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CLINICAL ARTICLE

The Efficacy of 3D Printing Model in the Intraarticular Osteotomy in the Treatment of Malunion of Tibial Plateau Fracture

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Objectives: Three-dimensional (3D) printing technology has shown potential advantages in accurate and efficient tibial plateau fracture (TPF) treatment. This technology can provide structural morphology to repair fracture fragments. Here, we summarize our experience with the use of 3D printing technology during intraarticular osteotomy in the treatment of the malunion of TPF.

Methods: The patients who were treated with malunion of TPF in our hospital between January 2015 and December 2018 were retrospectively analyzed. These patients were divided into two groups: the conventional group without 3D-printed model application and the 3D printing group with 3D-printed model application. All patients received the intraarticular osteotomy during operation, and we compared the operation time (min), fracture healing time (months), postoperative knee Rasmussen scores (0–30 points), knee mobility range (0–140°) (the independent *t*-test), fracture reduction evaluation (Biggi's method) (the chi-square test: Fisher's exact test), and postoperative complications of each group.

Results: Twenty-six patients aged 18–65 years who underwent TPF revision operation were included in this study, including 18 patients in the conventional group, and eight patients in the 3D printing group. The follow-up time was 24–48 months, and the operation time was 185 min in the conventional group and 180 min in the 3D printing group. All patients received a bone union at the last follow-up. The healing time was 4.2 months in the conventional group and 3.75 months in the 3D printing group ($p > 0.05$). The respective postoperative Rasmussen scores were 24.6 and 26.2, and postoperative knee mobility was 103.5° and 118.5° in the conventional group and 3D printing group, respectively. Both the Rasmussen scores and degrees of mobility were significantly improved after surgery ($p < 0.05$), and the postoperative knee mobility was significantly better in the 3D printing group *versus* the conventional group ($p < 0.05$). Four patients still had a 2-mm collapse on the articular surface, and two patients still had slight valgus (<5°) in the conventional group. Only one case in the 3D printing group suffered from an articular surface collapse. Superficial wound infections occurred in two patients in the conventional group.

Conclusion: The results show that 3D printing technology is an effective preoperative preparation in the treatment of TPF malunion. This technology can facilitate accurate preoperative planning to select the optimal surgical approach, plan the implant placement, visualize the screw trajectory, and anticipate possible intraoperative difficulties.

Key words: 3D printing technology; Intraarticular osteotomy; Preoperative planning; Tibial plateau fracture malunion

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Introduction

Dysfunction caused by tibial plateau fracture (TPF) malunion upon failure of initial TPF treatment or delayed treatment occurs frequently.[1,2] Revision indications for TPF malunion are generally considered as follows: articular surface collapse ≥5 mm, malalignment (varus or valgus ≥5°), and a posterior slope angle changed by ≥10°.[3–6] Currently, most cases of TPF malunion involve intraarticular tibial plateau deformity and the most widely used operation method is intraarticular osteotomy.[7,8] We previously introduced 25 patients with TPF malunion, and intraarticular osteotomy was performed in 15 cases.[9] However, intraarticular osteotomy remained challenging in some patients, and physicians require a long learning curve to perform an osteotomy perfectly.[10] For old fractures, it was difficult to identify and reposition the comminuted fragments according to a conventional preoperative plan such as a CT scan.[11]

In recent years, three-dimensional (3D) printing technologies have been applied in medical fields and have shown advantages in the accuracy and efficiency of assisted orthopaedic surgery.[12] Currently, 3D printing technology can produce an individualized 1:1 solid prototype of a fracture, which enables surgeons to observe the structural morphology of the fracture fragments. In turn, the model can be used by surgeons in the preoperative plan to determine the surgical approach more accurately to successfully reduce and fix fracture fragments. Moreover, 3D printing technology has been used for TPF treatment. Nie *et al.*[13] reported 11 patients suffering bicondylar TPF, Ozturk *et al.*[14] reported 20 patients with high-energy TPFs, and Lou *et al.*[11] reported 72 patients with TPFs. All confirmed the application of 3D printing technology assisted surgical planning, maximized the possibility of ideal anatomical reduction, and provided individualized information concerning TPFs. However, no reports are available regarding the application of 3D printing technology in TPF malunion.

To explore the use of 3D printing technology in the malunion of TPF, we retrospectively analyzed patients who underwent revision surgery for malunion of TPF in our hospital from January 2015 to December 2018. This study hopes to clarify: (1) the advantages and features of 3D printing technology in the treatment of TPF malunion; and (2) the effects of 3D printing technology on TPF patients' clinical outcomes.

Methods

General Conditions of the Patients

Patients who underwent revision surgery for TPF malunion were retrospectively analyzed in our hospital from January 2015 to December 2018. The patient inclusion criteria were as follows: (1) TPF malunion; (2) imaging examination showing one of the following indications: the tibial plateau articular surface collapsed ≥5 mm, the alignment changed (varus or valgus) by ≥5°, or the tibial plateau posterior slope angle changed by ≥10°; and (3) patients were followed for more than 2 years. Exclusion criteria were open fracture or infection, pathological fracture, and patients unable to receive osteotomy treatment because of poor bone quality or large bone defects. Patients who received intraarticular osteotomy based on an X-ray and CT scan without 3D printing technique were included in the conventional group. Patients who underwent intraarticular osteotomy based on the 3D printing technique were included in the 3D printing group.

Ethical approval was obtained by the ethics committee of the Second Affiliated Hospital of Zhejiang University Medical of College (EC-20220412-1020) (Zhejiang Province, China), and the trial registration number of our hospital was 20200167. Informed consent to participate was obtained from all participants.

Preoperative Planning

After patients were admitted to the hospital, routine knee X-rays, total lower extremity X-rays, and a CT scan of the knee were performed to confirm the characteristics of the malunion. If possible, an MRI scan was performed to check the ligaments. If the patient did not refuse the 3D printing technique, then a 3D-printed model was prepared for the malunited tibial plateau. Some patients refused because of the extra financial costs, which were about 600 US dollars and not covered by insurance. In patients who refused the 3D-printed model, revision surgery was performed based on preoperative examinations such as X-ray and CT scan. Moreover, revision surgery was performed according to both preoperative examinations, such as X-ray and CT scan, and the 3D-printed model in patients who used the 3D-printed tibial plateau model. The location of original fracture lines

TABLE 1 Patients' demographics

Demographics	Conventional group	3D printing group	Statistical analysis
No	18	8	
Gender (male: female)	4:14	2:6	
Age (years)	46.4	41.25	$p > 0.05$ ($t = 0.603$)
Schatzker classification			
Type II	2	0	
Type IV	5	2	
Type V	6	4	
Type VI	5	2	
Time interval (months)	9.9	7.3	$p > 0.05$ ($t = 1.471$)
Preoperative Rasmussen score	16.0	16.5	$p > 0.05$ ($t = 0.677$)
Knee motion activity	63.6	75	$p > 0.05$ ($t = -1.718$)
Articular surface collapse (mm)	6.2	5.8	$p > 0.05$ ($t = 2.080$)
Alignment change angulation (°)	7.4	6.5	$p > 0.05$ ($t = 1.142$)

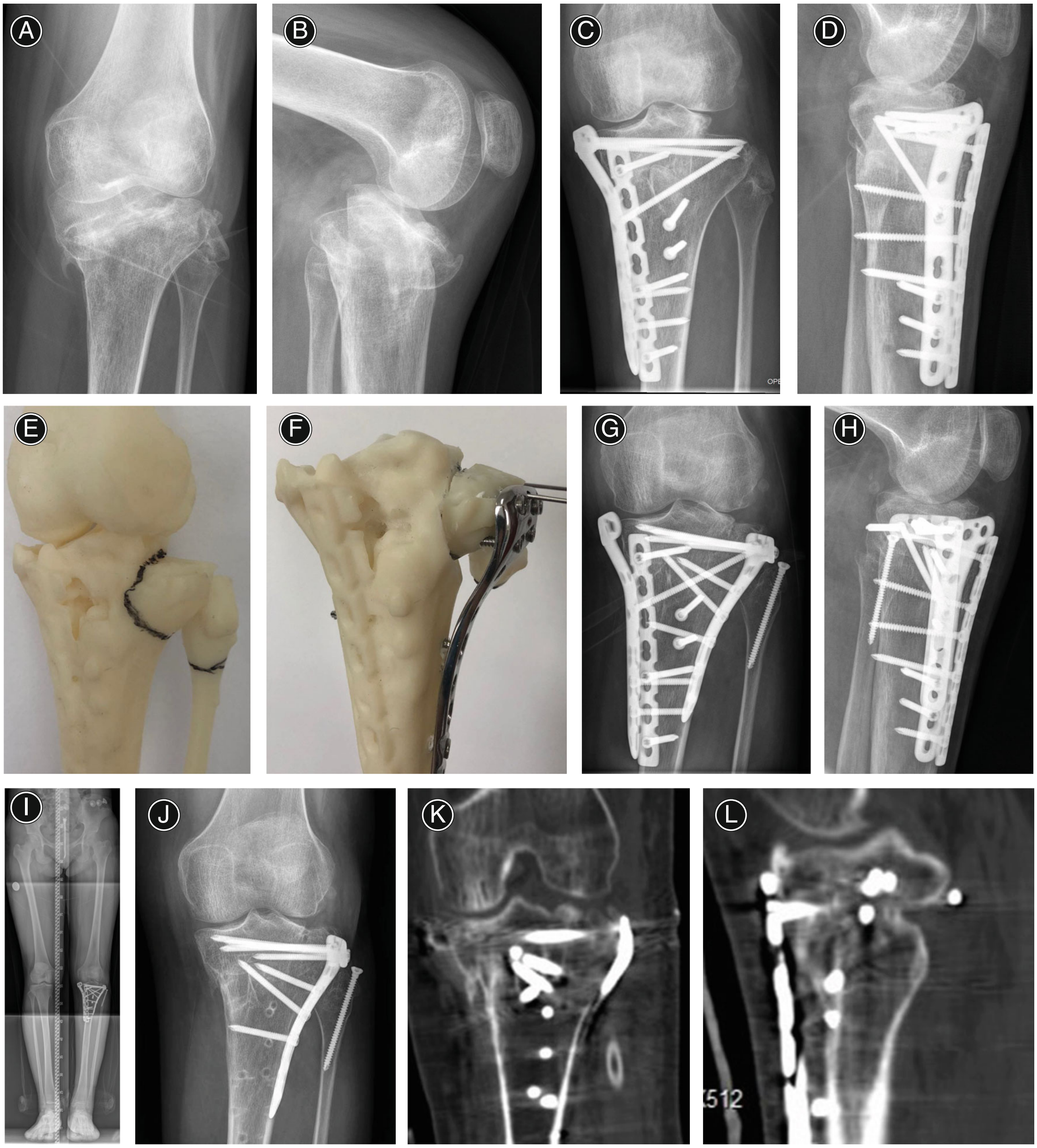

Fig. 1 (A, B) Preoperative knee X-rays of Schatzker type IV fracture in an 18-year-old female. The medial tibial plateau was dislocated, and the posterior tibial plateau slope angle changed >20°. (C, D) Postoperative knee X-rays performed at 6 months after the first operation. The medial plateau was reduced, and the posterior tibial plateau slope angle was 0°, but there was a large articular surface gap (1 cm) on the lateral plateau. (E, F) Pre-operation 3D-printed model and pre-surgery with plate and screws. The patients received lateral plateau osteotomy and fibular head osteotomy to rebuild the articular surface. (G–I) Knee X-rays performed 3 months after the second operation. The results showed a normal articular surface, a normal medial tibial plateau angle, and normal lower limb alignment. (J) The X-ray performed the medial plates were removed at 48 months after first surgery. (K, L) CT scans after the second operation.

and important fracture fragments were identified in patients' 3D-printed models to complete the preoperative plan.

In the 3D-printed model, the characteristics of the fracture were clearly shown and were helpful in designing the surgical plan. In addition, surgeons could perform a pre-operation by doing the intraarticular osteotomy, thus reducing and fixing the fracture *via* a Kirschner wire and plate *in vitro*. How to perform the intraarticular osteotomy and fracture reduction, and which type and size of implant would be best for the case, were known beforehand. Ideal screw types, locations, and orientations were also evaluated.

Surgical Treatment

Patients usually received general anesthesia in supine position with a tourniquet on the affected limb, and the injured limb and the anterior superior iliac spine area were disinfected. The detailed treatment method was based on the pre-established revision surgical strategy. All patients were treated following the intraarticular osteotomy method.

Intraarticular osteotomy was performed as per our previous report.[9] First, the original fracture line was identified using visual observations and C-arm fluoroscopy during surgery. Multiple K-wires were then placed to mark the location, and the position and direction of the osteotomy were confirmed using C-arm fluoroscopy. Next, multi-hole drills were made at the place of the osteotomy using a 2.5-mm drill or K-wire, and intra-articular osteotomy was performed with a sharp bone osteotome. After the scar tissue was cleaned, we reduced the osteotomy plateau and made a temporarily fix *via* K-wires. Autogenous iliac bone fragments were placed into the bone defect. Next, K-wires were used to temporarily fix the iliac bone fragment, and the width of the tibial plateau was restored *via* clamping the medial and lateral tibial plateau. After C-arm fluoroscopy was used to check reduction, a lateral anatomic locking plate with row-screws was used to fix the lateral tibial plateau, and a reconstructed plate or T-shaped plate was used to fix the medial tibial plateau. The patient sometimes needed tibial tubercle osteotomy or fibular head osteotomy; the exact method was adopted as per our previous method.[9]

Postoperative Treatment

Postoperative drainage continued for 24 h, and antibiotics were routinely administered for 48 h to prevent infection. Passive joint function activity was performed immediately after surgery, and partial weight training was started 2 weeks after surgery under the guidance of a physician. Patients were followed every 3 months, and the knee joint pain, joint activity, and radiography were assessed each time.

Outcome Measures

The operation time, fracture healing time, fracture reduction, knee function score, knee range motion, and postoperative

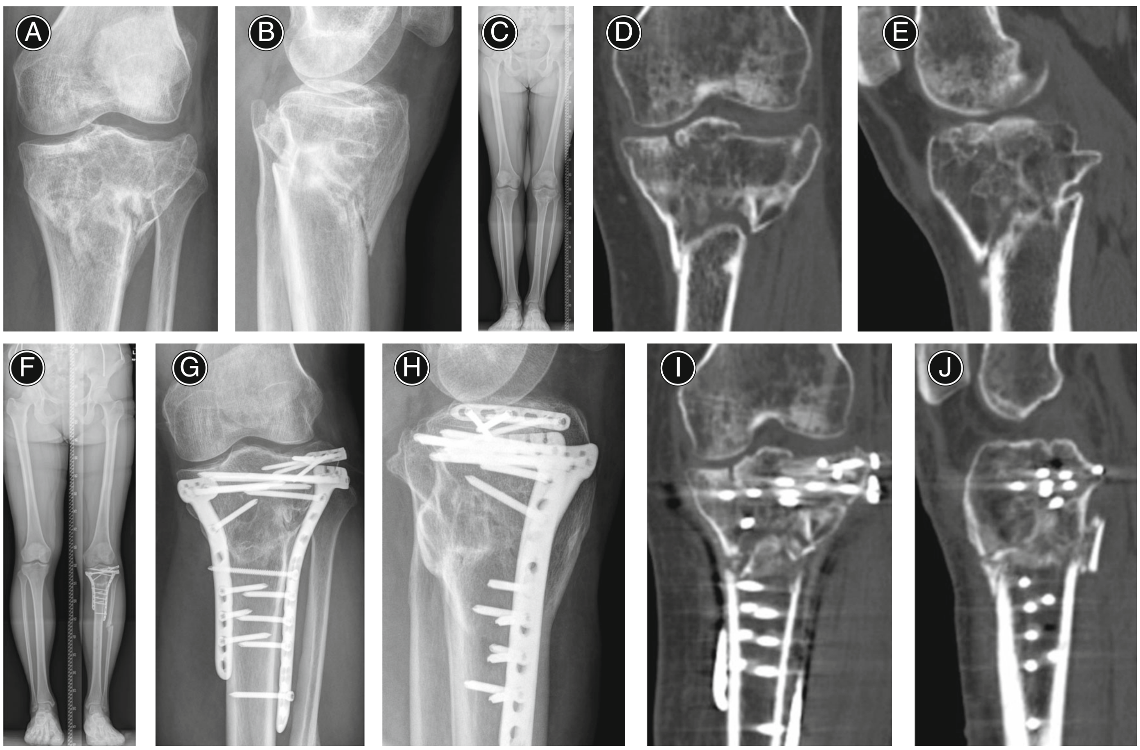

Fig. 2 (A–C) Preoperative knee X-rays of Schatzker type V fracture in a 31-year-old female. The lateral plateau articular surface was depressed, and the posterior tibial plateau slope angle changed >10°. The patient underwent an operation 4 months after the injury. (D, E) CT scans before operation. (F–H) Knee X-rays at 12 months after operation showing reduced lateral plateau articular surface. The posterior tibial plateau slope angle was 0°, and the lower limb alignment was normal. The patient underwent a lateral plateau osteotomy and proximal tibial metaphyseal osteotomy. (I, J) The postoperative CT scans at 3 months after operation indicated that the lateral plateau articular was reduced and the posterior tibial plateau slope angle was normal.

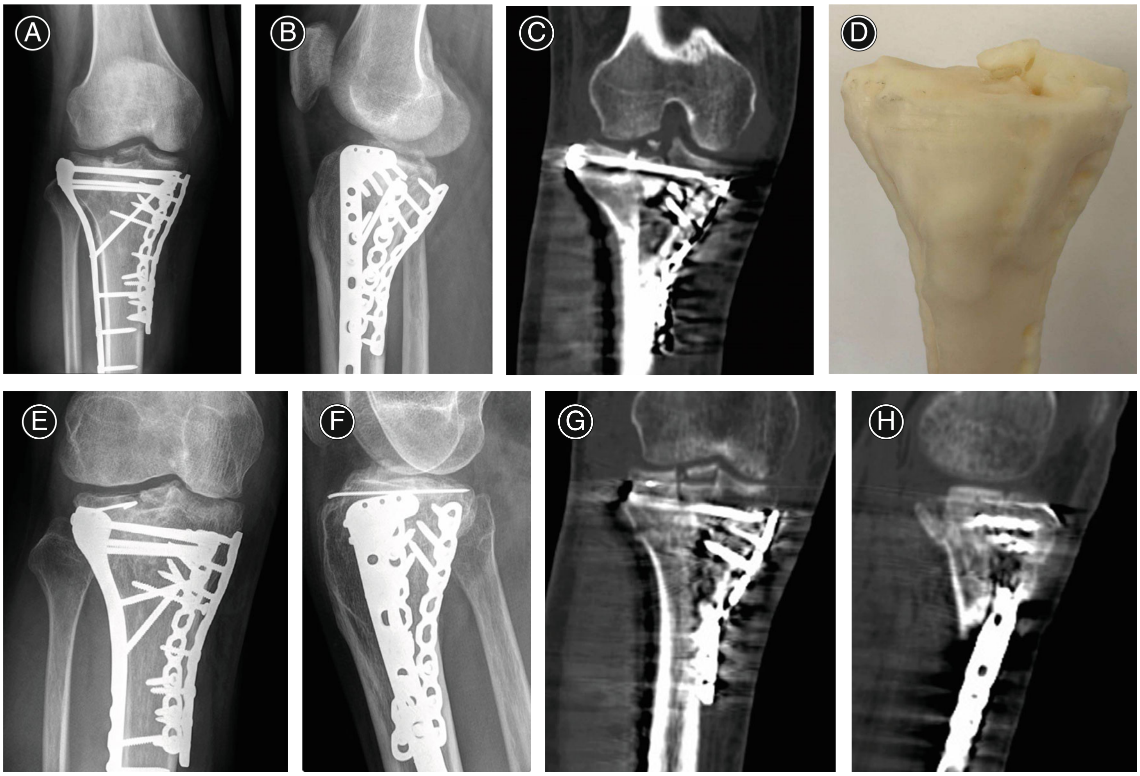

Fig. 3 (A–C) Preoperative knee X-rays and CT of malunion of Schatzker type V fracture in a 33-year-old female. The lateral plateau articular surface was depressed, and the lower limb alignment was valgus. The patient underwent her second operation 6 months after the first operation. (D) 3D-printed model of the malunited tibial plateau (E, F) Knee X-ray at 1 year after the operation. The results showed that the lateral plateau articular surface was reduced, with normal lower limb alignment. (G, H) The postoperative CT scans at 1 month after the operation showed that the lateral plateau articular space was reduced.

complications of each patient were recorded. The Rasmussen score system[5] was used to evaluate knee joint function according to the standard clinical and radiological criteria to judge the healing time of the fracture. The method proposed by Biggi *et al.*[15] was used to evaluate fracture reduction.

Statistical Analysis

The preoperative and postoperative Rasmussen score and knee joint mobility range were compared *via* a paired sample *t*-test between the conventional group and the 3D printing group. The preoperative articular collapse, the degree of alignment change, operation time, fracture healing time, knee Rasmussen score, and knee mobility range were compared between the conventional group and the 3D printing group using an independent *t*-test. The fracture reduction evaluation was compared between the conventional group and the 3D printing group using the chi-square test (Fisher's exact test). $p < 0.05$ was considered significant. SPSS software (22nd edition; SPSS) was used for statistical analyses.

Results

General Results

Twenty-six patients were analyzed, including 18 patients in the conventional group and eight patients in the 3D printing group. There were eight males and 18 females aged 18–65 years (average 46.2 years). Schatzker classification of the TBF: type II in two cases, type IV in five cases, type V in six cases, and type VI in five cases in the conventional group and type IV in two cases, type V in four cases, and type VI in two cases in the 3D printing group. The time interval between two surgeries was 1–24 months (average 9.9 months) in the conventional group and 2–15 months (average 7.3 months) in the 3D printing group. The preoperative Rasmussen score was 9–21 points (average 16.0 points) in the conventional group and 11–20 points (average 16.5 points) in the 3D printing group. The knee motion activity was 20–100° (average 63.6°) in the conventional group and 40–100° (average 75.0°) in the 3D printing group. The average collapse of the articular surface was 6.2 mm in the conventional group and 5.8 mm in the 3D printing group. The average change in angulation of the lower limb alignment

TABLE 2 Clinical results of our patients

	Conventional group	3D printing group	Statistical analysis
No	18	8	
Operation time (mins)	185	180	$p > 0.05$ ($t = 0.322$)
Fixation method			
Bilateral plates	8	2	
Lateral plate	7	6	
Medial plate	2		
Three plates	1		
Fracture healing time (months)	4.2	3.75	$p > 0.05$ ($t = 0.801$)
Postoperative Rasmussen score	24.1	26.2	$p > 0.05$ ($t = -1.615$)
Knee motion activity	103.5°	118.5°	$p < 0.05$ ($t = -2.971$)
Reduction evaluation (case)			$p = 0.833$
Articular surface collapse	4	1	
Mild valgus	2	0	

was 7.4° in the conventional group and 6.5° in the 3D printing group (Table 1).

All patients were followed up for 24–48 months (mean 32.6 months), and the total surgery time was 90–300 min (mean 185 min) in the conventional group and 140–220 min (mean 180 min) in the 3D printing group. In the conventional group, eight patients were treated using intraarticular osteotomy and bilateral plate fixation, seven patients were treated with intraarticular osteotomy and lateral plate fixation (Figs 1 and 2), two patients were treated using intraarticular osteotomy and medial plate fixation, and one patient was treated using intraarticular osteotomy and medial + lateral + posterior plate fixation. In the 3D printing group, two patients were treated using intraarticular osteotomy and bilateral plate fixation (Fig. 3); six patients were treated using intraarticular osteotomy and lateral plate fixation.

Clinical Function

In all patients, bone healing was achieved at the last follow-up, and the fracture healing time was 3–6 months with an average of 4.2 months in the conventional group and an average of 3.75 months in the 3D printing group ($p > 0.05$). None of the patients reported significant knee pain and could walk while bearing full weight. The postoperative Rasmussen score was 22 to 29, average 24.6, and postoperative knee mobility was 90° to 125° (average 103.5°); both were significantly improved after surgery ($p < 0.05$) in the conventional group (preoperative Rasmussen score 16.0, knee mobility 63.6°). The postoperative Rasmussen score was 23 to 29, with an average of 26.2, and the postoperative knee mobility was 105° to 130°, with an average of 118.5°. Both scores were significantly improved after surgery ($p < 0.05$) in the 3D printing group (preoperative Rasmussen score 16.5, knee mobility 75°). The postoperative Rasmussen score was not significantly different between the conventional group and 3D printing group ($p > 0.05$), but the postoperative knee mobility was significantly better in the 3D printing group ($p < 0.05$). The reduction evaluation was as follows: four patients still exhibited 2 mm of articular surface collapse, and two patients still had mild valgus (less than 5°) in the conventional group; one case exhibited 2 mm of articular surface collapse, and all patients achieved normal lower limb alignment in the 3D printing group ($p > 0.05$). Thus, the fracture reduction seemed better in the 3D printing group. The excellent and good rate was 100% in both groups (Table 2).

Complications

Two patients in the conventional group developed superficial infections after surgery. The infection manifested as wound exudate around 2 weeks after surgery and healed after two treatments with vacuum negative pressure. Both patients had a Schatzker type V fracture, and a long surgical time (200 and 180 min) was required. Patients that still exhibited postoperative articular surface collapse or mild valgus lower limb alignment had no obvious or limited walking ability. None of the internal fixations failed. There was no postoperative fascial compartment syndrome, and no postoperative complications, such as vascular and nerve injury.

Discussion

The results indicate that 3D-printing technology is an effective preoperative approach for accurate intraarticular osteotomy. This technique offers better fracture reduction and a better postoperative knee mobility in the treatment of malunion of TPF. Many studies have described the use of 3D-printing technology in the treatment of orthopaedic diseases.[16–18] A 3D-printed model may better define anatomical relationships and benefit the surgical approach.[19] The management of TPF malunion remains among the most challenging tasks for orthopaedic trauma surgeons because complex intraarticular osteotomy is needed to achieve an anatomical reduction and good fixation in TPF malunion. Many reports discuss the use of the 3D-printing technology in orthopaedic trauma surgery,[20–22] but no research is available on the 3D-printing technology with traditional preparations in TPF malunion revision surgery.

1. The advantages and features of 3D printing technology in the treatment of TPF malunion

Personalized surgery has been recognized as the most appropriate and optimized surgery for TPF malunion. This approach requires strict and accurate preoperative planning and can ensure successful surgery.[23] For the preoperative planning of TPF malunion, the appropriate surgical approach, method of intraarticular osteotomy, and the choice of implants are important.[24,25] A 3D-printed model can provide very direct and sufficient visual information of the TPF malunion to physicians in preoperative planning, and physicians can use the most suitable surgical approach and most effective osteotomy method to correct the deformity.[26] After successful intraarticular osteotomy and fracture reduction, a suitable internal fixation should be chosen for stable fixation. However, not all commercially available plates match the bone surface in the TPF malunion, and the screw trajectories of the locking plates cannot always satisfactorily fix the fragments.[27] A 3D-printed model can help decide if the plates match the appropriate screw trajectories during preoperative planning. Thus, the 3D-printed model in TPF malunion plays an important role not only in the surgical approach and osteotomy method but also in the choice of fixation.

2. The effects of 3D printing technology on TPF patients' clinical outcomes.

Our results showed the 3D printing technology in malunion of TPF improved postoperative knee mobility and fracture reduction, but there were no significant differences in the operation time, fracture healing time, knee Rasmussen score, and complications. Chen *et al.*[21] demonstrated that the 3D printing technology reduced the frequency of intraoperative fluoroscopy, blood loss volume, and operative time. It did not improve postoperative function *versus* routine treatment in distal radial fracture. They thought that the 3D-printed model was useful for communication with patients. Other reports[12–14] showed that the operation time, blood loss, and number of intra-operative fluoroscopy for the 3D printing group exhibited statistically significant differences compared with the traditional surgery group in TPFs. A recent review[12] showed that a 3D-assisted surgery resulted in reduced operation time (104.7 *vs* 126.4 min; $p < 0.01$), less blood loss (241 ml vs 306 ml; $p < 0.01$), and decreased frequency of fluoroscopy (5.8 *vs* 9.1 times; $p < 0.01$) in TPF. No differences in functional outcome were found (HSS: 88.6 *vs* 82.8; $p = 0.23$). Their clinical results were somewhat different than ours. In our study, the operative time, fracture healing time, and knee functional scores were not significantly different between two groups, but the fracture reduction and knee mobility were better in 3D group. The different results were caused by the choice of inclusion criteria. Our cases include malunion of TPF, which is the most complicated disease in TPF, but previous reports describe fresh fractures. It is more difficult to make intraarticular osteotomy, fracture reduction, and plate fixation in our cases; thus, the operation time and blood loss had no significant difference. Though the knee functional score had no difference as in other reports, we could achieve better fracture reduction *via* a 3D-printed model. A stricter and more accurate preoperative plan leads to accurate osteotomy, better fracture reductions with suitable fixation, and a knee mobility range that was better in the 3D printing group. We thought the 3D printing technology could lead to a more accurate preoperative plan and better fracture reduction and better knee mobility in malunion of TPF. These are critical in the treatment of malunion of TPF. The 3D-printed model was also useful during communications with patients.

3D printing technology still has some disadvantages: First, it needs extra hospitalization cost. Second, model printing also needs time, and therefore the technology is more suitable for old fractures. Third, 3D-printed models can only display bone shape and does not consider soft tissue such as blood vessels, ligaments, and cartilage. In fact, we should consider soft tissue management in the treatment of malunion of TPF.

Strengths and Limitations

There are several highlights that strengthen our conclusions. Few reports have focused on 3D printing technology-assisted osteotomy treatment for the malunion of TPF. Our research design was also well-controlled; patients were divided into two groups for comparison, and various fracture types were included. The follow-up time was relatively long, and the clinical results were relatively complete. Our study has a few limitations that may impact the conclusions. First, the study is a retrospective study with non-randomized-controlled design. The sample size is small, which may limit the reliability of the results. Second, group assignments (conventional planning group or 3D printing group) were made based on the patient's willingness, which might influence the final conclusions. Third, malunion TPF includes Schatzker type IV, V, and VI fractures, which were pooled to explore the clinical efficacy of the preoperative 3D printing model. The heterogeneity of fracture types may also influence the results.

Conclusion

Today, 3D-printing technology is an effective preoperative preparation in the treatment of TPF malunion. This technique can facilitate accurate preoperative planning to select the optimal surgical approach, plan implant placement, visualize screw trajectory, and anticipate possible intraoperative difficulties. We achieved accurate intraarticular osteotomy, improved fracture reduction, and improved postoperative knee mobility with a 3D-printed model. The use of 3D printing technology has value in the malunion of TPFs, but larger sample sizes are needed to understand the influence of this approach on clinical treatment and results. Meanwhile, higher resolution 3D-printed models may be needed in clinical practice.

Authors' Contributions

LJ Jiang performed the surgery and was a major contributor in writing the manuscript. L Huang performed the surgery and followed up on patients. H Li gave the idea and collected the patients' data. L Huang took responsibility for the integrity of the work from inception to published article. All authors read and approved the final manuscript.

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Declarations

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and that all authors are in agreement with the manuscript.

Disclosure

There was no conflict of interest and any financial disclosure statement.

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