Clinical efficacy and safety of surgery combined with 3D printing for tibial plateau fractures: systematic review and meta-analysis

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Background: The aim of the present study was to systematically evaluate the application value and complications of 3D printing technology on Schatzker tibial platform fracture surgery.

Methods: By searching the Cochrane Library, PubMed, Web of Science, Embase, Chinese Biomedical Literature Database (CBM), screening randomized controlled trials (RCTs), and two researchers included the study according to PICOS criteria and performed bias risk assessments. Quality evaluation and data extraction were performed for the included literatures, and meta-analysis was performed for RCTs included at using Review Manager 5.2 software.

Results: A total of 15 articles were included in the present study, which included a total of 758 patients, 342 3D printing techniques, 416 conventional surgical procedures. Meta-analysis showed 3D printing operation time [risk difference (RD) =–0.12, 95% CI: –0.16, –0.08, I^2=46%, P<0.00001], surgical bleeding [odds ratio (OR) =0.59, 95% CI: 0.45–0.77, I^2=0%, P<0.001), intraoperative fluoroscopy (OR =0.59, 95% CI: 0.41–0.85, I^2=0%, P=0.004), fracture healing time (OR =0.46, 95% CI: 0.33–0.63, I^2=0%, P<0.00001), and complication morbidity (OR =0.60, 95% CI: 0.45–0.81, I^2=0%, P=0.001) were significantly lower than in the traditional group.

Discussion: 3D printing technology for tibia platform fracture surgery has advantages of reduced operation time, less surgical bleeding, less complications, less intraoperative perspective, fast fracture healing, and can improve the accuracy of tibial platform fracture reduction and postoperative knee function recovery.

Keywords: Surgical treatment; 3D printing; tibial plateau fracture; meta-analysis

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Introduction

The current incidence of tibial plateau fracture accounts for about 26% of knee fractures, a composite mechanism damage from high-energy trauma that is usually a combination of rotational and axial compressive forces (1). Such fractures are often associated with intraarticular lesions, such as cartilage injury, meniscus tear, and ligament rupture (2). In particular, the success Schatzker IV–VI surgery depends on the recovery of articular cartilage and bone surface smoothness, alignment of mechanical axes of lower limbs, recovery of joint stability, and preservation of motor function to accommodate early knee activity (3). Improper treatment is often combined with soft tissue infection, delay for late healing, chronic pain, knee stiffness, and osteoarthritis (4).

In recent years, with the rapid development of computer-assisted surgical navigation technology and digital orthopedics (5). However, making a 3D model requires additional preoperative computed tomography (CT) scans and increases the radiation amount in patients. Current 3D printing is compared with traditional surgical methods. There is no uniform and clear comparison of the relevant effective observational outcome indicators for clinical efficacy and safety of Schatzker IV–VI tibial platform fracture, and the relevant evidence-based medical evidence is insufficient. Various scholars have reported an insufficient number of cases and a lack of large multicenter control quantitative experiments. The conventional treatment of tibial plateau fracture: (I) traction treatment; (II) plaster fixation or bracing fixation; (III) surgical treatment, etc.

At present, the surgical methods of tibial platform fracture are knee arthroscopic-assisted surgery, double-incision plate-fixation closed reduction of double-reverse traction, and various external fixation reductions (6). The choice of specific surgical methods is related to the type of fracture, skin condition, concomitant injury, and the patient's choice. The bidirectional traction device can produce large longitudinal forces at the distal tibia. Due to the obstruction of the linkage, the equivalent reverse force is produced at the same time, but complex tibial platform fracture reduction results and other deficiencies can occur. Arthroscopy ranges from diagnostic examination, debridement, and partial meniscectomy, to arthroscopic restoration (7). Arthroscopy can achieve accurate diagnosis and treatment of joint pathology, less soft tissue dissection, and no formal arthrotomy or anterior angle detachment of the lateral meniscus, but also has long surgical time, some fluid extravasation to the surgical limb gap, high surgical cost, and low-fixation rigidity. This study used 3D printing technology to complex tibial plateau fractures in patients with preoperative design and surgery simulation, and the results showed that the physical model based on 3D printing can clear display fracture block position and size, accurate simulation of the screw, steel plate placement process, preoperative can determine the plate number, location, length and screw parameters such as number, length and Angle, Determine surgical data in advance for the development of surgical strategy. The results of postoperative fracture reduction and internal fixation were consistent with the results of preoperative simulated operation, and the virtual operation design was basically consistent with the real operation. The surgical method of tibial plateau fracture should be given after manipulative repair of split fracture, with tension loose bone graft screw and Kirschner wire fixation. For the collapse fracture in the anterolateral cortex of the upper tibia, an osteotomy hole was opened, and the fracture plate was lifted from the bone hole to the cavity. Bone grafting was performed in the cavity, and then fixed with screws. For fracture with split and collapse, the collapsed bone fragment was pried up and bone grafted in the cavity. After the split fracture was reduced, T-shaped plate was externally fixed. Open reduction should be performed for internal and external condylar fractures. Meta-analysis is quantitatively evaluated between controversial treatment modalities, and while Meta-analysis is best applied to RCT, it remains an effective method for making a comprehensive quantitative evaluation of existing results in the absence of prospective randomized comparison trials (8). Considering that research articles with positive results are more likely to cause publication bias problems for publication than articles with negative results, to reduce publication bias, the present study was conducted to collect as comprehensively as possible through multiple pathways and short literature with reproducibility were excluded.

Previously published studies (9,10) have analyzed simple meta-analyses of 3D printing and tibial platform fractures. Now, such articles are generally classified. Therefore, it is necessary to summarize the effect of 3D printing on tibial plateau fracture surgery through meta-analysis. There are more and more clinical researches on joint 3D printing operation in the treatment of tibial plateau fractures. But for the treatment of tibial plateau fracture need to apply 3D printing auxiliary, there are a lot of controversy. Studies showed that 3D printing technology in tibial plateau fractures has great application value in the operation, to promote the success rate of surgery, reduce the incidence of postoperative complications. However, some scholars believe that imaging data can also replace 3D printing. Therefore, we provide a comprehensive and systematic evaluation of 3D printing technology compared with traditional surgical methods for Schatzke IV–VI tibial platform fracture literature, a meta-analysis of both intraoperative indicators and medium- and long-term efficacy, and a detailed analysis of complications to provide reasonable and sufficient evidence for clinicians in the future treatment of Schatzker IV–VI tibial platform fractures. We present the following article in accordance with the PRISMA reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-21-7008/rc).

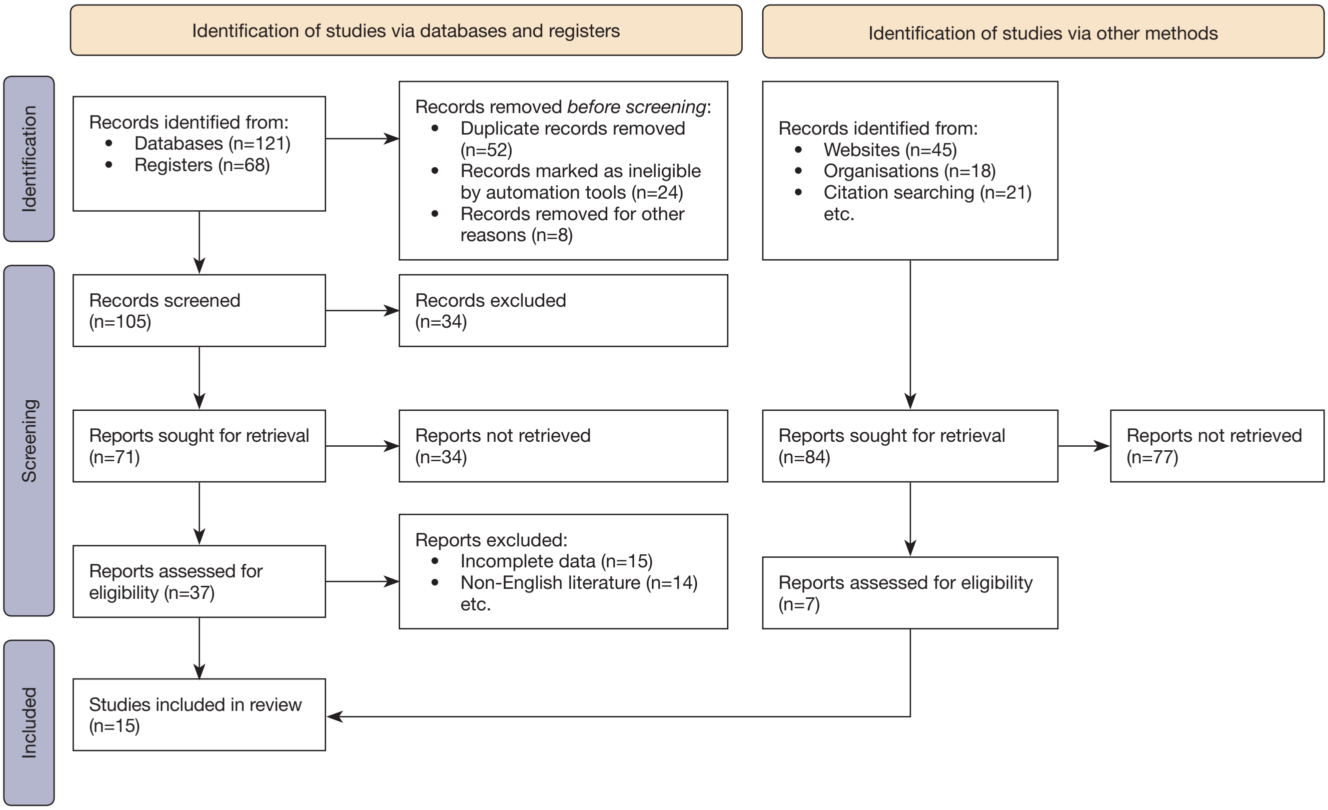

Figure 1 Flowchart of the literature screening.

Methods

Search strategy

PubMed, Cochrane Library, Web of Science, National Knowledge, Chemical Biological Munitions (CBM), WanFang, and other databases were searched. Related literature was also searched through other means, including the institute database, unpublished academic papers for master's and doctoral degrees, and relevant clinical trials registered at home and abroad. The search time was the start of each literature library construction to December 2021. The English search terms were as follows: Schatzker IV–VI, tibial plateau fractures, tibial plateau, proximal tibial fractures, tibial fractures, proximal tibial, 3D printing, 3D model and 3D printing (*Figure 1*).

Inclusion criteria

The patients included in the study had no age, sex, or geographical restrictions. The inclusion criteria were as follows: (I) clearly diagnosed as having any type Schatzker IV–VI tibial platform fracture through clinical physical examination and imaging data; all patients required surgical treatment; (II) the 3D tibial platform was constructed based on the patients' CT electronic data; a personalized model of the tibial platform was made for surgical planning, preoperative design, or use as a surgical guide plate; (III) operation time, amount of surgical bleeding, excellent Hospital for Special Surgery (HSS) score, excellent Rasmussen score, HSS postoperative score, number of intraoperative image perspectives, and postoperative complications were included; (IV) inclusion criteria for inclusion studies should be clarified using PICOS criteria.

Exclusion criteria

The exclusion criteria were as follows: (I) non-randomized controlled studies, reviews, meta-analyses, and case reports; (II) the literature mentioned tibial platform fractures, but the patients had arbitrarily typed fractures of Schatzker I–III tibial platform fractures; (III) clinical case-control reports inconsistent with 3D printing and traditional surgical methods; (IV) single and only experimental results; (V) similar or repeated publications, incomplete data, fracture typing methods and statistical methods, and no access to full text of the article.

Literature screening and quality evaluation

According to Cochrane RoB 2.0, two researchers read the retrieved literature independently, while screening strictly following the inclusion criteria and exclusion criteria. The title, abstract, and full literature were read to determine whether the literature could be included in the study. If there was a difference in opinion between the 2 researchers after cross-verification of the included literature information, a third researcher assisted in resolving the differences. PICOS criterion was used to screen and include: P: Participant or Patient, study object; I: Intervention; C: Comparison; O: Outcome; S: Study design.

Data collation and acquisition

Two investigators fully extracted the literature data, including basic literature information, such as author, year of publication, journal of publication, sample content, age, sex ratio, fracture Schatzker type, number of days from injury to surgery, and time of follow up. Outcome indicators were included, such as operation time, intraoperative bleeding amount, excellent HSS score rate, excellent Rasmussen score, anatomical reduction rate, number of intraoperative perspectives, and postoperative complications. Results the indicators: (I) clinical efficacy: Operation time, fracture healing time, etc.; (II) safety: surgical bleeding, intraoperative fluoroscopy, complication morbidity, etc.

Statistical analysis

Stata 15.0 software (UCLA, USA) was used for the statistical analysis. The effect size index used in the data was relative risk, the effect size index used for continuous data was standardized mean difference, and Cochran's Q test and I^2 value index were used for the inter-literature heterogeneity test. Q-test $P<0.1$ or $I^2>50\%$ indicated heterogeneity between studies. Data were analyzed using the random-effect model, otherwise the fixed-effect model.

Bias analysis

Sensitivity methods excluding literature were used to evaluate the robustness of the combined results. Publication bias was judged by Begg's test funnel plots and Egger's test funnel plots (P>0.05 for both). If the conclusions of both tests were inconsistent, the splicing method determined whether there was publication bias (*Figures 2,3*).

Results

Basic characteristics and quality evaluation of the included literature

In total, 189 relevant articles were obtained through preliminary database retrieval, 84 were obtained through other channels, and 84 that were repeatedly published were removed. Through careful reading of the titles and abstracts of the articles, and full text when necessary, 34 articles that did not meet the selection criteria were screened according to their research objectives and methodology. Articles that did not meet the inclusion criteria due to fracture type or the absence of a control group were excluded. Fifteen articles were finally included (11-25). In addition, there was no significant publication bias in the literature included in this study (*Figure 3*).

The literature screening process is shown in *Figure 1*. A total of 1,165 patients were enrolled; 749 of these were assisted with 3D printing and 416 were treated with traditional surgery (*Table 1*).

Operation time

A total of 15 articles described operation time for Schatzker type IV–VI tibial plateau fractures in the traditional and 3D printing groups. There was no significant statistical heterogeneity among the literature results, and Egger's test showed no significant publication bias. After excluding clinical heterogeneity factors, the random-effect model was used for statistical analysis. The results showed that the operation time of patients in the 3D printing surgery group was lower than that in the traditional group, and the difference was statistically significant [risk difference (RD) =–0.12, 95% CI: –0.16, –0.08, $I^2=46\%$, P<0.00001] (*Figure 4*).

Surgical bleeding

A total of 9 articles described the amount of surgical blood loss in Schatzker IV–VI tibial plateau fractures in the traditional and 3D printing groups. There was no statistical heterogeneity, and Egger test's showed no obvious publication bias. After excluding clinical heterogeneity

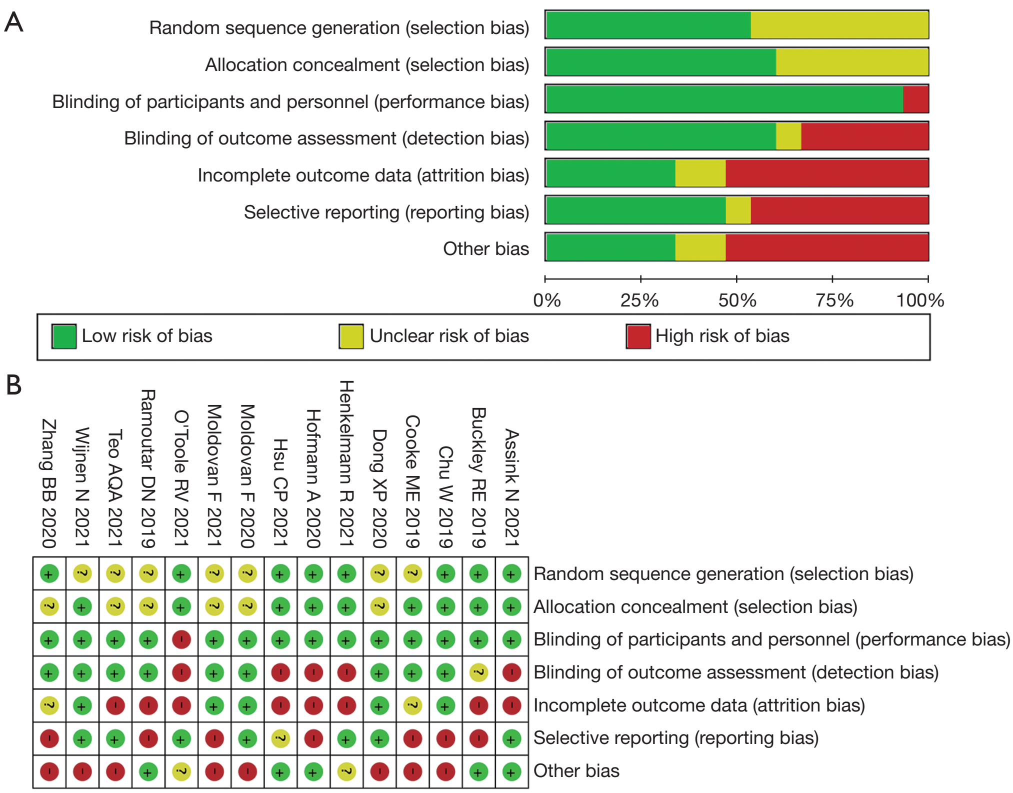

Figure 2 Literature quality evaluation. (A) Risk of bias graph; (B) risk of bias summary.

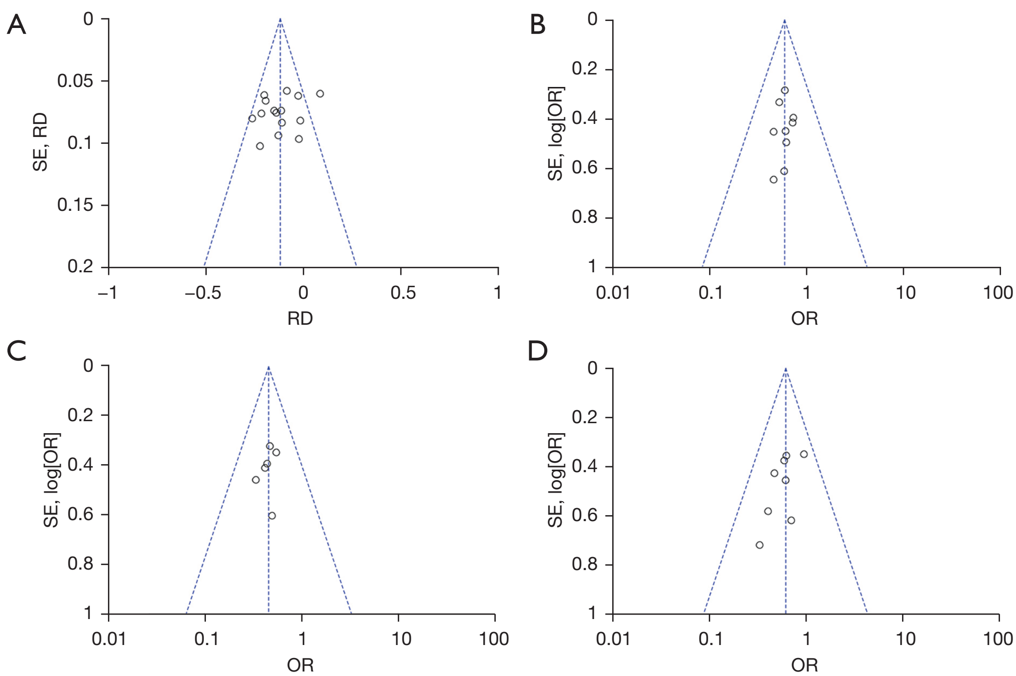

Figure 3 Funnel plot of literature publication bias.

Table 1 Basic clinical features of the 15 articles included in our study

Study	Study type	Cases (n)	Age (years)	Schatzker fracture classification	Time from injury to surgery (days)	Follow-up time (months)
Dong XP 2020	RCT	68	44.75±1.56	IV–VI	7.6	15.8
Dai G 2021	RCT	90	48.51±3.56	IV–VI	5.6	14.4
Hsu CP 2021	RCT	90	51.72±2.26	IV–VI	7.9	10.4
Teo AQA 2021	RCT	67	47.12±1.25	IV–VI	8.2	18.2
Moldovan F 2020	RCT	55	42.18±4.22	IV–VI	6.6	20.1
Wijnen N 2021	RCT	120	50.12±1.14	IV–VI	6.4	12.4
Moldovan F 2021	RCT	80	42.12±6.25	IV–VI	7.9	15.2
Hofmann A 2020	RCT	70	47.33±2.56	IV–VI	8.2	7.5
Ramoutar DN 2019	RCT	75	48.19±3.21	IV–VI	8.5	11.2
O'Toole RV 2021	RCT	96	55.12±1.49	IV–VI	7.8	6.5
Buckley RE 2019	RCT	110	57.12±2.25	IV–VI	6.5	6.2
Zhang BB 2020	RCT	90	52.45±2.33	IV–VI	7.2	12.5
Cooke ME 2019	RCT	65	53.66±1.33	IV–VI	6.2	10.2
Henkelmann R 2021	RCT	50	46.48±1.66	IV–VI	8.2	7.8
Chu W 2019	RCT	84	50.28±2.78	IV–VI	7.5	6.5

RCT, randomized controlled trial.

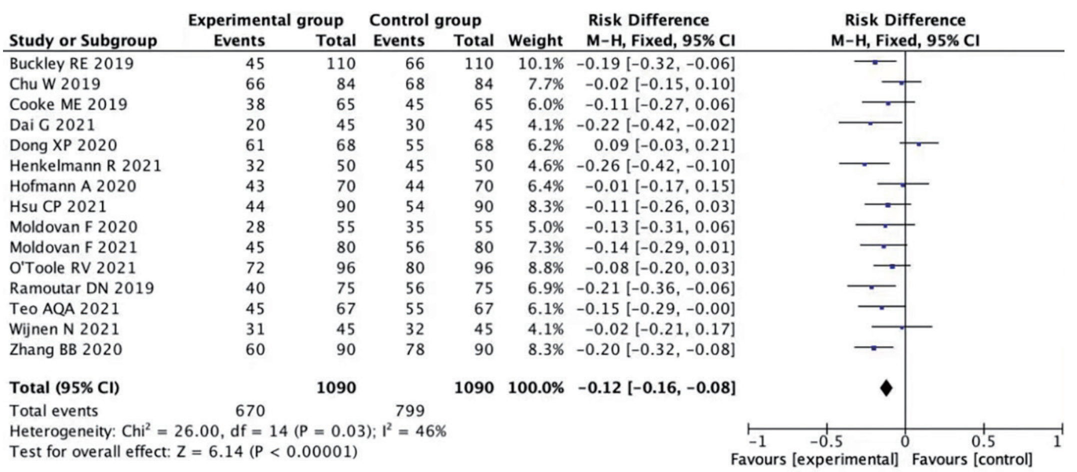

Figure 4 Meta-analysis of operation time.

factors, the random-effect model was used for the statistical analysis, and the results showed that the amount of surgical bleeding in the 3D printing surgery group was reduced compared with the traditional group, and the difference was statistically significant (OR =0.59, 95% CI: 0.45–0.77, I^2=0%, P<0.001) (*Figure 5*).

Intraoperative fluoroscopy

The results of the meta-analysis indicated that was no significant heterogeneity among 5 studies, so the random-effect model was used to merge the literature data. The results showed that intraoperative fluoroscopy in the 3D printing group was significantly less than that in the

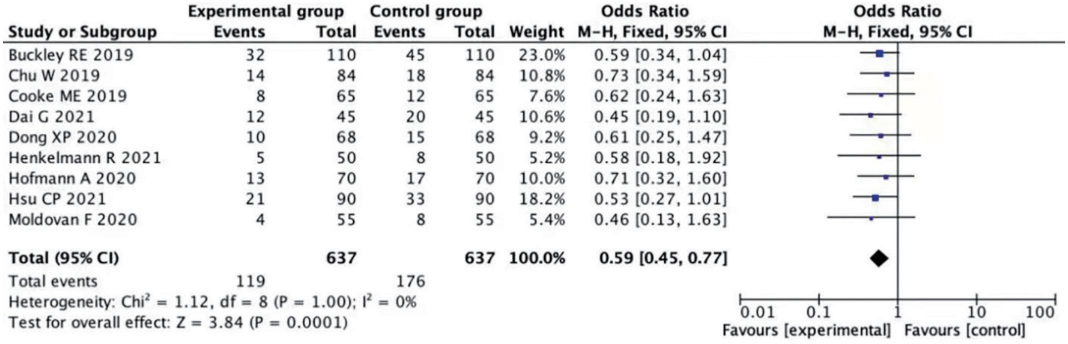

Figure 5 Meta-analysis of surgical bleeding.

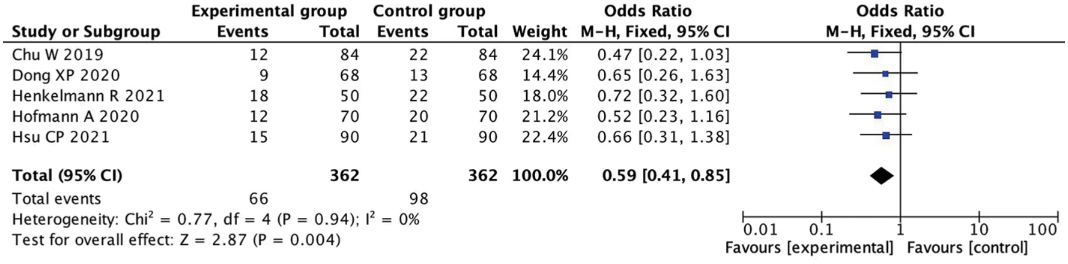

Figure 6 Meta-analysis of intraoperative fluoroscopy.

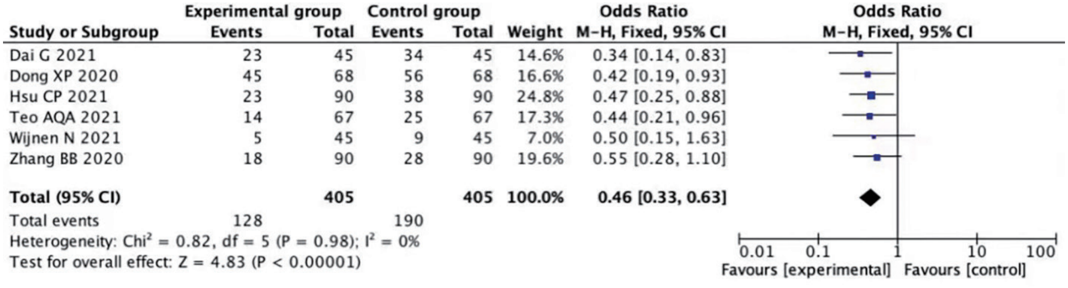

Figure 7 Meta-analysis of fracture healing time.

traditional group, and the difference was statistically significant (OR =0.59, 95% CI: 0.41–0.85, I^2=0%, P=0.004) (*Figure 6*).

Average fracture healing time

Six articles compared the mean healing time of fractures. Meta-analysis results showed that there was no significant heterogeneity among the studies, and literature data were combined using the random-effect model. The results showed that the healing time of the 3D printing group was shorter than that of the traditional group (OR =0.46, 95% CI: 0.33–0.63, I^2=0%, P<0.00001) (*Figure 7*).

Rate of Rasmussen score

Four articles compared the excellent and good Rasmussen scores, and fixed-effect model was used.

No significant statistical heterogeneity was found in the results of the meta-analysis.

The Rasmussen score of the printing group was significantly higher than that of the traditional operation group (OR =3.08, 95% CI: 1.89–5.02, I^2=0%, P<0.00001) (*Figure 8*).

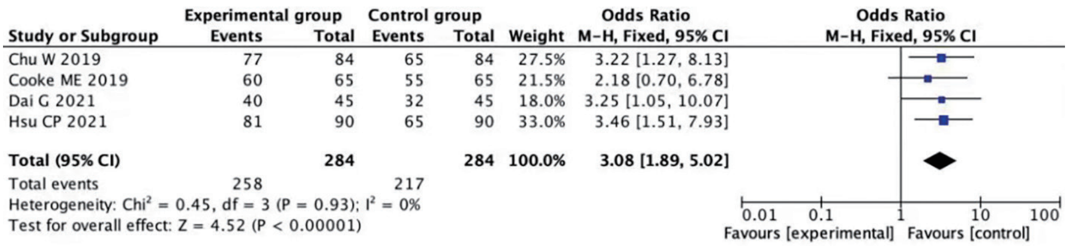

Figure 8 Meta-analysis of Rasmussen score.

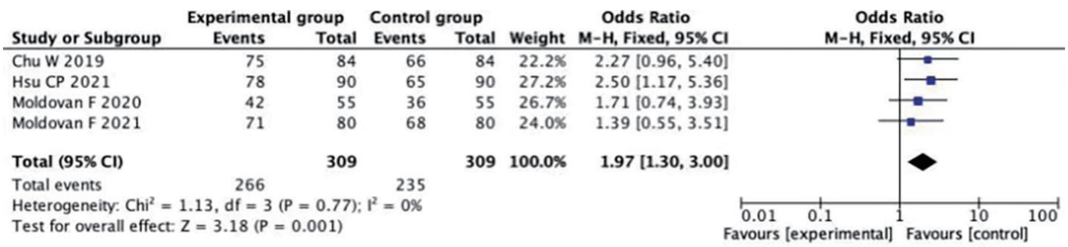

Figure 9 Meta-analysis of HSS score. HSS, Hospital for Special Surgery.

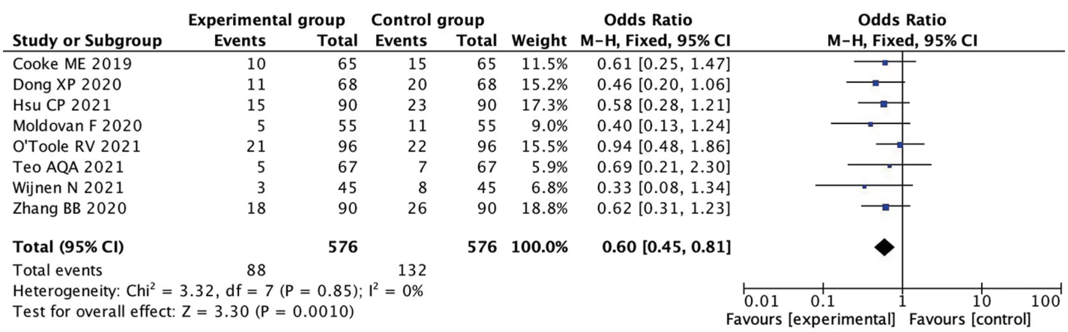

Figure 10 Meta-analysis of complications.

Rate of HSS score

Four articles compared the excellent and good rates of the HSS score. Meta-analysis results showed that there was no significant heterogeneity among the studies, so the fixed-effect model was adopted. The results showed that the excellent and good rates of the HSS score in the 3D printing group was significantly higher than that in the traditional group (OR =1.97, 95% CI: 1.30–3.00, I^2=0%, P=0.001) (*Figure 9*).

Complications

Nine articles compared the complications of surgery between the 2 groups. Meta-analysis results showed that there was no significant heterogeneity between the studies, so the fixed-effect model was adopted for merger, and the results showed that the complication rate of the 3D printing group was lower than that of the control group (OR =0.60, 95% CI: 0.45–0.81, I^2=0%, P=0.001) (*Figure 10*).

Discussion

Schatzker IV–VI tibial platform fractures are seen in directly or indirectly damage high energy violence, platform inside and lateral fracture end crushing, fracture block separation displacement obvious, the knee joint as human bearing joint, through stable internal fixation anatomical reduction is the normal knee biomechanics, realize the best knee joint function process is indispensable important measure (26). Tibial platform fractures are an internal knee fracture, and open reduction internal fixation surgery can restore joint consistency, axial alignment, and joint stability (27), and can be practical while reducing the risk of post-traumatic arthritis early limb activity. Current surgical treatments for tibial platform fractures are internal fixation of internal and lateral locking plate, cortical bone screw and intramedullary nail, and external fixation (28). The surgical mode and rehabilitation concept are also being gradually improved (29). The double repeated tractor closure scheme, internal and lateral minimally invasive incision reduction, and arthroscopic-assisted internal fixation are important trends in the clinical treatment of Schatzker IV–VI tibial platform fracture in the future.

At present, 3D printing technology can reconstruct the tibial platform fracture form into 1:1 physical entity model through computer data, so that clinicians can clearly observe the degree of joint surface damage and the plane fracture collapse position of the tibial platform, and avoid unnecessary soft tissue dissection and reduce postoperative incision complications (30). In addition, 3D printing preoperative planning can also assist clinicians to accurately design the surgical approach of fracture treatment, choose the appropriate internal fixed steel plate, pre-corrected steel plate radian, design screw track and the needle injection position of the external fixed device, so as to obtain more accurate surgical results and improve the fracture reduction quality and operation stability, more vivid realization of preoperative conversation communication with patients and their families, and the price is low, is conducive to patients to receive surgical treatment, so as to improve the compliance with the treatment process (31). 3D printing in Schatzker tibia platform fracture surgery advantage: reduced the limb ischemia time, reduce the risk of tissue necrosis, wound infection, and the use of 3D printing technology can meet the high-precision of the treatment of complex tibial plateau fractures, personalized requirements, can be used to complex tibial plateau fracture surgery simulation and design (32). After meeting strict inclusion and exclusion criteria and no missing cases, all included case data were complete, so there is no recall bias, but the methods of outcome evaluation differed; therefore, measurement bias could exist.

The present study had some limitations: (I) there are no suitable inclusion data after the screening and exclusion of the foreign language literature, and there could be partial publication bias; (II) there is currently an insufficient number of articles on specific 3D printed radiation and economic costs. Heterogeneity may result from differences and diversity in the inclusion criteria of patients in the studies, interventions, and measures across a range of studies, or from variations in the inherent authenticity of those studies. Statistical heterogeneity is used specifically to describe the degree of variation in effect sizes across a series of studies and to indicate variability between studies except for foreseeable chance.

3D printing-assisted Schatzker IV–VI tibial platform fracture has the advantages of reduced surgical time, perspective times, bleeding volume, and complications, and better postoperative functional recovery of patients, which is worthy of clinical application and promotion (33-35). More large clinical RCTs and relevant biomechanical research are needed for theoretical and clinical demonstration.

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Footnote

Reporting Checklist: The authors have completed the PRISMA reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-21-7008/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-21-7008/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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