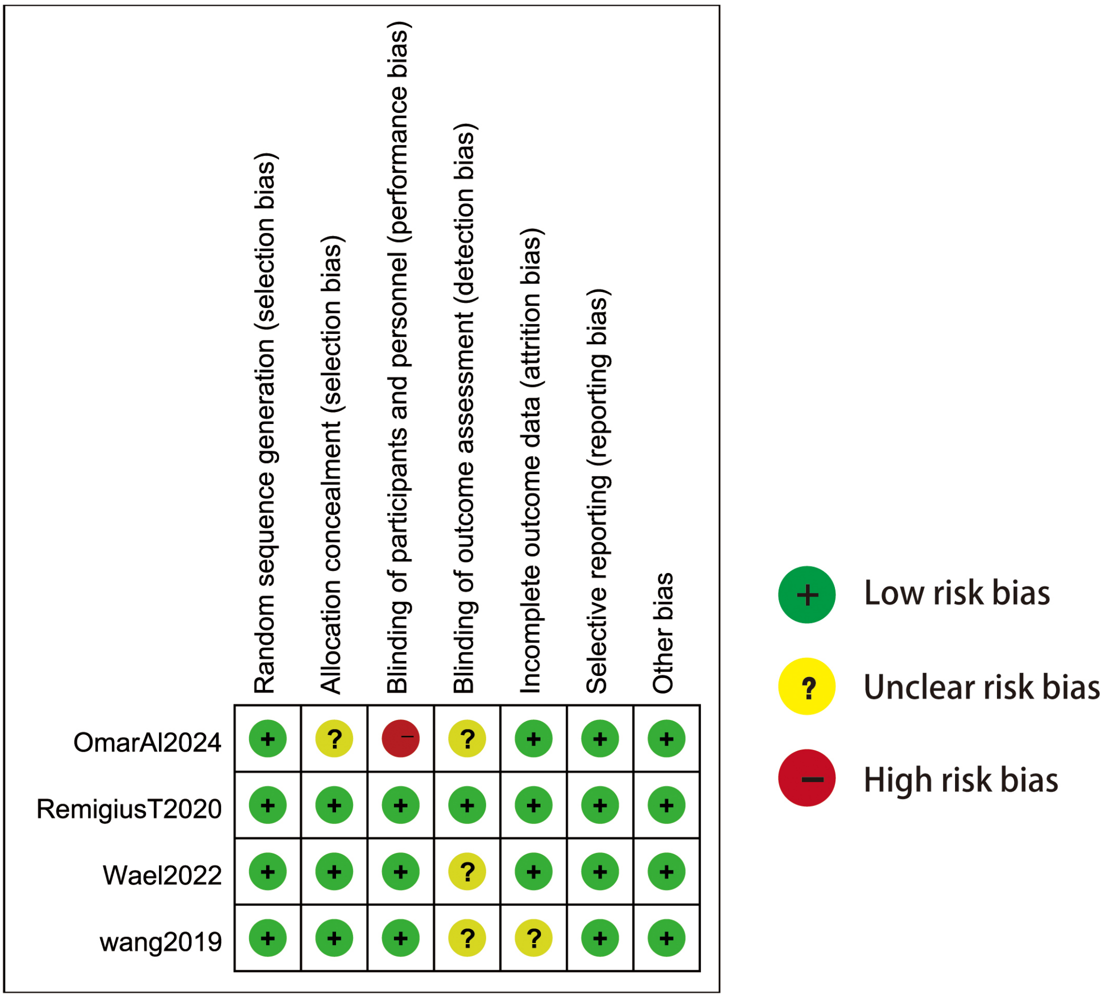

Fig. 2. A summary of bias risk assessments for included studies.

Results

Search Results

Initially, 453 studies were identified based on the search strategy. After screening based on pre-established inclusion-exclusion criteria, only 13 studies, published from 2018 to 2024, containing 1061 patients, were finally selected for this meta-analysis [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29]. The selection criteria and process are shown in Fig. 1, and the general characteristics of the included studies are summarized in Table 1 (Ref. [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29]).

Methodological Quality Assessment

Out of the 13 included studies, 9 were retrospective studies, and 4 were RCTs. The quality of retrospective studies was assessed based on selection, comparability, and outcome using the NOS score. Only 2 studies described the outcomes at the start of the study, scoring as 4 in the selection column; 5 studies described the influencing factors, scoring as 2 in the comparability column. 3 studies were able to provide only more adequate outcomes, and 6 studies were able to describe a period of follow-up, which were scored as 1 and 2, respectively. As shown in Table 2 (Ref. [17, 18, 19, 20, 22, 23, 24, 25, 29]), the final NOS scores between 6 and 7 were considered high quality. Among RCTs, 1 study did not describe the randomization method in detail or mention the double-blind setting, 2 studies had possible detection bias, and 1 did not report lost-to-follow-up, as described in Fig. 2.

Pooled Analysis of Operative Time

Operative time was counted in 10 of the included studies, with a mean difference value of –1.50 (95% confidence interval (CI): –2.31, –0.69; $p = 0.0003$; $I^2 = 95\%$). The meta-analysis found shorter operative time in the interlocking intramedullary nailing group than in the percutaneous plate placement group (Fig. 3). Similarly, variations were observed between the adults and children, with estimated effects of –0.43 (95% CI: –0.67, –0.19; $p = 0.0003$; $I^2 = 0\%$) and –2.24 (95% CI: –3.50, –0.98; $p = 0.0005$; $I^2 = 96\%$), respectively. The p-value < 0.01 was used to test the variations among subgroups (Fig. 3A). We observed difference in the retrospective studies, with an estimated effect of –

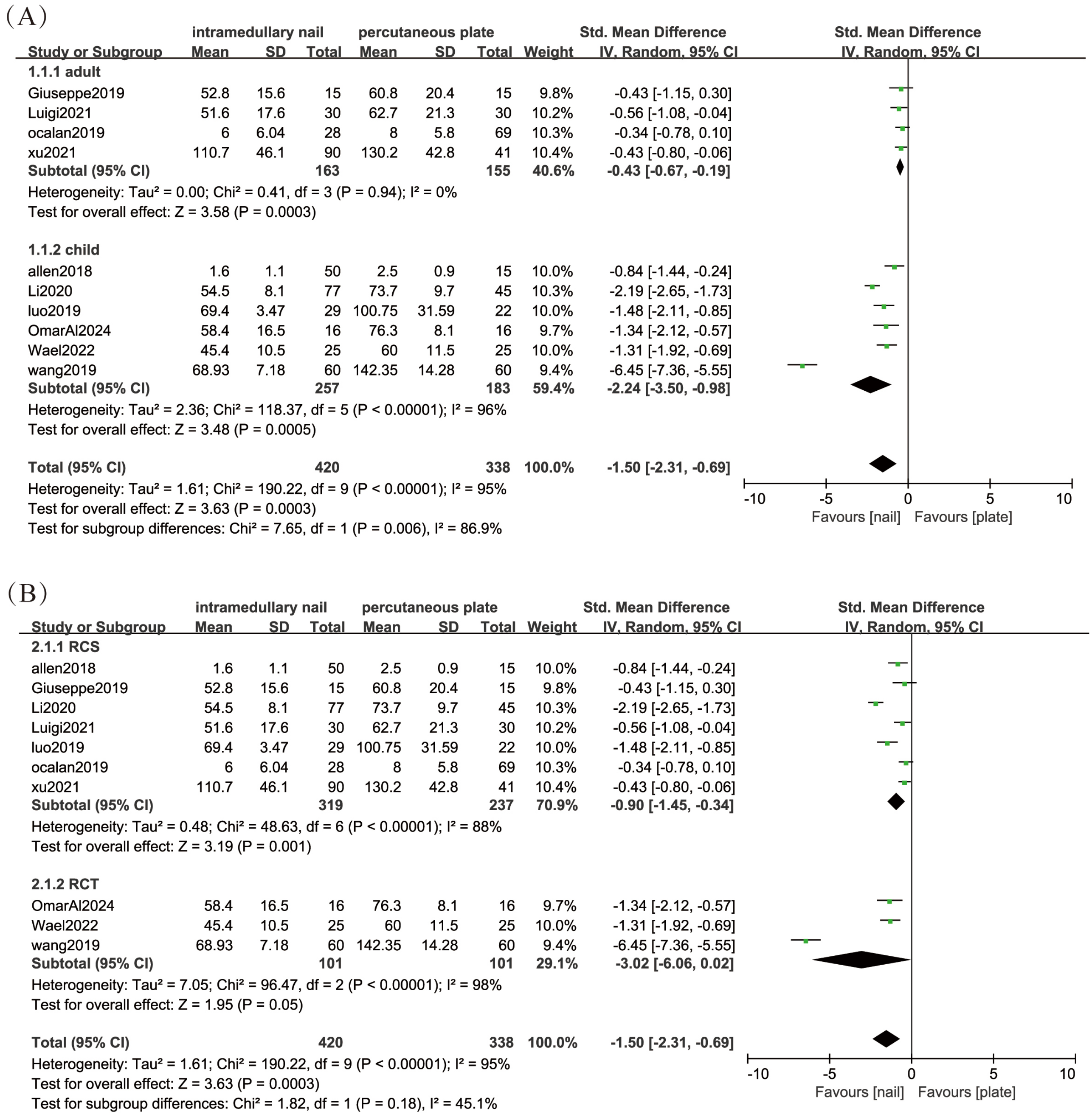

Fig. 3. Pooled analysis of operative time. (A) Variations among subgroups based on age. (B) Comparison of subgroups based on study type. RCS, retrospective cohort study; RCT, randomized controlled trial; SD, standard deviation; CI, confidence interval.

0.90 (95% CI: –1.45, –0.34; $p = 0.001$; $I^2 = 88\%$), whereas no difference was observed in the RCT, with an estimated effect of –3.02 (95% CI: –6.06, 0.02; $p = 0.05$; $I^2 = 98\%$). The test for subgroup differences was $p = 0.18$, as shown in Fig. 3B.

Pooled Analysis of Estimated Blood Loss

Estimated blood loss was counted in 9 of the included studies, with a mean difference value of –2.90 (95% CI: –4.28, –1.52; $p < 0.0001$; $I^2 = 97\%$). The meta-analysis found that the interlocking intramedullary nailing group had a lower estimated blood loss than the percutaneous plate placement group (Fig. 4). No differences were observed among the adults, with an estimated effect of –0.29 (95% CI: –0.79, 0.21, $p = 0.26$; $I^2 = 64\%$). In contrast, significant differences were observed among the children, with an estimated effect of –4.32 (95% CI: –6.32, –2.32; $p < 0.0001$; $I^2 = 97\%$). The test for subgroup differences was $p = 0.0001$, as shown in Fig. 4A. Notably, differences were observed between retrospective studies and RCTs, with estimated effects of –1.54 (95% CI: –2.66, –0.42; $p = 0.007$; $I^2 = 96\%$) and –5.62 (95% CI: –7.34, –3.91; $p < 0.00001$; $I^2 = 84\%$),

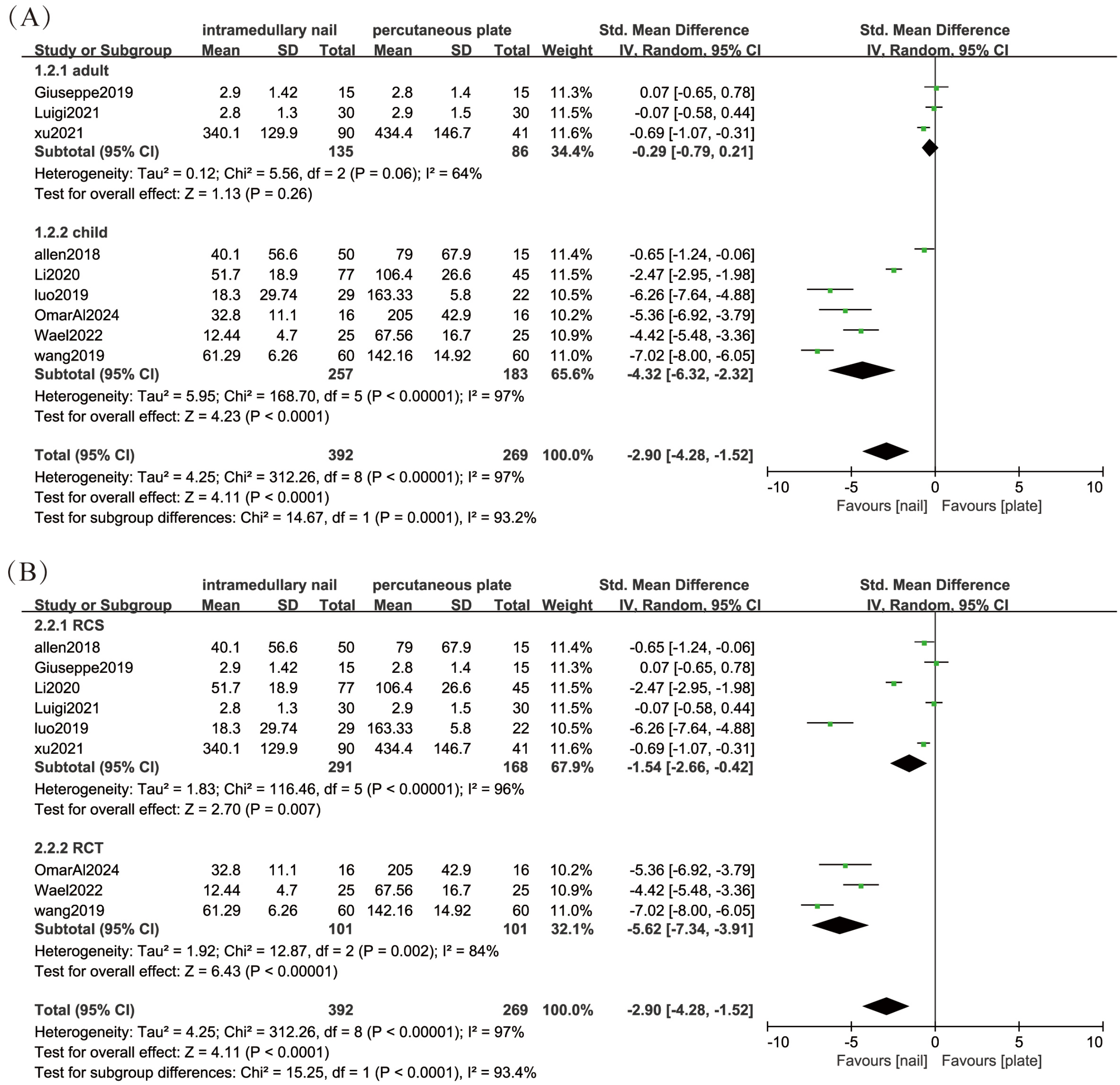

Fig. 4. Pooled analysis of estimated blood loss. (A) Variations among subgroups based on age. (B) Comparison of subgroups based on study type.

respectively. The test for subgroup differences was $p < 0.0001$, as shown in Fig. 4B.

Pooled Analysis of Fluoroscopy Time

Fluoroscopy time was reported in 3 of the included studies, of which only data from children were available. Based on the mean difference value for all studies as –0.91 (95% CI: –1.71, –0.10; $p = 0.03$; $I^2 = 22\%$), this meta-analysis found a shorter fluoroscopy time in the interlocking intramedullary nailing group compared to the percutaneous plate placement group (Fig. 5). However, differences were observed between retrospective studies and RCTs, with estimated effects of –0.80 (95% CI: –1.62, 0.02; $p = 0.06$; $I^2 = 0\%$) and –5.00 (95% CI: –10.07, 0.07; $p = 0.05$), respectively. The test for subgroup differences was $p = 0.11$, as shown in Fig. 5B.

Pooled Analysis of Length of Stay

Length of hospital stay was calculated in 9 of the included studies, with a mean difference value of –1.72 (95% CI: –4.51, 1.06; $p = 0.22$; $I^2 = 100\%$). Consequently, this meta-analysis found no significant difference in the length of hospital stay between the two groups (Fig. 6). Additionally, no differences were observed between adults and children, with estimated effects of –0.65 (95% CI: –1.81, 0.51, $p = 0.27$; $I^2 = 0\%$) and –2.25 (95% CI: –5.56, 1.07; $p = 0.18$;

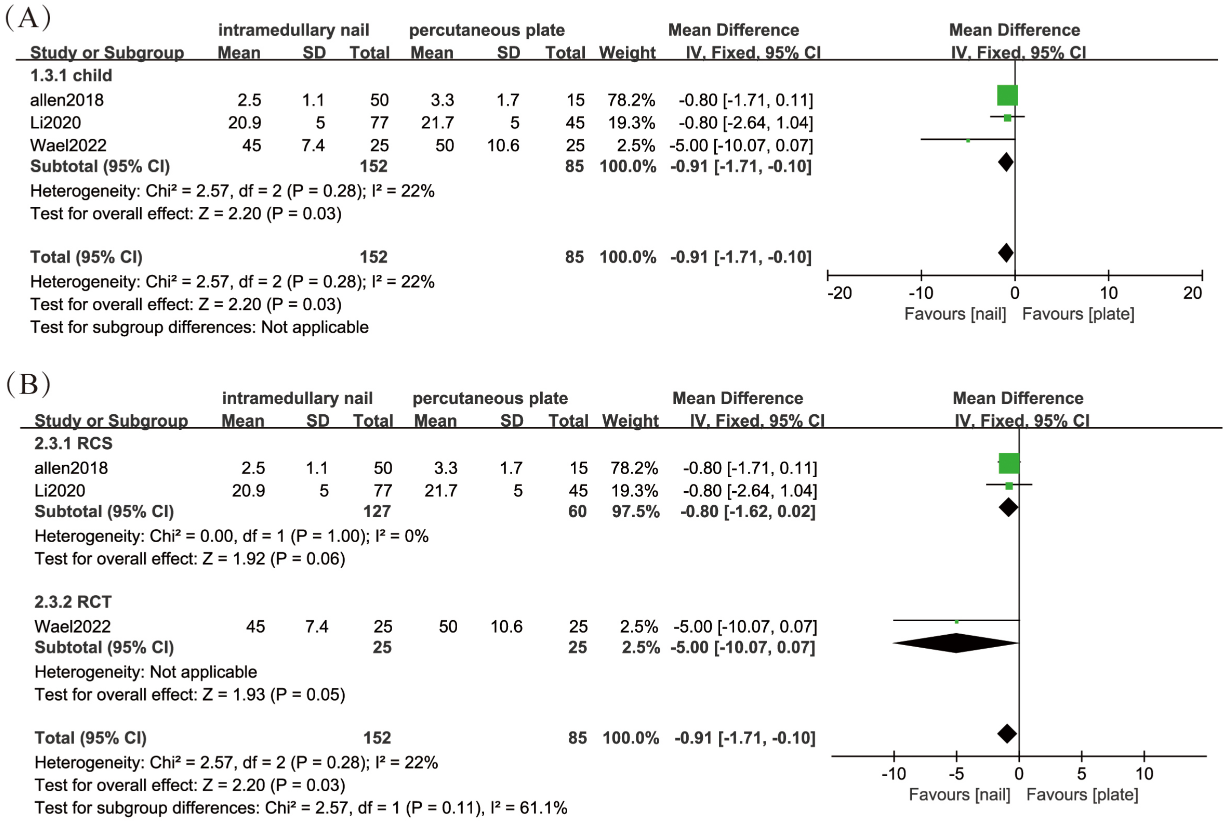

Fig. 5. Pooled analysis of fluoroscopy time. (A) Differences between subgroups based on age. (B) Comparison of fluoroscopy time between subgroups based on study type.

I^2 = 100%), respectively. The test for subgroup differences was $p = 0.37$, as shown in Fig. 6A. And no differences were observed between retrospective studies and RCTs, with estimated effects of –0.67 (95% CI: –2.00, 0.65, $p = 0.32$; I^2 = 72%) and –4.33 (95% CI: –12.48, 3.81; $p = 0.30$; I^2 = 100%), respectively. The test for subgroup differences was $p = 0.38$, as shown in Fig. 6B.

Pooled Analysis of Healing Time

Healing time was counted in 6 of the included studies, with a mean difference value of –0.92 (95% CI: –1.92, 0.08; $p = 0.07$; I^2 = 94%). This meta-analysis found no significant difference in the comparison of healing time between the two groups (Fig. 7). Similarly, no differences were observed among adults, with an estimated effect of 0.03 (95% CI: –0.38, 0.44, $p = 0.88$; I^2 = 0%). However, a significant difference was observed among children, with an estimated effect of –1.39 (95% CI: –2.70, –0.08; $p = 0.04$; I^2 = 95%). The test for subgroup differences was $p = 0.04$, as shown in Fig. 7A. Furthermore, the retrospective studies showed no significant differences, with an estimated effect of –0.08 (95% CI: –0.41, 0.25; $p = 0.63$; I^2 = 0%). However, there were significant differences in the RCT, with an estimated effect of –1.76 (95% CI: –3.36, –0.16; $p = 0.03$; I^2 = 95%). As shown in Fig. 7B, the test for subgroup differences was $p = 0.04$.

Pooled Analysis of Excellent Rate

Excellent rate was counted in 6 of the included studies, with a mean difference value of 1.20 (95% CI: 0.41, 3.54; $p = 0.74$; I^2 = 57%) across all studies. The meta-analysis found no significant difference in the comparison of the excellent rates of recovery between the two groups (Fig. 8). Similarly, no differences were observed between adults and children, with estimated effects of 1.62 (95% CI: 0.53, 4.95, $p = 0.40$) and 1.19 (95% CI: 0.28, 5.12; $p = 0.82$; I^2 = 64%), respectively. The test for subgroup differences had $p = 0.74$, as shown in Fig. 8A. Additionally, no differences were observed between retrospective studies and RCTs, with estimated effects of 0.67 (95% CI: 0.08, 5.97, $p = 0.72$; I^2 = 46%) and 1.55 (95% CI: 0.41, 5.84; $p = 0.51$; I^2 = 62%), respectively. The test for subgroup differences had $p = 0.52$, as shown in Fig. 8B.

Reporting Bias

The outcomes from more than 3 studies were pooled and plotted in inverted funnel plots. These funnel plots were free of missing corners, suggesting that there may be no publication bias. Ideally, the distribution of outcomes should be balanced on both sides of the null line and within the 95% confidence interval. However, in this analysis, only the scatters of operative time and excellent rate fell mostly within the confidence interval, suggesting that these

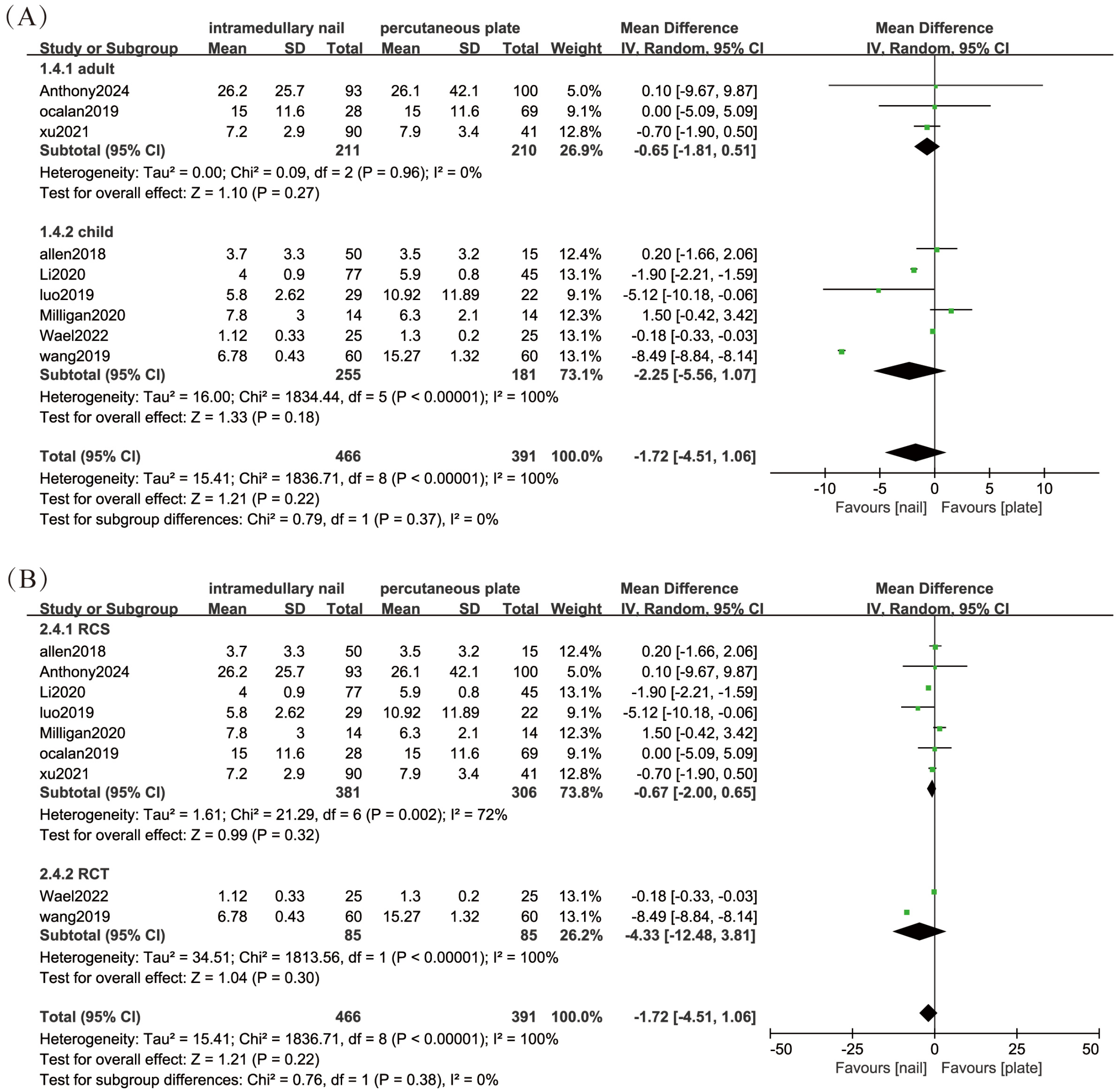

Fig. 6. Pooled analysis of length of stay. (A) Differences between subgroups based on age. (B) Comparison of subgroups based on study type.

outcomes are highly heterogeneous and consistent with the previous results (Fig. 9).

Heterogeneity

Subgroup regression analyses were used to explore sources of heterogeneity for outcomes that were highly heterogeneous and included more than 5 studies. Previous subgroup analyses were based on two factors, age and study type. Here, two additional subgroup factors of sample size (sample size >30 and sample size ≤30) and geographic region (America, China, West Asia, Europe and Africa) were added.

The outcomes of operative time, estimated blood loss, length of stay, and healing time showed no significant reduction in their heterogeneity for the 4 subgroup factors (Fig. 10 and Table 3). However, for the operative time, certain subgroups showed significantly lower heterogeneity. The I^2 within the ADULT group was 0%, whereas, the I^2 within the CHILD group was 96%, indicating that the heterogeneity of the adult group was significantly lower than that of the CHILD group (Fig. 3A).

For the excellence rate, age and study type showed slightly reduced heterogeneity, whereas geographic region and sample size showed a significant reduction in the heterogeneity (I^2 = 0%) (Figs. 8,10), suggesting the potential im-

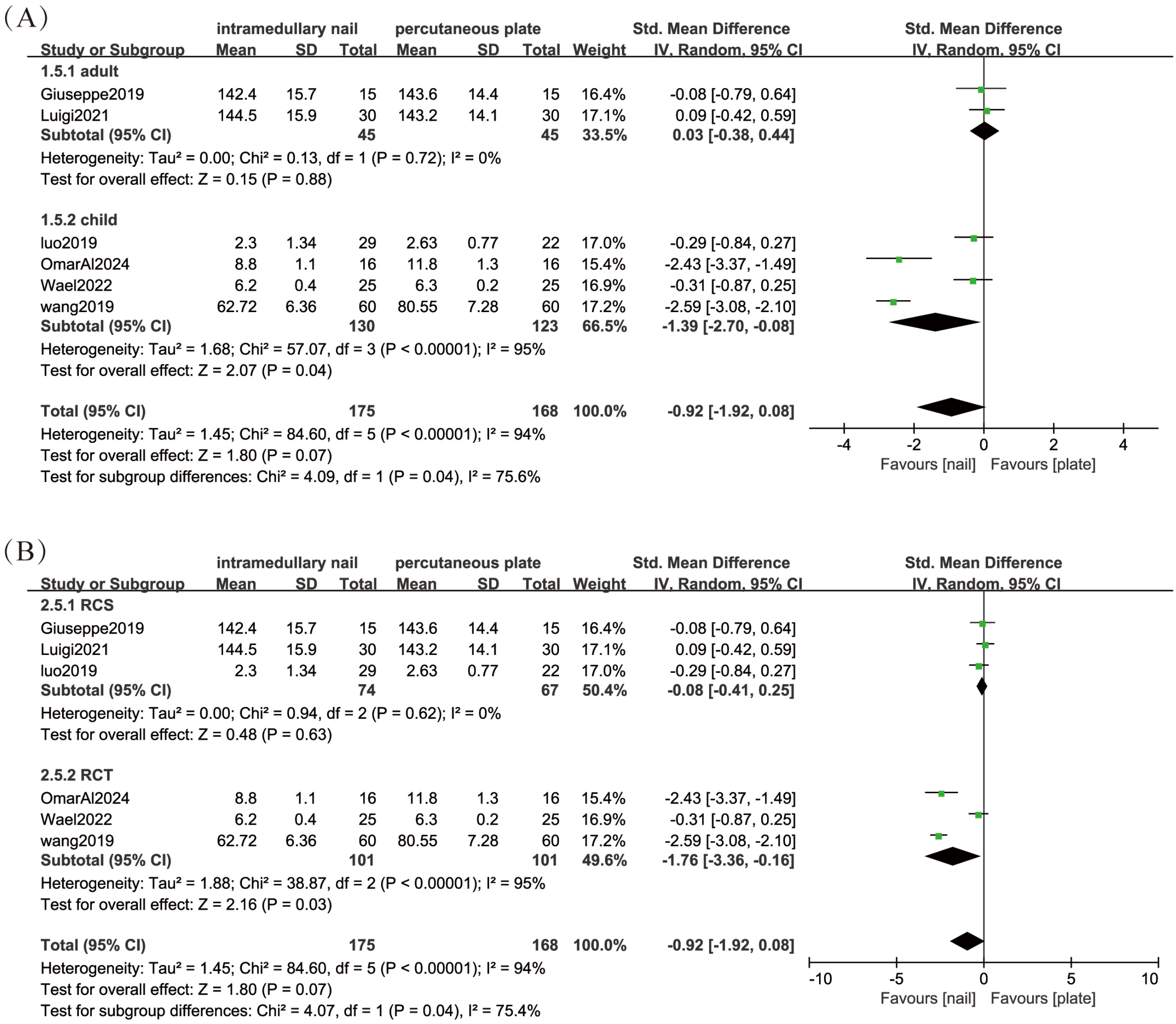

Fig. 7. Pooled analysis of healing time. (A) Variations among subgroups based on age. (B) Comparison of subgroups based on study type.

pacts of age, geographic region, study type, and sample size on the heterogeneity in the excellence rate of recovery in patients with femur shaft fracture.

Sensitivity Analysis

Sensitivity analyses were performed separately on the data from each outcome indicator, as shown in Fig. 11. After excluding the literature one by one, the combined results from the remaining data were consistent with the results of the original forest plot analysis, indicating the reliability and robustness of the meta-analysis findings. However, for fluoroscopy time, after excluding the data from Allen *et al*. [17] and El-Adly *et al*. [27] one by one, the combined results from the remaining literature were inconsistent with the original forest plot analysis, indicating that the findings of the meta-analysis were not robust.

Discussion

Interlocking Intramedullary Nailing Therapy has Shorter Operative Time and Less Blood Loss

Meta-analyses of RCTs are generally considered the most convincing evidence for comprehensive assessment of clinical interventions. In practice, however, researchers often need longer time and larger financial support to collect and observe patients' data in larger sample sizes [30]. In the current meta-analysis, the included 9 retrospective studies initially provided reasonable selectivity of the study population and ensured comparability and objective completeness of the outcomes. Among the 4 included RCTs, three described the randomization methodology in detail. However, descriptions of loss to follow-up were missing, which could be a moderate bias.

This meta-analysis revealed that interlocking intramedullary nailing had shorter operative time for

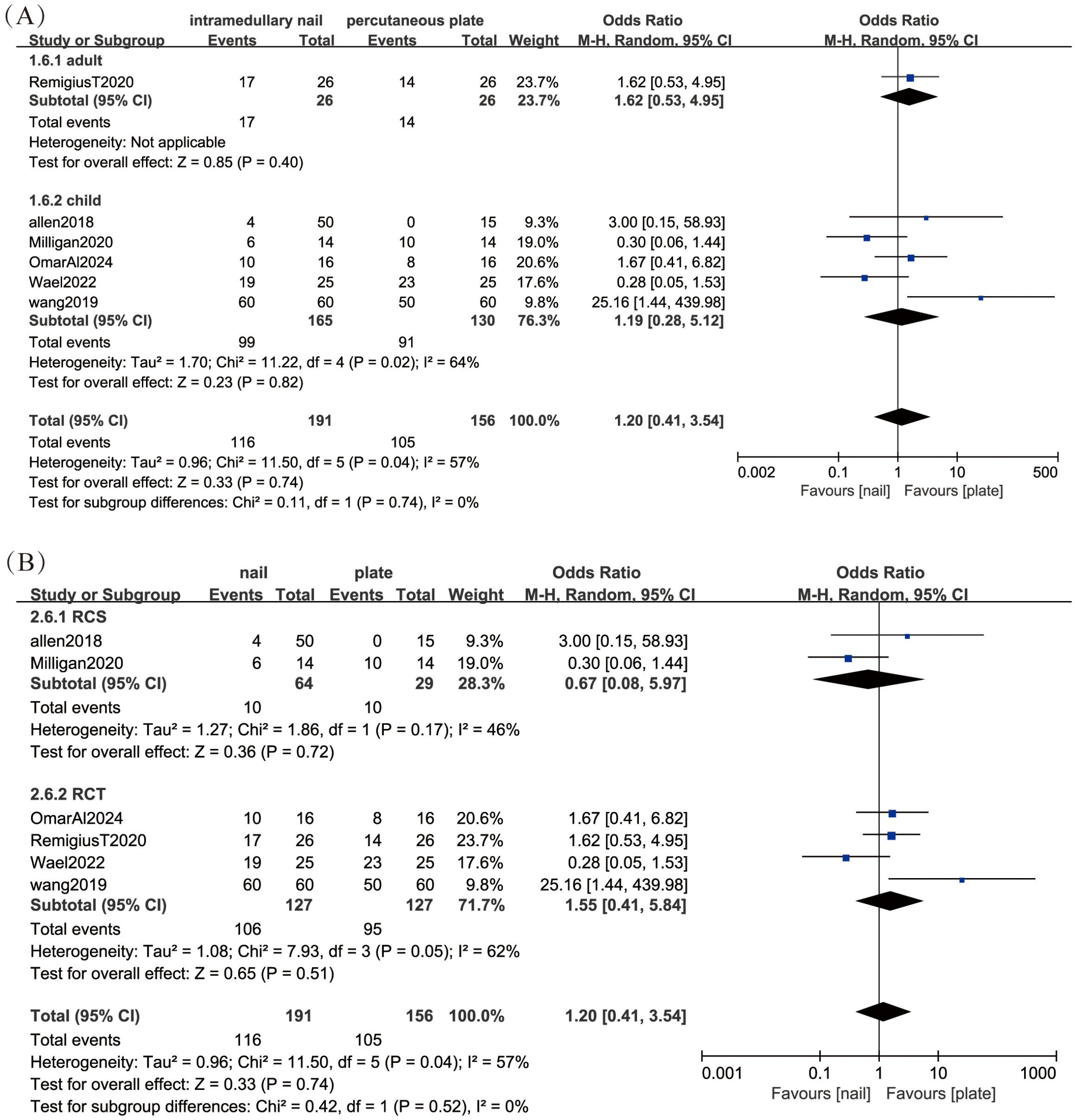

Fig. 8. Pooled analysis of excellent rate. (A) Variations among subgroups based on age. (B) Comparison of subgroups based on study type.

fractures, shorter fluoroscopy time, and reduced estimated blood loss compared to percutaneous plate implantation. However, regarding length of stay, healing time, and excellence rate of patient healing, there was no significant difference between the two groups. By observing the forest map of blood loss, the current study identified that all clinical studies on children showed less blood loss in the intramedullary nail group. Additionally, Li *et al*. [22] and Chen *et al*. [31] found that the blood loss after removing internal fixation materials was reduced in intramedullary nail therapy compared to that in plate therapy. Theoretically, interlocking intramedullary nails have the advantage of less soft tissue and vascular disruption and are more biomechanically stable. Therefore, patients may experience better and faster fracture healing, reduced infections and complications, shorter operative time, and reduced blood loss [32, 33]. However, the findings of the current study do not seem to support the conclusion that interlocking intramedullary nailing is significantly superior to percutaneous plate placement in all aspects of treating femoral shaft fractures. It is obvious that percutaneous plate placement treating femoral shaft fractures has its clinical advantages [34]. In fact, the controversy between the two treatments remains inconclusive.

Reduced Blood Loss in Children in the Interlocking Intramedullary Nailing Group

Due to the immature skeletal development of younger patients, their femoral anatomy and blood supply are differ-

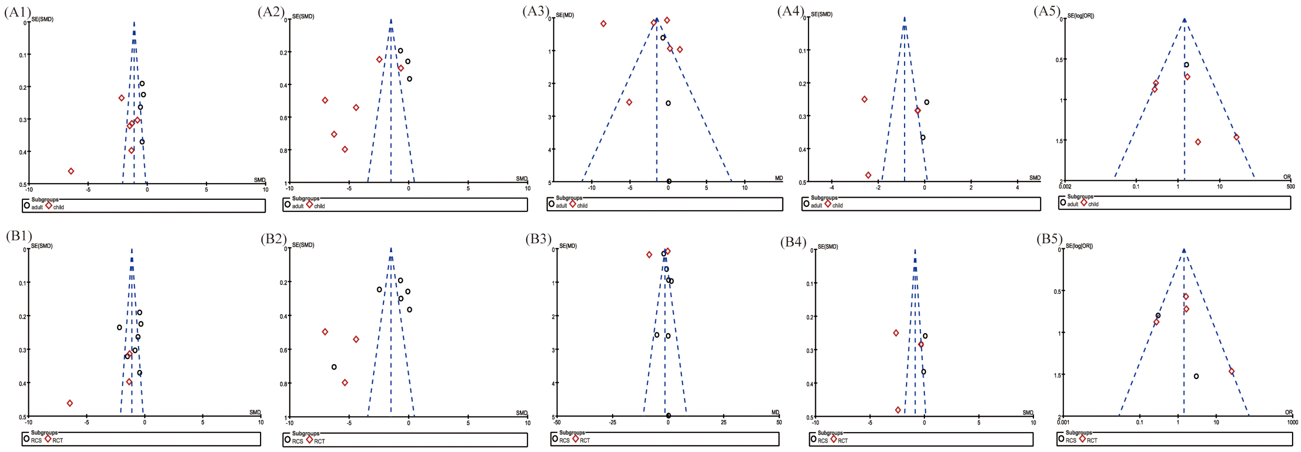

Fig. 9. Inverted funnel chart of all outcomes. (A) Funnel plot for subgroups of adults and children. (A1) Operation time: divided subgroups based on age. (A2) Estimated blood loss: divided subgroups based on age. (A3) Length of stay: divided subgroups based on age. (A4) Healing time: divided subgroups based on age. (A5) Excellent rate: divided subgroups based on age. (B) Funnel plot for subgroups of RCS and RCT. (B1) Operation time: divided subgroups based on study type. (B2) Estimated blood loss: divided subgroups based on study type. (B3) Length of stay: divided subgroups based on study type. (B4) Healing time: divided subgroups based on study type. (B5) Excellent rate: divided subgroups based on study type.

ent from those of adult patients. Therefore, greater attention should be given to the impact of intraoperative blood loss on fracture healing in children during clinical treatment [35]. After comparing each outcome in the subgroups of adults and children, it was identified that the findings of the subgroups were consistent with the results of the pooled data. However, regarding estimating blood loss and healing time, children demonstrated significant differences between the two treatment options, supporting the choice of using the interlocking intramedullary nailing to reduce blood loss and promote faster healing. These results suggest that in children with femoral shaft fractures, the risk of excessive blood loss and the impact of longer healing time on life quality require extensive clinical considerations regarding care and management [36]. Conversely, in adult patients, selecting an appropriate treatment method between interlocking intramedullary nailing and percutaneous plate implantation depends on considering fewer clinical factors, as both techniques are associated with better recovery in adults [37]. Based on the findings of this study, it is recommended to prioritize the use of interlocking intramedullary nailing therapy in clinical practice, particularly in children with femoral shaft fractures.

The Differences between Retrospective Studies and RCTs Have Been Insignificant

Various outcomes in the retrospective studies and RCT subgroups were compared and interpreted [38]. For the retrospective studies, interlocking intramedullary nailing for femoral shaft fractures showed shorter operative time and reduced blood loss compared to percutaneous plate placement. For the RCTs, interlocking intramedullary nailing for femoral shaft fractures was associated with reduced blood loss and shorter healing time compared to percutaneous plate placement. Additionally, only three of the overall included studies calculated the fluoroscopy time and it showed that although the interlocking intramedullary nailing group showed shorter fluoroscopy time, there was no significant difference between the retrospective and RCT studies.

Furthermore, there was no significant difference between the two groups in terms of length of the stay and healing time of the patients in the various retrospective studies. However, in the RCT studies, the intramedullary nailing group showed a shorter length of stay and healing time. This observation suggests that we should include more RCT studies to enhance the scientific validity and objectivity of the findings.

Limitations

This study compared the outcomes of using interlocking intramedullary nailing and percutaneous plate placement in adult and pediatric patients with femoral shaft fractures. Only 4 of the included studies were RCTs, and the remaining 9 were retrospective studies, which somewhat limited our ability to draw conclusions more objectively. The sample size for assessing the fluoroscopy time was also very small, which was covered by only three studies. Interestingly, the exclusion of only one study during sensitivity analysis led to the opposite results. Efforts were made to address the heterogeneity, but some heterogeneity was inherent and unavoidable for the meta-analysis. To dissipate these effects, we added sensitivity analyses and found that most of the outcomes were more robust. In addition, due to language and search tool limitations, we may have missed some information on published or unpublished studies.

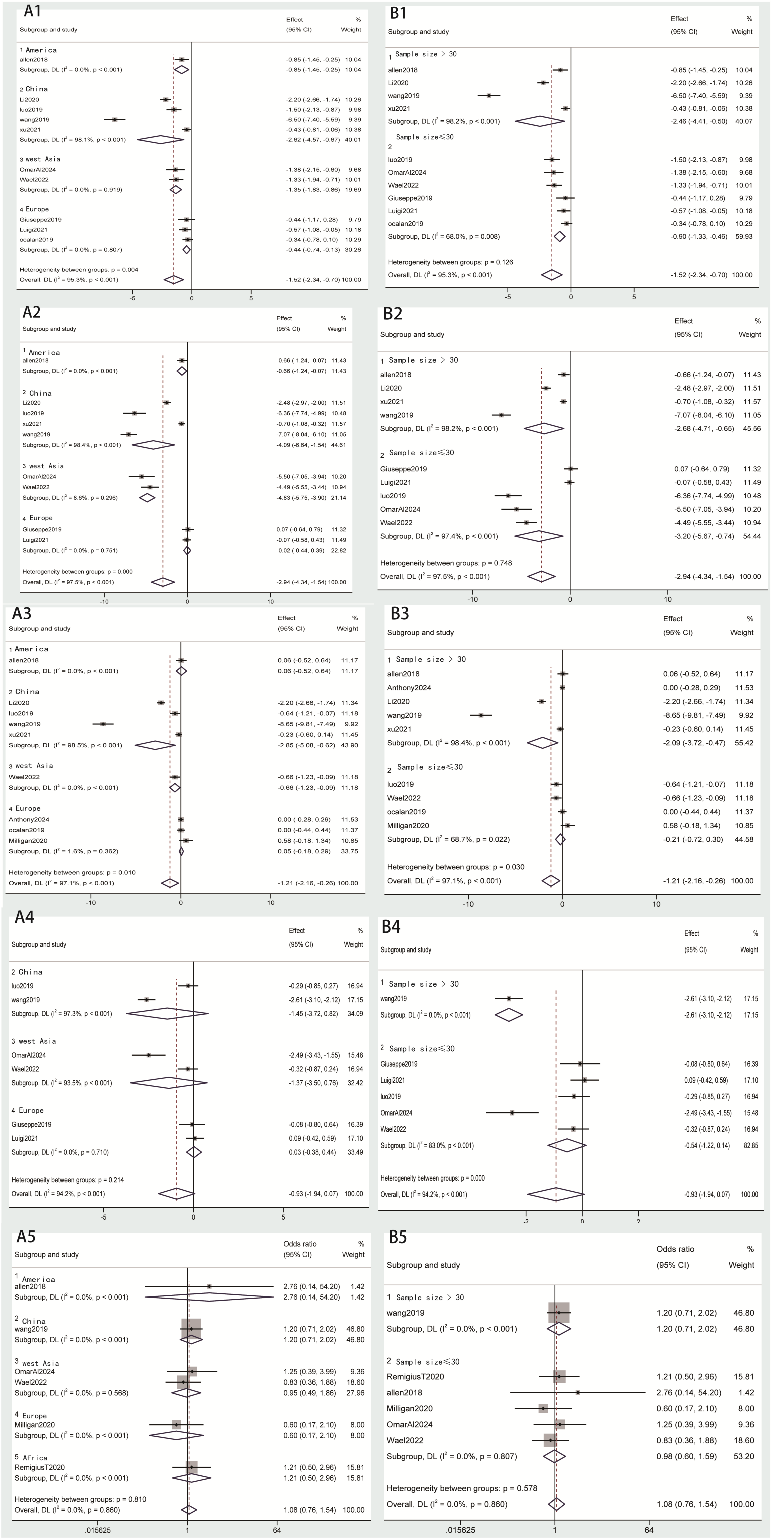

Fig. 10. Heterogeneity analyses. (A) Geographic region. (A1) Operation time: divided subgroups based on geographic region. (A2) Estimated blood loss: divided subgroups based on geographic region. (A3) Length of stay: divided subgroups based on geographic region. (A4) Healing time: divided subgroups based on geographic region. (A5) Excellent rate: divided subgroups based on geographic region. (B) Sample size. (B1) Operation time: divided subgroups based on sample size. (B2) Estimated blood loss: divided subgroups based on sample size. (B3) Length of stay: divided subgroups based on sample size. (B4) Healing time: divided subgroups based on sample size. (B5) Excellent rate: divided subgroups based on sample size.

Table 3. Subgroup regression analysis of heterogeneities.

	Grouping factors	t	p (reg)	95% CI
Operative time	age	1.73	0.123	(–0.61, 4.25)
	study type	–1.93	0.089	(–4.66, 0.41)
	sample size	1.36	0.210	(–1.05, 4.10)
	geographic region	1.09	0.308	(–0.69, 1.91)
Estimated blood loss	age	1.60	0.155	(–1.42, 7.30)
	study type	–2.64	0.033	(–7.70, –0.42)
	sample size	–0.25	0.810	(–5.32, 4.30)
	geographic region	0.69	0.515	(–1.72, 3.12)
Length of stay	age	0.90	0.40	(–2.97, 6.59)
	study type	–2.29	0.056	(–8.54, 0.13)
	sample size	1.05	0.330	(–2.48, 6.43)
	geographic region	0.90	0.40	(–1.33, 2.95)
Healing time	age	1.44	0.222	(–1.30, 4.11)
	study type	–2.20	0.092	(–3.80, 0.44)
	sample size	1.88	0.134	(–0.98, 5.06)
	geographic region	1.25	0.280	(–0.89, 2.35)
Excellent rate	age	0.29	0.789	(–1.24, 1.52)
	study type	0.63	0.561	(–1.33, 2.11)
	sample size	–0.56	0.608	(–1.21, 0.81)
	geographic region	–0.43	0.690	(–0.52, 0.38)

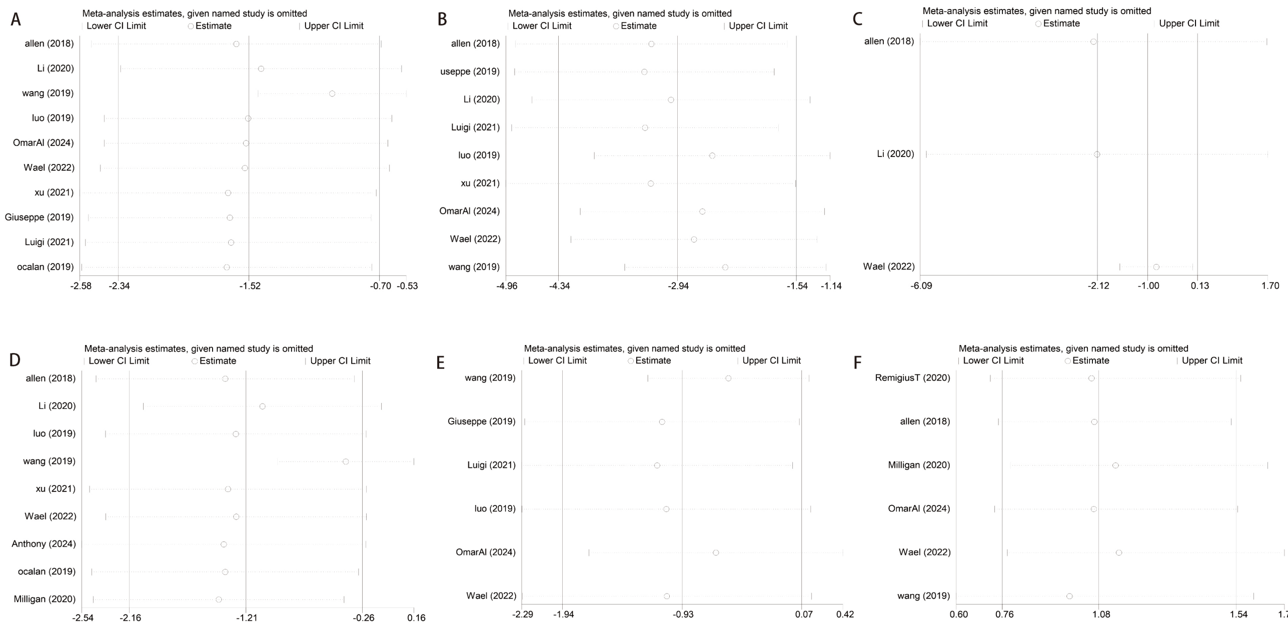

Fig. 11. Sensitivity analysis using the one-by-one elimination method. (A) Operative time. (B) Estimated blood loss. (C) Fluoroscopy time. (D) Length of stay. (E) Healing time. (F) Excellent rate.

Conclusions

This review compares the efficacy of interlocking intramedullary nailing and percutaneous plate placement for treating femoral shaft fractures. They are preliminarily examined from three perspectives: overall, adult, and child populations. Retrospective and RCT studies are included to assess the differences in operative time, estimated blood loss, fluoroscopy time, length of stay, healing time, and excellence rate. Interlocking intramedullary nailing is more advantageous for treating femoral shaft fractures with shorter operative time, shorter fluoroscopy time, and reduced blood loss. More RCTs with large sample sizes are needed in the future to explore and confirm the conclusions of this review.

Availability of Data and Materials

The data used in this study were obtained from published papers, and the analyzed datasets generated during the study are available upon request from the corresponding author.

Author Contributions

Substantial contributions to conception and design: YMN. Data acquisition, data analysis, and interpretation: YMN, YLZ, JR. Data validation and visualization: YMN, YLZ, JR. Drafting the article: YMN. Revised the manuscript critically for important intellectual content: All authors. Final approval of the version to be published: All authors. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of the work are appropriately investigated and resolved: All authors.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.62713/aic.3577.

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