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REVIEW

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Efficacy and safety of three-dimensional printing technology assisted open reduction and internal fixation versus conventional surgery in the treatment of acetabular fractures: a meta-analysis of randomized controlled trials

Wenzheng Liu[1,2,3†], Chaoyi Zhang[1,2,3†], Jixi Liu[1,2†], Pengrui Feng[1,2,3], Ping Yi[4*], Zhencheng Xiong[5*] and Guanglin Wang[1,2,3*]

Abstract

Purpose The objective of this meta-analysis was to assess the influence of three-dimensional (3D) printing technology on open reduction and internal fixation (ORIF) of acetabular fractures from current randomized controlled trials (RCTs).

Methods A structured meta-analysis was conducted, and we searched online databases for published RCTs related to 3D printing and acetabular fracture, including PubMed, Cochrane Library, ScienceDirect, Wan fang, and CNKI up to November 2024. The outcome data of intraoperative blood loss, operation time, hip function (Harris score), quality of fracture reduction (Matta score) and incidence of complications were extracted. Stata16.0 and RevMan5.3 were used for our meta-analysis.

Results 19 RCTs met our inclusion criteria and a total of 1046 patients were included in this meta-analysis. The meta-analysis showed significant difference in intraoperative blood loss (WMD = -274.65, 95% CI [-326.47, -222.83]), operation time (WMD = -53.26, 95% CI [-63.72, -42.80]), intraoperative fluoroscopy (WMD = -5.24, 95% CI [-6.57, -3.91]), instrumentation time (WMD = -35.31, 95% CI [-53.42, -17.21]), and post-surgery Matta score (RR = 1.17, 95% CI [1.09,

†Wenzheng Liu, Chaoyi Zhang and Jixi Liu contributed equally to this work.

*Correspondence:
Ping Yi
13811758985@139.com
Zhencheng Xiong
xiongzc0527@163.com
Guanglin Wang
wgllfrank@163.com

Full list of author information is available at the end of the article

1.25]), incidence rate of complications (RR = 0.34, 95%CI [0.22, 0.52]). There is no significant difference in time from injury to operation (WMD=-0.06, 95%CI [-0.36, 0.24]) and Harris score (RR = 1.22, 95%CI [0.83, 1.79]) between two groups.

Conclusion 3D printing group showed reduced intraoperative blood loss, shorter operation time, faster instrumentation, less intraoperative fluoroscopy, better post-surgery reduction, and reduced incidence rate of complications. Therefore, based on existing research, ORIF guided by 3D printing technology should be a more effective method for treating acetabular fractures.

Keywords 3D printing technology, Acetabular fractures, Open reduction and internal fixation, Intraoperative blood loss, Complications, Meta-analysis

Introduction

The incidence rate of pelvic and acetabular fracture is concerning with the aging population and increasing traffic accident [1, 2]. Elderly patients usually suffer low-energy injuries, with forces on the landing side transmitted through the greater trochanter and femoral head to the anterior medial acetabulum [3]. These patients must be distinguished from younger patients, in whom the most common mechanism of acetabular fracture is high-energy trauma [4]. Fractures involving articular surface require anatomical reduction to maintain proper joint function and prevent post-traumatic arthritis. Therefore, open reduction and internal fixation (ORIF) are recommended by Letournel and Judet as the preferred treatment for displaced acetabular fracture [5]. Due to the complexity of anatomical structures and morphology, proximity to important nerves and blood vessels, high surgical difficulty, the management of acetabular fractures poses significant challenges in clinical practice, even for the most experienced surgeons. Conventional surgery mainly relies on X-ray, CT and doctor's experience to achieve preoperative planning and intraoperative navigation. Such approaches, however, have failed to access the precise anatomical structure before surgery, which reducing the accuracy of fracture reduction, increasing the operation time, intraoperative bleeding and affecting the perioperative outcome [6].

Three-dimensional (3D) printing technology stands as the one of the most efficient and vital technologies in medical application over the past two decades, particularly in orthopedics [7, 8]. 3D printing of personalized pelvic and acetabular model enables orthopedic specialists to create anatomically accurate models for preoperative planning and customize implants to match the specific anatomy of a patient or the details of an injury. Through 3D printed models, surgeons can simulate surgeries in advance, determining surgical approaches, reduction techniques and screw placement locations, thus avoiding repeated shaping of plates, drilling, stripping of periosteum and surrounding soft tissues during surgery. The application of 3D printing technology has yielded encouraging results in the relevant literature, which have shown that 3D printing technology assisted ORIF may reduce operation time and intraoperation blood loss, better reduction quality and hip function [9]. While previous studies have explored the impact of 3D printing technology on acetabular fracture treatment, no consistent conclusions have been drawn [10].

Currently, there is no definitive conclusion regarding the efficacy of using 3D printing technology to assist in ORIF treatment for acetabular fractures, and further exploration is still needed [11]. Although several researches have investigated the efficacy of using three-dimensional printing to assist in ORIF treatment for fracture management, comprehensive evaluation of meta-analysis focusing on acetabular fractures is still lacking [12–14]. By collecting and analyzing published RCTs, we conducted this meta-analysis aiming to investigate whether 3D printing technology-assisted ORIF shows significant clinical superiority over traditional surgical treatment and provide evidence-based proof for the treatment of acetabular fractures.

Materials and methods

This meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines [15]. We did not perform ethical approval because Meta-analysis extracted data from published papers.

Search method

To obtain all relevant research on the study topic, two researchers conducted searches independently, including PubMed (1966 to November 1, 2024), Cochrane library (1966 to November 1, 2024), ScienceDirect (1990 to November 1, 2024), Wanfang Database (1990 to November 1, 2024), and CNKI (1990 to November 1, 2024), following the Cochrane Collaboration guidelines. Database searches were performed using "AND or OR" to combine MeSH terms with keywords, including "acetabular fracture", "acetabulum fracture", "three-dimensional", "three dimensional", "3-dimensional", "3 dimensional", and "3D". All retrieved literature was independently screened by two researchers, evaluating each title and abstract, followed by reading the full texts and references, in order to identify all potential studies that meet the inclusion criteria. We have no restrictions on the types of languages and magazines in which literature can be distributed. Potentially relevant literature was searched from the references of the included studies. Finally, the relevant literature was further screened by reading the full text. Controversial literature was resolved after group discussion.

Selection criteria

Screening of all retrieved articles was performed according to the inclusion and exclusion criteria developed for the topics of this meta-analysis. Inclusion criteria included: (1) The experimental group received ORIF treatment assisted by 3D printing technology, while the control group underwent conventional surgical treatment; (2) Only studies examining at least one main outcome were included; (3) all included studies were randomized controlled trials (RCTs); and (4) data relevant to the outcome measures could be successfully extracted. Exclusion criteria included (1) studies lacking a control group that met the inclusion criteria; (2) relevant data for the outcome measures could not be extracted; (3) the type of study was a review, conference abstract, commentary, cadaver study, case report, letter; and (4) all studies that did not meet the inclusion criteria.

Data extraction

Two researchers independently complete the extraction of the required data, and then another researcher summarizes the above data and resolves the divergent data after discussion within the research team. Of the data extracted in this meta-analysis, blood loss and operation time were the primary outcome measurement, while Matta score, Harris score, times of intraoperative fluoroscopy, instrumentation time, time from injury to operation, complication were secondary outcome measurements. The following data were also extracted: first author, year of publication, study design, sample characteristics (Number of participants, age, country/region, body mass index, gender).

Quality assessment

The Cochrane Handbook of Systematic Reviews is a standard tool for assessing the quality of RCTs in meta-analysis [16]. Two researchers evaluated each RCT using a "risk of bias" table that includes seven key elements: randomized sequence generation, allocation concealment, selective reporting, blinding of participants and personnel, blinding of outcome detection, incomplete outcome data, and other biases. Each element was rated as high risk, low risk, or unclear risk of bias.

Statistical analysis

Statistical analysis was conducted with Stata software (version 16.0) and RevMan 5.3. Effect values were expressed as weighted mean difference (WMD) and 95% confidence interval (CI) for continuous outcomes and as risk ratio (RR) and 95% CI for dichotomous outcomes. Random-effects model was applied when heterogeneity was statistically significant ($P \leq 0.1$, $I^2 > 50\%$), with subgroup analyses and meta-regression conducted for factors that might contribute to heterogeneity. A fixed-effects model was applied when heterogeneity was not detected ($P > 0.1$, $I^2 \leq 50\%$). To assess the strength and stability of the pooled results, we conducted a sensitivity analysis by sequentially omitting individual studies. Additionally, publication bias was evaluated using Begg's test and Egger's test. P-value < 0.05 was considered a statistically significant difference.

Results

Search results for literature

Based on the search strategy, a total of 2739 potentially eligible articles were identified, including PubMed ($n = 521$), ScienceDirect ($n = 1443$), Cochrane Library ($n = 69$), Wanfang database ($n = 277$) and CNKI ($n = 1268$). After careful independent screening of titles and abstracts, along with a brief review of the full text by two researchers, 2672 articles were excluded. Subsequently, the full text of the remaining 67 articles underwent detailed evaluation based on the predefined inclusion and exclusion criteria, 48 studies were excluded. In total, 19 RCTs were included in the meta-analysis (Fig. 1) [17–35].

Study characteristics

A total of 19 RCTs, all published between 2017 and 2022, were included in this meta-analysis [17–35]. These studies involved 1046 patients, with 515 in the 3D printing-assisted ORIF group and 531 in the conventional group. The average age of the patients was over 30 years. Image processing was performed using Materialise Mimics in all studies except for two, which did not report the software used. All included studies investigated the intraoperative blood loss and operation time as the primary outcome. A variety of assessment tools were employed to measure the secondary outcome of surgeries, including the Matta score, Harris score, times of intraoperation fluoroscopy, instrumentation time, and the time from injury to operation. Among these, 10 studies reported complications associated with acetabular fracture, including traumatic arthritis, heterotopic ossification, femoral nerve dysfunction and infection [17, 18, 20, 25, 27, 28, 32–35]. The characteristics of all included studies are listed in Table 1.

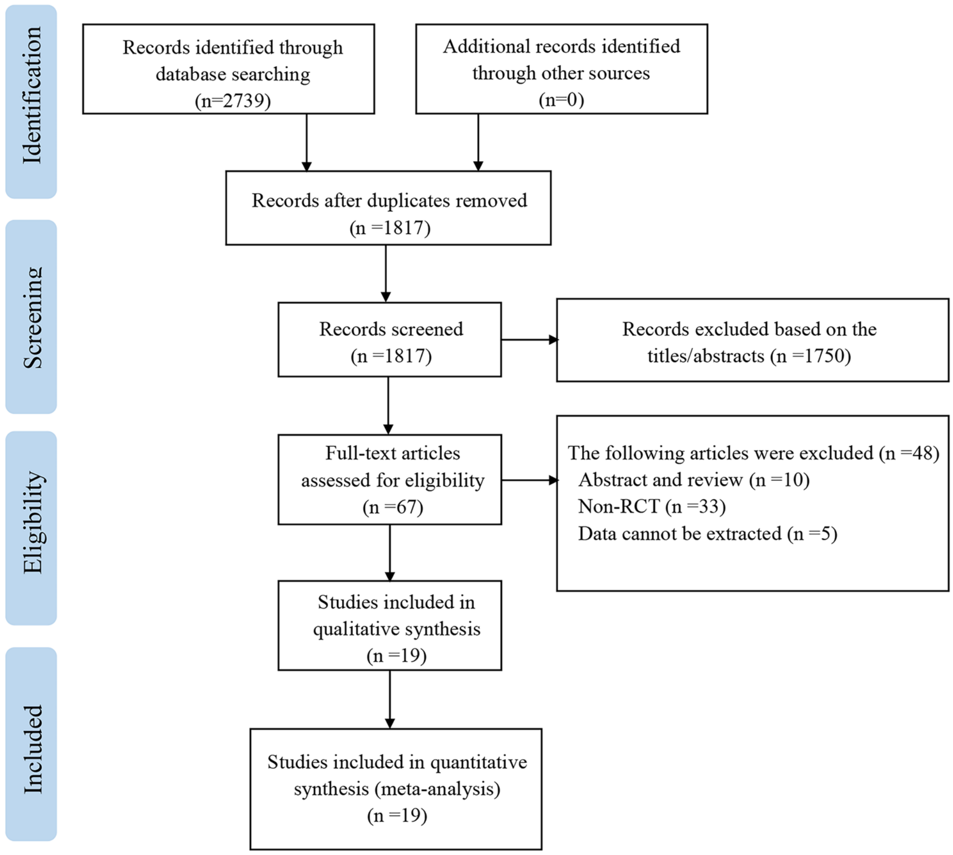

Fig. 1 Flow chart of literature search and screening for meta-analysis

Risk of bias assessment for the included studies

Figure 2 illustrates the risk of bias assessment for the 19 included RCTs, following the Risk of Bias Tool recommended by the Cochrane Collaboration [17–35]. All studies reported random assignment, but only one (Bouabdellah et al., 2022) explicitly mentioned blinding of participants, personnel, and outcome assessment [35]. Allocation concealment was reported in three studies. No instances of selective reporting or incomplete outcome data were found, and other biases could not be identified.

Results of the meta-analysis

Intraoperative blood loss

All the studies reported intraoperative blood loss [17–35]. Heterogeneity testing indicated significant heterogeneity among the included studies ($I^2 = 98.9\%$, $P < 0.001$). Consequently, sensitivity analysis was conducted, wherein individual studies were sequentially excluded; however, heterogeneity did not markedly decrease. Therefore, a random-effects model was applied for analysis. As shown in Fig. 3, the 3D printing group had significantly reduced intraoperative blood loss (WMD = -274.65, 95% CI [-326.47, -222.83], $P < 0.001$), corresponding to an average reduction of about 275 mL compared to the conventional group. The results of publication bias and sensitivity analysis are shown in Fig. S1.

Operation time

Operation time was reported in all included studies [17–35]. Heterogeneity testing revealed significant heterogeneity among the studies ($I^2 = 93.7\%$, $P < 0.001$). Subsequently, leave-one-out analysis was conducted to sequentially exclude individual studies; however, it did not substantially reduce the heterogeneity. Therefore, a random-effects model was applied for the analysis. As shown in Fig. 4, the operation time in the 3D printing group was significantly shorter than in the conventional group (WMD = -53.26, 95% CI [-63.72, -42.80], $P < 0.001$), representing an average time saving of about 53 min. The results of publication bias and sensitivity analysis are shown in Fig. S2.

Times of intraoperative fluoroscopy

A total of 10 studies reported times of intraoperative fluoroscopy among 19 included studies [17, 23, 24, 26, 27, 29, 31–34]. Heterogeneity testing revealed significant heterogeneity among the studies ($I^2 = 95.8\%$, $P < 0.001$) and the random effects model was applied to the analysis. As shown in Fig. 5, the number of intraoperative

Table 1 Characteristics of all studies included in the meta-analysis

Study	Country	Study type	Mean age (years)		No. of patients (male)		3D image processing	Outcome measures
			3D printing	Conventional	3D printing	Conventional	software	
Chen et al., 2017	China	RCT	38.3 ± 7.4	37.5 ± 6.2	20 (15)	20 (14)	Materialise Mimics	A, B, C, E, G, H
Liu et al., 2017	China	RCT	42.16 ± 6.77	42.20 ± 6.72	22 (15)	22 (14)	Materialise Mimics	A, B, H
Xia et al., 2017	China	RCT	48.36 ± 6.27	48.27 ± 6.53	49 (28)	49 (25)	Materialise Mimics	A, B
Maini et al., 2018	India	RCT	38.3 ± 10.7	39.1 ± 12.9	10 (9)	11 (9)	Materialise Mimics	A, B
Guan et al., 2018	China	RCT	47.9 ± 6.6	48.1 ± 6.5	39 (20)	39 (22)	Materialise Mimics	A, B, H
Qin et al., 2018	China	RCT	46.9 ± 11.2	47.2 ± 10.3	30 (23)	30 (21)	Materialise Mimics	A, B, C, E, G
Maini L et al., 2018	India	RCT	38.25 ± 13.82	40.38 ± 12.78	12 (11)	13 (12)	Materialise Mimics	A, B
Wan et al., 2019	China	RCT	43.44 ± 4.53	41.88 ± 4.97	48 (34)	48 (32)	Materialise Mimics	A, B, C, D, E, G, H
Chen et al., 2019	China	RCT	43.64 ± 3.55	44.43 ± 3.59	32 (18)	32 (16)	Materialise Mimics	A, B, C, E
Huang et al., 2019	China	RCT	49.31 ± 15.72	48.31 ± 14.28	46 (28)	46 (31)	Materialise Mimics	A, B, C, G, H
Li et al., 2019	China	RCT	38.6 ± 3.5	38.1 ± 4.2	42 (28)	42 (25)	Materialise Mimics	A, B, C, E
Huang et al., 2020	China	RCT	43.4 ± 11.6	37.4 ± 12.7	20 (12)	20 (14)	Materialise Mimics	A, B, D, F, H
Zhang et al., 2020	China	RCT	38 ± 14	40 ± 13	12 (7)	13 (7)	Materialise Mimics	A, B
Zou et al., 2020	China	RCT	36.06 ± 6.08	35.98 ± 5.93	26	26	Materialise Mimics	A, B, C, E
Öztürk et al., 2020	Turkey	RCT	46.2 ± 12.7	41.7 ± 21.1	9 (9)	9 (9)	NP	A, B, E, F
Song et al., 2021	China	RCT	57.62 ± 13.34	57.33 ± 7.72	13 (9)	15 (11)	Materialise Mimics	A, B, C, E, F, G, H
Xing et al., 2021	China	RCT	31.65 ± 4.77	31.87 ± 4.59	36 (19)	36 (20)	Materialise Mimics	A, B, C, E, H
Yang et al., 2021	China	RCT	41.28 ± 8.78	42.41 ± 9.23	29 (19)	29 (18)	Materialise Mimics	A, B, C, E, G, H
Bouabdellah et al., 2022	Tunisia	RCT	36.05	37.22	20 (14)	23 (19)	NP	A, B, C, D, H

RCT: randomized controlled trial; NP: not provided. Outcome measures: (A) Blood loss; (B) Operation time; (C) Matta score; (D) Harris score; (E) Times of intraoperative fluoroscopy; (F) Instrumentation time; (G) Time from injury to operation; (H) Complication

fluoroscopy exposures was significantly lower in the 3D printing group (WMD = -5.24, 95% CI [-6.57, -3.91], $P < 0.001$), corresponding to an average reduction of about 5 exposures. The results of publication bias and sensitivity analysis are shown in Fig. S3.

Time from injury to operation

A total of 6 studies reported time from injury to operation among 19 included studies [17, 23, 25, 27, 32, 34]. Heterogeneity testing revealed no heterogeneity among the studies ($I^2 = 0\%$, $P = 0.605$) and the fixed effects model was applied to the analysis process. The results showed no statistical significance in the time from injury to operation between the two groups (WMD=-0.06, 95%CI [-0.36, 0.24], $P = 0.686$), as shown in Fig. 6, which represents 3D printing-assisted ORIF group was not time-consuming compared to conventional group. The results of publication bias and sensitivity analysis are shown in Fig. S4.

Instrumentation time

A total of 3 studies reported instrumentation time among 19 included studies [28, 29, 32]. The instrumentation time was the time to complete plate fixation, including plate configuration adjustment, screw drilling, screw length measurement and plate locking. Heterogeneity testing revealed significant heterogeneity among the studies ($I^2 = 90\%$, $P < 0.001$) and the random effects model was applied to the analysis process. As shown in Fig. 7, instrumentation time was significantly shorter in the 3D printing-assisted group compared to the conventional group (WMD = -35.31, 95% CI [-53.42, -17.21], $P < 0.001$), indicating an average time saving of about 35 min. The results of publication bias and sensitivity analysis are shown in Fig. S5.

Post-surgery Matta score

A total of 11 studied with Matta score as the secondary outcome were included among the 19 studies [17, 23–27, 31–35]. Post-surgery Matta score represents the quality of acetabular fracture reduction [6]. According to the clinical satisfaction, participants were standardized into two groups: Excellent/Good and Fair/Poor. Heterogeneity testing revealed low heterogeneity among the studies ($I^2 = 0\%$, $P = 0.655$). Fixed effects model was applied to the analysis. The forest plot shown in Fig. 8 shows the effect of 3D printing-assisted ORIF group compared to the conventional group on Matta score. The 3D printing group had a significantly higher rate of satisfactory postoperative reduction (RR = 1.17, 95% CI [1.09, 1.25], $P < 0.001$),

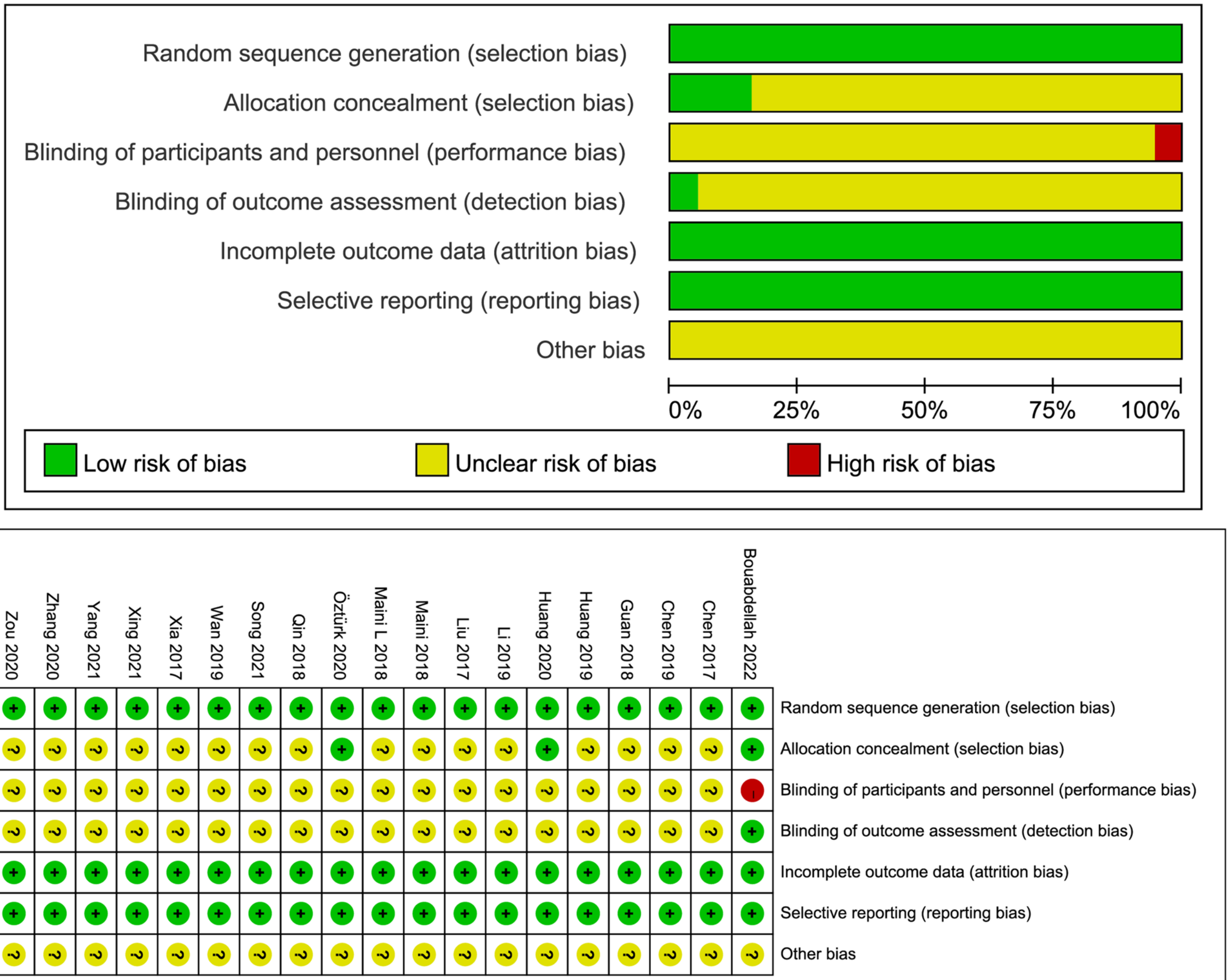

Fig. 2 Risk of bias summary. +: low risk of bias; –: high risk of bias;?: bias unclear

indicating a 17% relative improvement in achieving Excellent/Good Matta scores. The results of publication bias and sensitivity analysis are shown in Fig. S6.

Harris score
3 studies reported post-surgery excellent rate of Harris score (Excellent/Good: Harris score ≥ 80 points; Fair/Poor: Harris score < 80 points), which reveals hip function and pain level [27, 28, 35]. Heterogeneity testing revealed significant heterogeneity among the studies (I^2 = 71%, P = 0.032). Random effects model was applied to the analysis. The analysis results showed no statistical significance in the excellent and good rate of hip Harris score between the two groups (RR = 1.22, 95%CI [0.83, 1.79], P = 0.318), as shown in Fig. 9. Although the 3D printing group showed a slightly higher proportion of patients with satisfactory functional outcomes, the result was not statistically significant, indicating that 3D printing assistance did not lead to a conclusive improvement in hip function compared to conventional surgery in the included studies. The results of publication bias and sensitivity analysis are shown in Fig. S7.

Complications
10 studies reported incidence rate of complications among 19 studies, including traumatic arthritis, heterotopic ossification, femoral nerve dysfunction, incision fat liquefaction [17, 18, 20, 25, 27, 28, 32–35]. Heterogeneity testing revealed no heterogeneity among the studies (I^2 = 0%, P = 0.87) and the fixed effects model was applied to the analysis process. As shown in Fig. 10, the incidence of postoperative complications was significantly lower in the 3D printing group (RR = 0.34, 95% CI [0.22, 0.52], P < 0.001), indicating a 66% relative risk reduction compared to the conventional group. The results of publication bias and sensitivity analysis are shown in Fig. S8.

Publication bias
The funnel plot method permits only a visual assessment of publication bias, whereas the Begg's rank method and

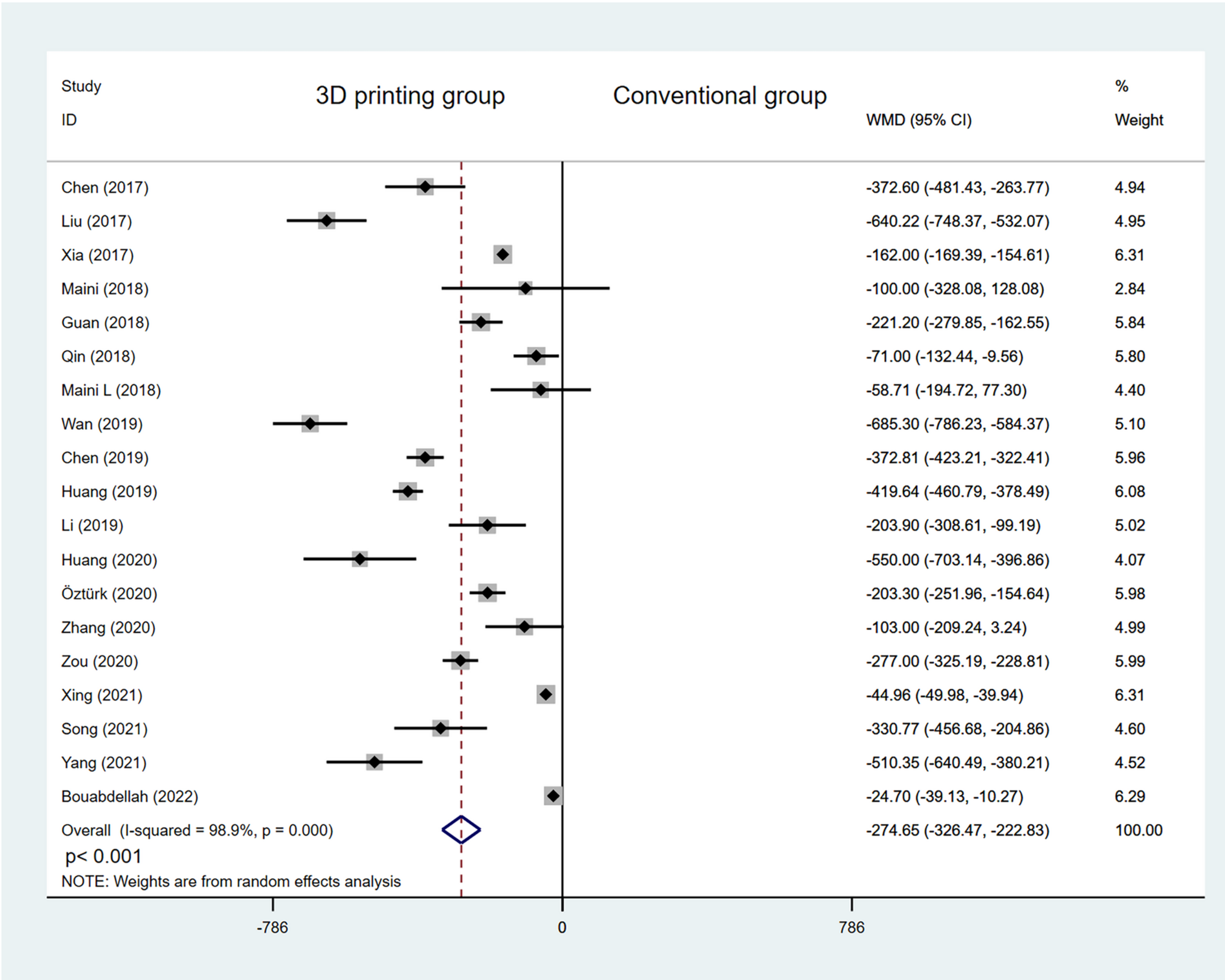

Fig. 3 Forest plot showing the intraoperative blood loss volume of the 3D printing-assisted ORIF group compared to the conventional group (ORIF, open reduction and internal fixation; WMD, weighted mean difference)

Egger's regression method are able to achieve a quantitative detection of publication bias [36, 37]. Begg's and Egger's tests are now frequently applied in meta-analyses to evaluate publication bias, typically for a minimum of 10 studies. Since $P<0.05$ for Begg's test and Egger's test results, this suggests a potential publication bias for the included studies of intraoperative blood loss (Egger's test: $P=0.012$), Operation time (Egger's test: $P=0.005$), and times of intraoperative fluoroscopy (Egger's test: $P=0.002$). No bias was published for other outcome measurements as the results of Begg's test and Egger's test $P>0.05$. The above-mentioned outcome measurements have potential publication bias, which may be related to the overall low quality of the included studies. In the future, more high-quality RCTs that meet the research objectives are needed to supplement the existing conclusions.

Sensitivity analysis

Sensitivity analyses were conducted for meta-analyzed outcomes displaying notable variability among the studies. Generally, sensitivity analysis in a meta-analysis assesses the consistency of the pooled results when substantial heterogeneity exists [38]. In performing the sensitivity analyses, we paid particular attention to the sources of heterogeneity across different studies to ensure the robustness of the overall conclusions after excluding specific study results. For instance, certain studies might have a disproportionate impact on the pooled results due to smaller sample sizes or differences in study design. By systematically excluding these potential confounding factors, we ensured the reliability of our meta-analysis findings. The application of these methods not only strengthened the credibility of our study conclusions but also provided valuable insights for future related research.

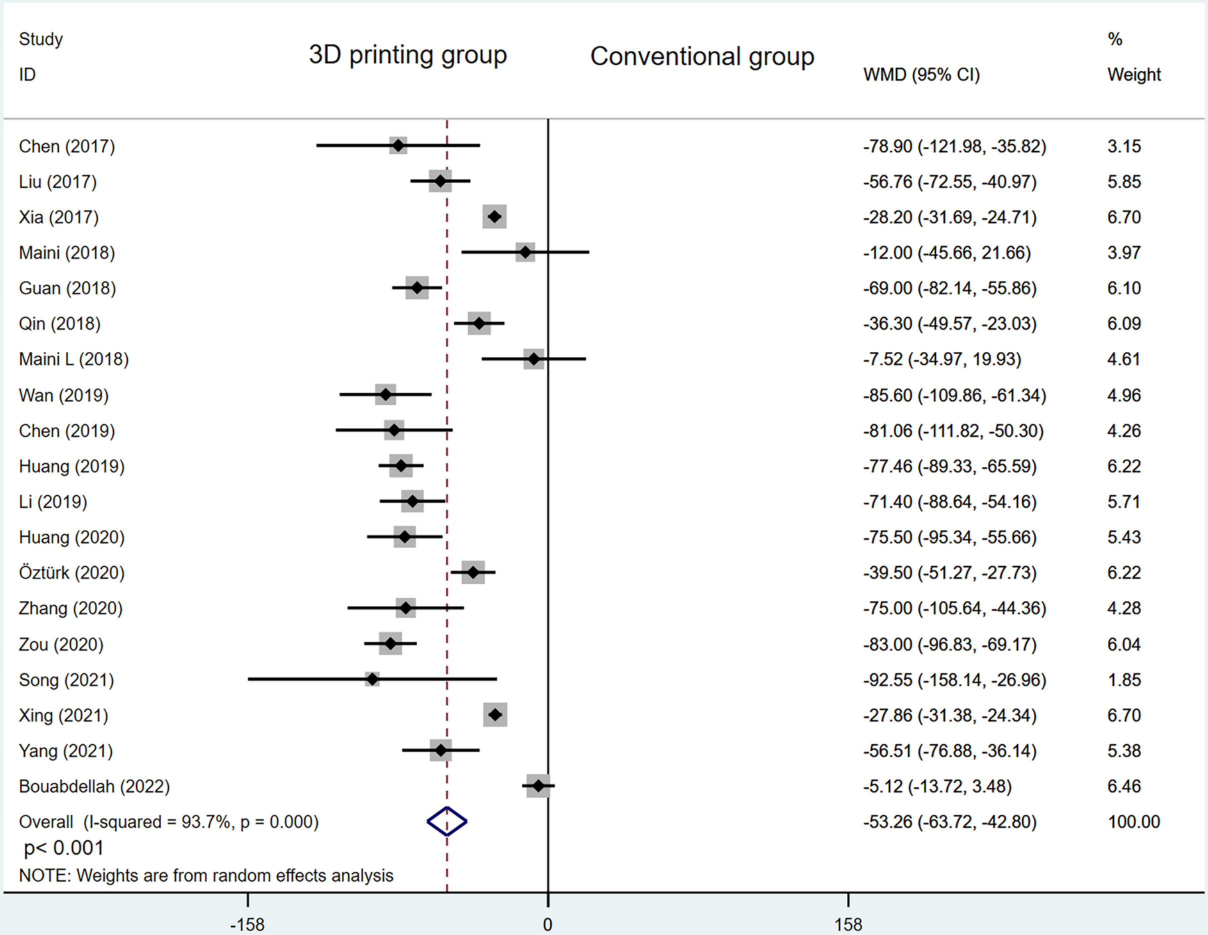

Fig. 4 Forest plot showing the operation time of the 3D printing-assisted ORIF group compared to the conventional group

Discussion

A fracture of the acetabulum is the result of a violent impact between the femoral head and acetabulum, which account for approximately 0.7% of all body fractures [39]. In recent years, the incidence of acetabular fractures has gradually increased with the aging of the population. This damage not only has an impact on the psychological well-being of patients, but also constitutes a considerable socioeconomic burden [40]. The management of acetabular fracture poses a significant challenge to radiologists and orthopedists as a consequence of its intricate anatomy and experience-dependent operation. Prior studies and related meta-analysis have highlighted the importance of 3D printing technology in medical applications, which enabling surgeons to prepare comprehensive preoperative planning, simulate surgeries, and utilize intraoperative navigation templates [6, 39]. They have not explicitly addressed its influence on clinical outcomes, radiographies, and postoperative hip function. In this meta-analysis, we sought to investigate the efficacy of 3D printing technology assisted open reduction and internal fixation in acetabular fracture treatment and expect to provide evidence-based treatment for acetabular fracture.

Due to the complex anatomy of an acetabular fracture, preoperative planning is crucial for a successful surgical outcome [11, 41]. The data summary analysis of the included studies found that the 3D printing-guided ORIF

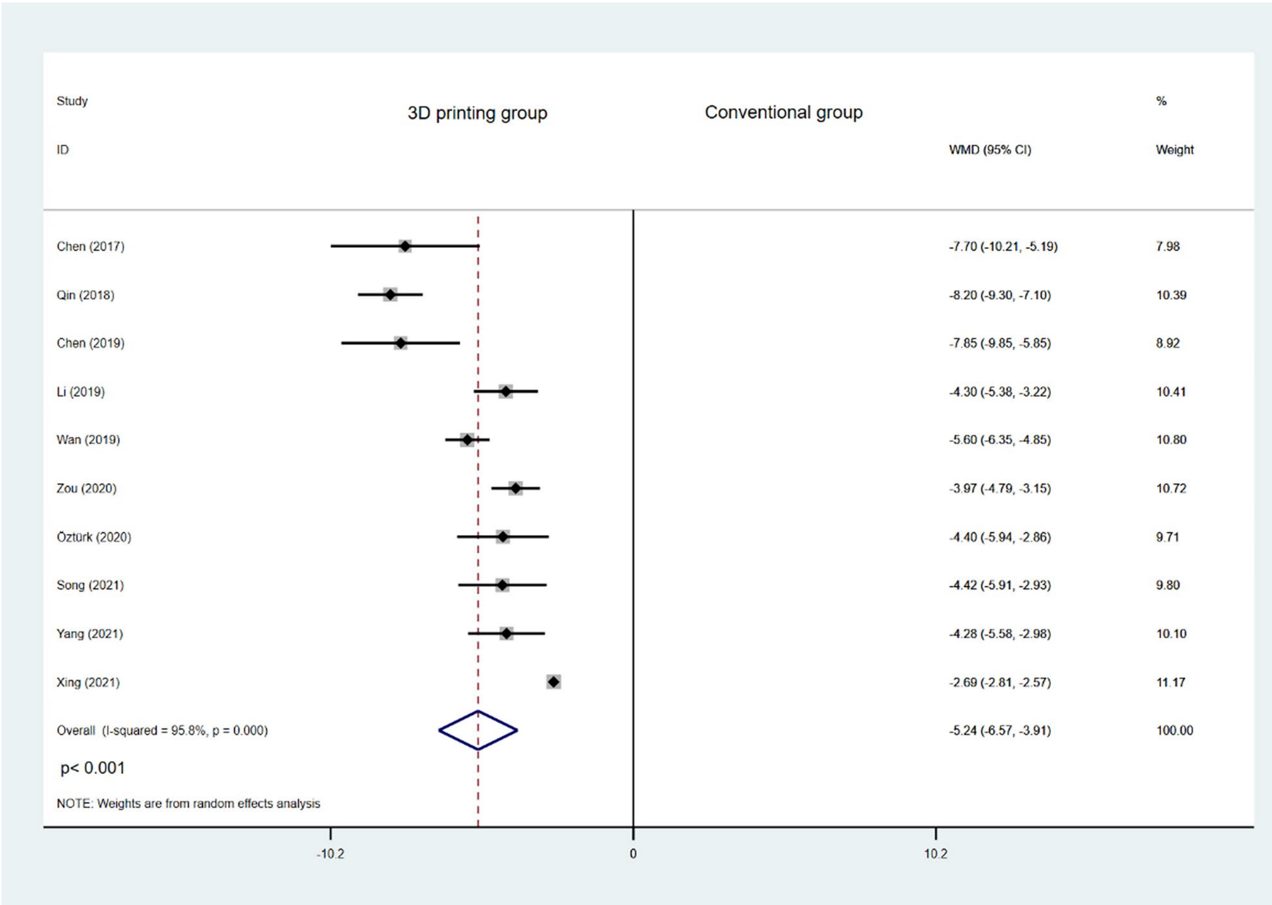

Fig. 5 Forest plot showing times of intraoperative fluoroscopy of the 3D printing-assisted ORIF group compared to the conventional group

group was superior to the conventional surgery group in terms of operation time, intraoperative blood loss, intraoperative fluoroscopy times, and instrumentation time. After searching the studies involved one by one, we found that out of the 19 included studies, 16 studies reported a statistically significant reduction in operative time ($P<0.05$) in the 3D printing group compared to the conventional group. This suggests that 3D printing-especially when used for pre-contouring fixation plates and preoperative planning-can enhance surgical efficiency. These individual study findings are consistent with the results of the overall meta-analysis, which also showed that 3D printing significantly shortened operative time. Traditional imaging techniques such as X-rays and CT scans, while useful, often struggle to demonstrate the full extent of the fracture pattern. 3D printing has changed this by generating a model that is equal in scale to the patient's actual fracture, helping surgeons to better understand the fracture morphology, plan the surgical approach more efficiently, and accurately pre-contour the fixation plate. Moreover, surgeons are able to simulate the surgical operation through the 3D printed model, thereby becoming familiar with the surgical methods and steps. This has the effect of reducing the number of ineffective operations, the duration of the operation, intraoperative bleeding and radiation exposure of surgeons. The heterogeneity of some outcome measurements in this meta-analysis was high, which may be related to the relatively poor quality of the included studies and the relatively single countries in which the studies were published.

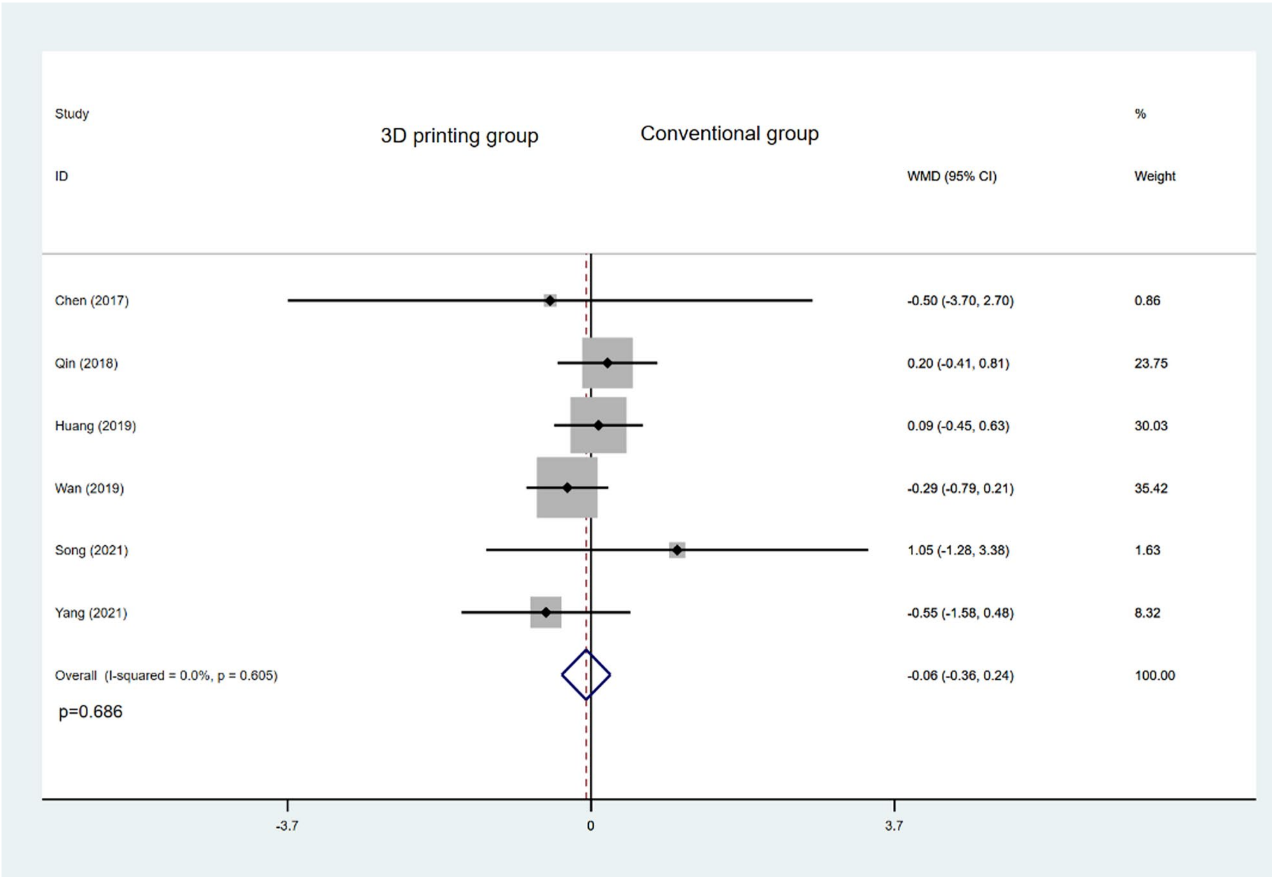

Fig. 6 Forest plot showing time from injury to operation of the 3D printing-assisted ORIF group compared to the conventional group

The post-operative Matta score represents the quality of the reduction of the acetabular fracture, while Harris score at last follow up represents hip function. A reduction within 3 mm of displacement and Harris score ≥ 80 (alias excellent/good) was considered to be clinically satisfactory [42, 43]. In this meta-analysis, we found that 3D printing-assisted group could improve the accuracy of reduction, but the improvement of hip joint function was not significant. This result is similar to and different from the findings of Hsu et al. (2019), who found similar postoperative radiological outcomes in both groups [41]. In terms of fracture reduction, among the 11 studies that reported on reduction quality, 5 studies showed significantly better reduction in the 3D printing group ($P < 0.05$), while the remaining 6 reported no significant difference between groups ($P > 0.05$). However, the pooled results from the meta-analysis demonstrated a statistically significant improvement in fracture reduction quality in the 3D printing group overall ($P < 0.05$). These findings should be extrapolated to all patients with caution, as the prognosis of acetabular fractures may be significantly influenced by the surgeon's experience and the specific fracture pattern involved.

Our results indicate that 3D printing-assisted surgery group exhibited a reduced incidence of postoperative complications in comparison to the conventional surgical group. The most frequently reported complications of acetabulum fracture are traumatic arthritis, infections, injury to blood vessels and nerves, femoral head necrosis and deep vein thrombosis [35]. The use of 3D printing-assisted ORIF for acetabular fracture, along with personalized screws and implants, allows for a more precise fit

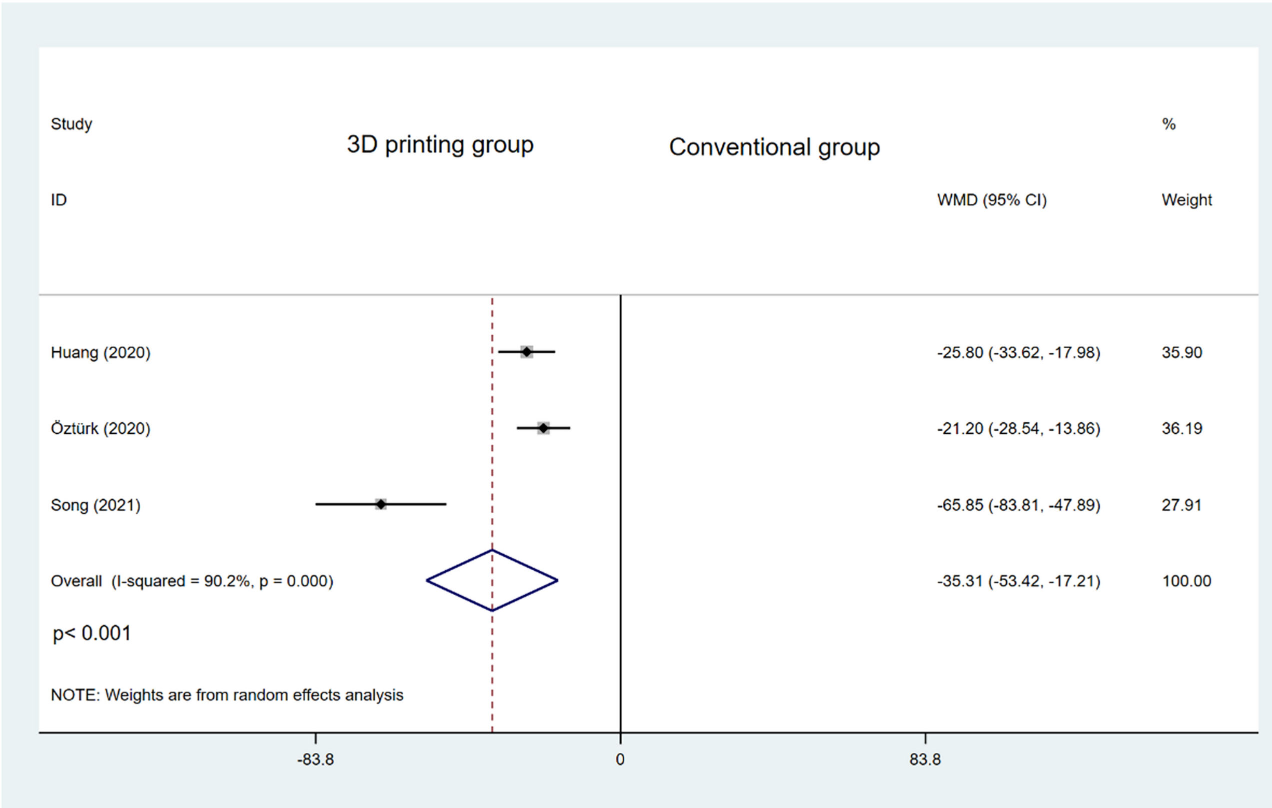

Fig. 7 Forest plot showing instrumentation time of the 3D printing-assisted ORIF group compared to the conventional group

to the patient's anatomy. This has been shown to improve the efficacy of internal fixation and reduce the incidence of complications.

Despite the broad application of 3D printing technology in medicine, its adoption in fracture care is hindered by several drawbacks. The primary disadvantages of 3D printing can be attributed to its limited accuracy, lengthy processing time and high costs [44, 45]. Reconstructing the fracture pattern using Computer-Aided Design (CAD) software may take fewer hours to create a 3D fracture model [46]. Notably, our results of time from injury to operation showed no difference between two groups, which represents the preoperative preparation of 3D printing-assisted ORIF was not time-consuming compared to conventional surgery. Acetabular fractures caused by high-energy trauma are often combined with multiple organ injuries and hemodynamic instability, deferred surgery to save lives is a common treatment option for acetabular fractures [6]. The average time from injury to operation in this meta-analysis is approximately 8 days, which means there is sufficient time for doctors to capture images, create 3D virtual models and 3D print. It should be noted, however, that 3D printing is not a viable option for all patients with fractures that require immediate surgical intervention. To date, 3D printing technology has been used primarily for acetabular fracture surgery [47]. In future, the implementation of a more automated and intelligent full-process 3D printing-assisted healthcare system has the potential to enhance the efficiency of surgical teams, enabling accurate, rapid, and cost-efficient orthopedic surgery for patients.

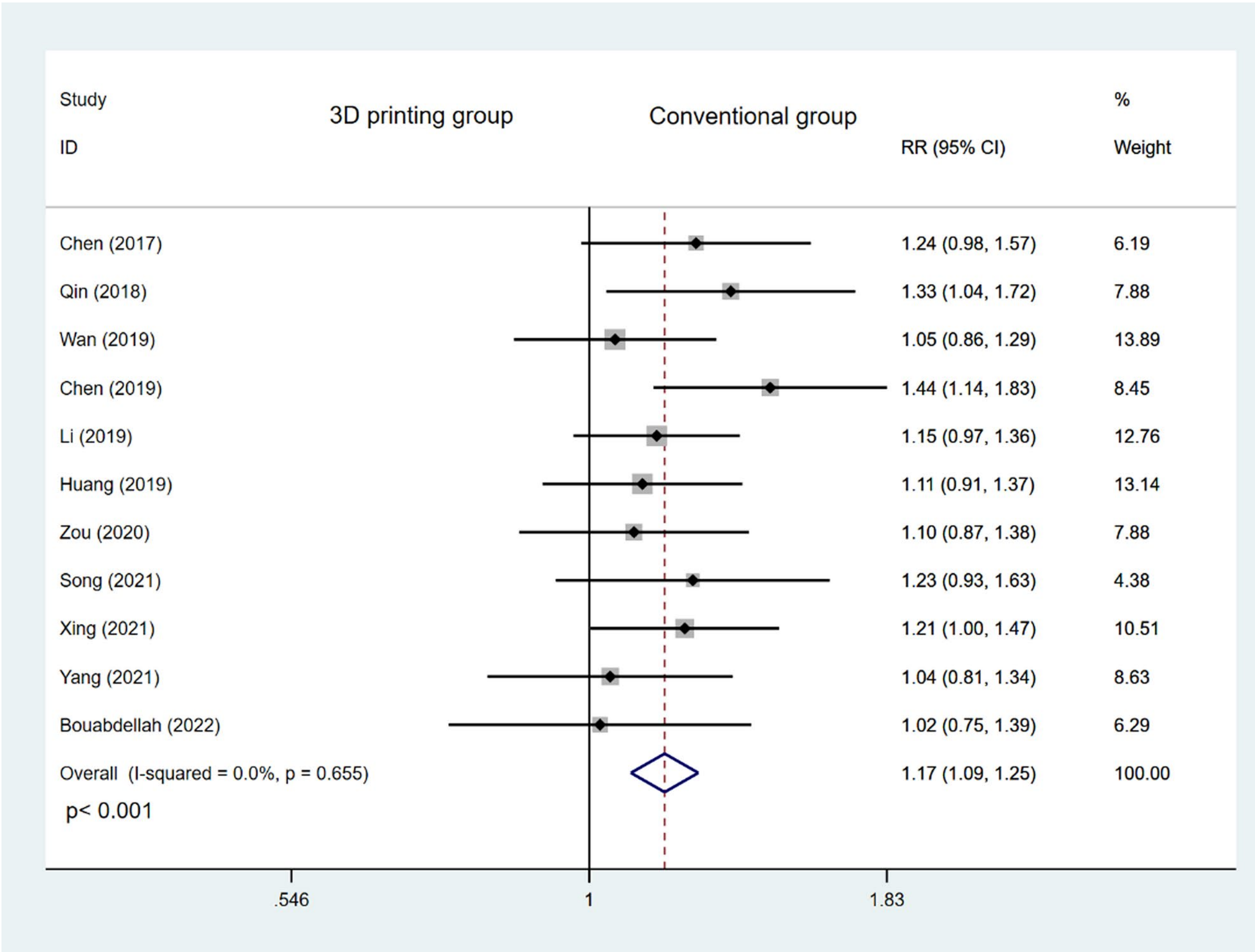

Fig. 8 Forest plot showing Matta score of the 3D printing-assisted ORIF group compared to the conventional group (RR, relative risk)

This meta-analysis synthesizes the current evidence on 3D printing-assisted ORIF versus conventional ORIF for acetabular fractures. By including 19 RCTs and analyzing key surgical and clinical outcomes, the strength of this study is that it provides powerful insights into the use of 3D printing in acetabular fractures, such as shortened operative time, reduced intraoperative blood loss, and complication rates. Although some functional outcomes did not show significant differences, the overall findings suggest that 3D printing can improve the safety and efficiency of surgery. Clinically, this supports its use as a valuable adjunct to preoperative planning and management of complex fractures, especially helping to improve efficiency and reduce intraoperative risks.

Nevertheless, some limitations are worth noting. Although this meta-analysis included 19 RCTs, some outcomes (e.g., Instrumentation time, Harris score) were not reported in all studies, which may introduce bias due to small study effect. Besides, included RCTs exhibited relatively inferior quality, lacking essential details of blinding and concealment of allocation. Furthermore, certain results displayed considerable heterogeneity, with most of the included studies coming from one country (China). Acetabular fracture pattern is an important factor affecting prognosis, fractures involving posterior column, posterior wall and T-type fractures often predicts poor clinical outcome [48, 49]. This meta-analysis did not include acetabular fracture type in subgroup analysis due to the paucity of clinical trials on different types of acetabular fractures and the unavailability of primary data. In-depth studies on 3D printing assisted ORIF in the context of acetabular fracture treatment are still imperative to be investigated.

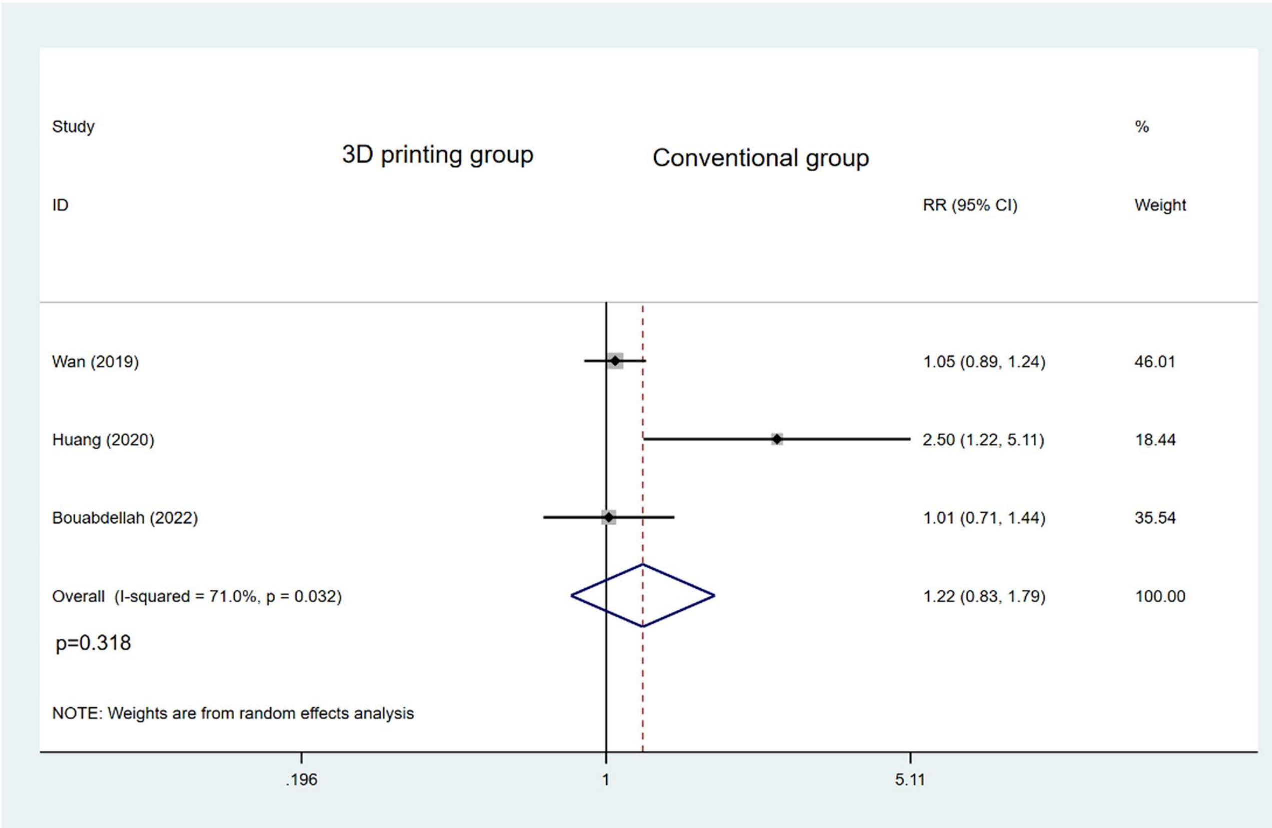

Fig. 9 Forest plot showing Harris score of the 3D printing-assisted ORIF group compared to the conventional group

Conclusion

In conclusion, the current application of 3D printing technology provides valuable preoperative planning support without altering the fundamental principles of the standard ORIF procedure. Our meta-analysis suggests that 3D printing-assisted ORIF may offer advantages over conventional methods in terms of reducing intraoperative blood loss and operative time, facilitating instrumentation, lowering the need for intraoperative fluoroscopy, and potentially improving postoperative reduction quality, and complication rates. However, these findings are influenced by variations in the heterogeneity, study design, sample size, and overall methodological quality across the included trials. In addition, most studies did not report outcomes stratified by fracture classification, limiting our ability to assess the technique's effectiveness across different fracture types. Future large-scale, high-quality randomized controlled trials with stratified reporting by fracture pattern are needed to confirm these findings and better define the role of 3D printing technology in the surgical management of acetabular fractures.

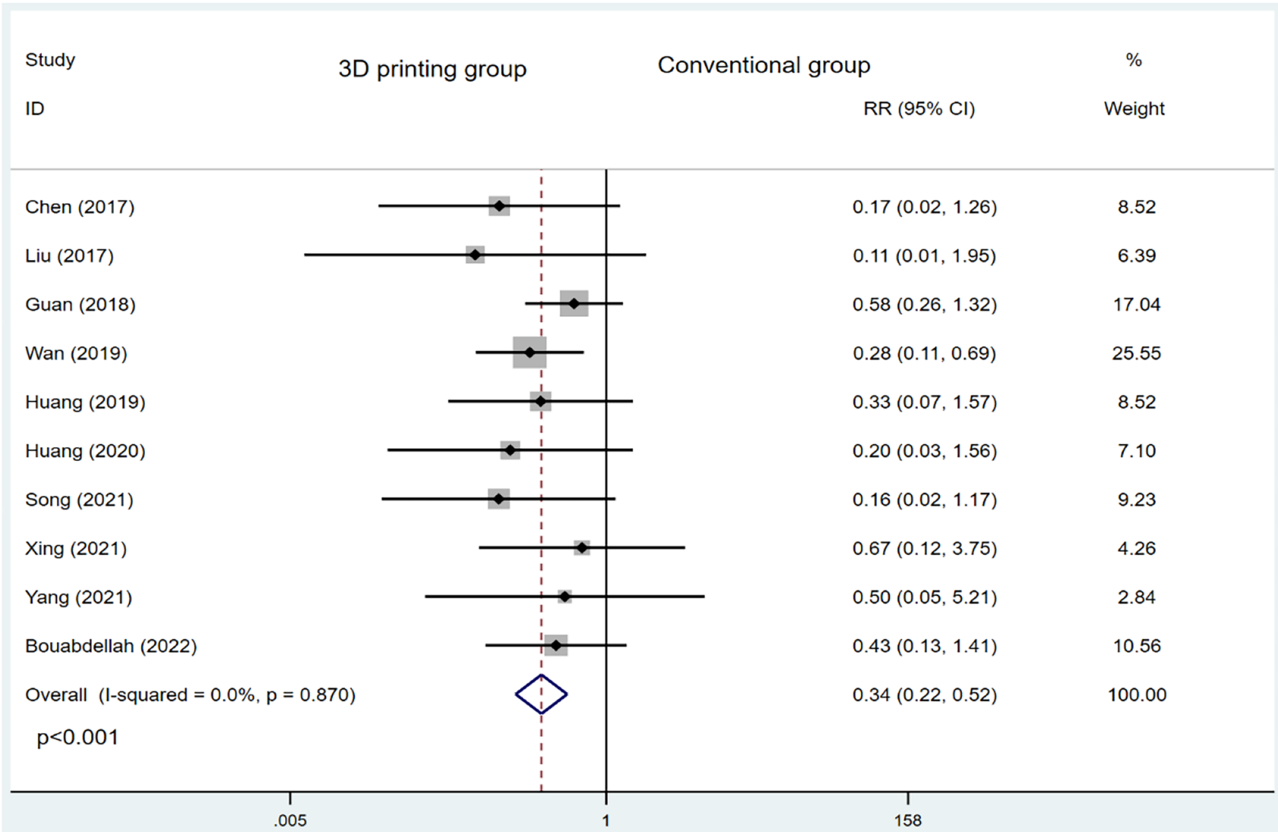

Fig. 10 Forest plot showing incidence rate of complications in the 3D printing-assisted ORIF group compared to the conventional group

Supplementary Information

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Supplementary Material 1

Author contributions

All authors contributed to the study conception and design. W. Z. L., C. Y. Z., J. X. L., and P. R. F. were responsible for the study concept and writing the article. P. Y., Z. C. X., and G. L. W. was responsible for reviewing and writing the article. All authors read and approved the final manuscript. †Wenzheng Liu, Chaoyi Zhang and JixiLiu contributed equally to this work.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Yes.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Orthopedic Surgery, West China Hospital, Orthopedic Research Institute, Sichuan University, Chengdu 610041, China
[2]West China Hospital, Trauma Medical Center, Sichuan University, Chengdu 610041, China
[3]Med-X Center for Manufacturing Sichuan University, Chengdu 610041, China
[4]Department of Orthopaedic Surgery, China-Japan Friendship Hospital, Beijing 100029, China
[5]Department of Thoracic Surgery, Peking University Third Hospital, Beijing 100191, China

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