

## Original Article

# Comparison of three-dimensional printing and conventional imaging in surgical treatment of Tile C pelvic fractures: a long-term follow-up study

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**Abstract:** *Objective:* Three-dimensional (3D) printing model has been proved to facilitate the operative procedure of complex fractures. The aim of this study is to investigate the near and distant efficacy of three-dimensional printing (3D printing) assisted operation in the surgical treatment of Tile C pelvic fractures. *Methods:* Sixty-four patients with Tile C pelvic fractures were analyzed retrospectively from June 2004 to June 2006. In experimental group (n=28), 3D printing model of the pelvic fracture was used to guide the surgery. In control group (n=36), the surgery was guided by traditional radiography and CT examination. The operation time, intraoperative blood loss and transfusion, postoperative reduction, fracture healing time and complication rate as well as functional recovery at 1 or 10 years post the operation were compared between the two groups. *Results:* There was no difference between the age, gender, body weight or injury severity score of the two groups. The operation time ( $128.9 \pm 59.2$  vs.  $191.4 \pm 85.1$  min), intraoperative blood loss ( $481.4 \pm 103.2$  vs.  $771.1 \pm 114.4$  mL) and blood transfusion ( $345.1 \pm 75.4$  vs.  $736.6 \pm 125.9$  mL) of experimental group were significantly less than those of control group ( $P < 0.05$ ). Fracture healing time ( $12.0 \pm 0.6$  vs.  $12.3 \pm 0.5$  weeks) and complication rate (3.6% vs. 8.3%) were homogeneous between the two groups. According to the Matta standard, the rate of good or excellent grading in experimental group was significantly higher than that in control group (92.9% vs. 66.7%,  $P < 0.05$ ). At 1 year postoperatively, the proportion of patients with excellent or good Majeed grading in experimental group (92.9%) was significantly higher than that in control group (69.4%,  $P < 0.05$ ). However, that difference between the experimental and control group (85.7% vs. 66.7%) at 10 years postoperatively was not statistically significant ( $P > 0.05$ ). *Conclusions:* Besides the advantage of improved perioperative outcomes, 3D printing assisted surgery could also improve long-term clinical results of Tile C pelvic fractures.

**Keywords:** Pelvic fracture, rapid prototyping, clinical outcome, long term follow up

## Introduction

It is estimated that about 3% of the skeletal fractures happening in the pelvis, which are usually caused by high-energy injuries [1]. Open reduction and internal fixation are still considered to be the main treatment for complex pelvic fractures [2]. In order to achieve anatomic reduction and optimal outcome, the precise anatomy and type of the fracture needs to be clarified preoperatively. Currently, this process mainly relies on the comprehension of two-dimensional imaging method such as CT or MRI, which is difficult even for a skilled sur-

geon due to the complexity of its anatomic structure [3]. Moreover, the irregular and non-uniform shape of the pelvis necessitates tailored internal fixation, which is usually conducted by bending the plates during the operation. This process is often time-consuming and inevitable deficient, consequently increasing the risk of iatrogenic injury and postoperative malunion [4]. Therefore, there is an urgent demand to improve the surgical treatment of pelvic fractures.

Recently, the rapid development of 3D printing technique with the support of CT scanning data

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have made it feasible to make tangible models of complex fracture with an accuracy of submillimetric degree [5]. This would be helpful for the surgeon to fully understand the fracture pattern and to make detailed surgical plan. Moreover, these models could serve as accurate and individualized simulation to facilitate the surgical training process. In recent years, the 3D printing assisted operation has been proved to facilitate the surgical process of pelvic fractures [6]. However, its long-term effect on the clinical results remains to be clarified.

In this study, we compared the efficacy of 3D printing model or two-dimensional imaging method in the treatment of Tile C pelvic fractures, with an observation period for up to 10 years.

### Materials and methods

#### *Patients*

A total of 64 patients with Tile type C pelvic fractures were retrospectively studied. These patients received open reduction and internal fixation between June 2004 to June 2006 at our hospital. According to whether the use of 3D printing model, these patients were divided into experimental group or control group. In experimental group, 28 cases were enrolled, with 3D printing model of pelvic fracture being produced before the operation. In control group, the group without 3D printing fracture models, there were 36 cases. The age, weight, sex and Injury Severity Score (ISS) of the two groups were compared. Before being included in the study, all the patients had given informed consent. This study was performed in accordance with the 1964 Helsinki Declaration as revised in 2000 and authorized by the Human Research Ethics Committee of the Fourth Military Medical University.

#### *Manufacture of 3D printing models*

Before the operation, all the patients received X-ray plain film and two-dimensional (2D) CT scan of the pelvic. CT scanning was performed in an accuracy of 1 mm. In experimental group, the CT scan data were imported into Mimics 14.0 software (Materialise, Belgium) for the reconstruction of virtual 3D pelvic model. Then the 3D model data of STL format was imported into rapid prototyping system (Yinhua Rapid

Prototyping Technology Inc., Beijing) to build a full scale model of the pelvis. The specific type of the pelvic fracture was clarified by careful observation of the 3D fracture model.

#### *Surgical simulation*

In experimental group, simulated operation was performed through the most appropriate approach. In order to select the optimal hardware for internal fixation, different types of plates were compared with each other. The selected plate was bent to fit the surface of the fracture region and then fixed on the 3D printing model with screws. The number, size and direction of the screws were explored to reach the best effect of fixation. At the end of the surgical simulation, the pre-bent plate and screws were taken out and sterilized for the actual operation.

#### *Operative procedures*

The surgeries of experimental group were performed according to the surgical simulation. In control group, the surgical procedure was conducted under the conventional guidance of preoperative X-ray plain film and 2D CT scanning results. At the end of surgery, intraoperative fluoroscopy was taken to make sure that satisfactory reduction of the fracture had been achieved, and the plates or screws being reliably placed. The operation time, intraoperative blood loss and blood transfusion were recorded. All the surgical procedures were performed by one experienced surgical team led by an expert surgeon.

#### *Postoperative care and follow-up*

During the perioperative period, smoking and drinking in all the cases were strictly banned. Antibiotic prophylaxis was administered intravenously before the operation and for the following 72 hours. Nadroparin calcium was administered for 30 days after the operation to prevent the thrombosis of deep vein. Analgesic therapy was given to all patients for the first postoperative 24 hours. The drainage was pulled out within 48 hours post the operation. Patients were allowed to sit up from postoperative day (POD) 1 and to perform static muscular exercise from POD 3. Since POD 7, patients were encouraged to take passive motion of lower limbs without weight-bearing. Partial wei-

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**Table 1.** General characteristics of the patients

Measure	Experimental group (n=28)	Control group (n=36)	P
Age (years, mean ± SD)	32.4 ± 7.6	34.5 ± 8.4	0.305
Weight (kg, mean ± SD)	68.3 ± 5.5	66.4 ± 6.2	0.206
Gender (male/female)	18/10	28/8	0.272
Injury severity score (n, mean ± SD)	18.4 ± 15.3	17.2 ± 12.1	0.727

**Table 2.** Perioperative parameters and fracture healing time (mean ± SD)

Measure	Experimental group (n=28)	Control group (n=36)	P
Operation time (min)	128.9 ± 59.2	191.4 ± 85.1	0.002
Intraoperative blood loss (mL)	481.4 ± 103.2	771.1 ± 114.4	<0.001
Intraoperative blood transfusion (mL)	345.1 ± 75.4	736.6 ± 125.9	<0.001
Fracture healing time (week)	12.0 ± 0.6	12.3 ± 0.5	0.330

ght-bearing walking with a crutch was started from 6 weeks post the operation, while full weight-bearing walking beginning from 3 months post the operation.

The healing time of fracture was recorded when the patients reached complete radiographic healing. Reduction of the fractured pelvis at POD 1 or 2 was assessed and graded according to the Matta standard [7]. At 1 and 10 years postoperatively, the patients' functional recovery was assessed and classified according to the Majeed standard [8]. Complications including infections, nerve and vascular injuries, bone fragments displacement, osteoarthritis, malunion or nonunion were observed and recorded.

### Statistical analysis

All the data were independently collected by two reviewers and subsequently entered into SPSS 18.0 software package for further analysis. Student's t-test and Pearson's Chi-squared test were respectively applied for quantitative and qualitative comparisons. In this study, a *P* value less than 0.05 was considered as statistically significant.

### Results

The differences between the gender, age, weight, and injury severity score (ISS) of the two groups were not statistically significant (*P* > 0.05, **Table 1**). In experimental group, full scale 3D models of fractured pelvises were suc-

cessfully printed based on the CT scan data. Patients in experimental group had smoothly underwent the surgical procedure in accordance with the preoperative surgical simulation. The operation time of experimental group was, on average, 62.5 minutes less than that of control group. The intraoperative blood loss and blood transfusion for experimental group had an average of 289.7 and 391.5 mL less than control group, respectively. The difference between

the operation time, blood loss and blood transfusion of the two groups were all statistically significant (*P* < 0.05, **Table 2**). The difference between the fracture healing time of the two groups was not statistically significant (*P* > 0.05, **Table 2**).

The proportion of postoperative Matta ratings with anatomic or satisfactory in the experimental (92.9%) group was significantly higher than that in the control (66.7%) group (*P* < 0.05, **Table 3**). At 1 year post the operation, the proportion of Majeed score with excellent or good in experimental group was significantly higher than that in control group (*P* < 0.05, **Table 4**). However, at 10 years postoperatively, the difference between proportion of patients in the two groups with excellent or good Majeed grading was not statistically significant (*P* > 0.05, **Table 4**).

During the perioperative period, one case of incision infection and another case of femoral anterolateral nerve injury were observed in control group. In experimental group, only one case of femoral anterolateral nerve injury was observed. At 10 years post the operation, one case of hip joint osteoarthritis was observed in control group. The difference between the total incidence of complications in the two groups was not statistically significant (*P* > 0.05, **Table 5**).

### A typical case

A 45-year-old male was admitted with a history of pain and limited motion of the left hip,

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**Table 3.** Comparison of postoperative Matta ratings (n, %)

Group	Anatomic	Satisfactory	Unsatisfactory	Rate of anatomic or satisfactory reduction
Experimental group (n=28)	20 (71.4%)	6 (21.4%)	2 (7.1%)	26 (92.9%)
Control group (n=36)	8 (22.2%)	16 (44.4%)	12 (33.3%)	24 (66.7%)
<i>P</i> =0.015				

**Table 4.** Comparison of postoperative Majeed ratings (n, %)

Postoperative time (year)	Group	Excellent	Good	Fair	Failed	Rate of excellent or good
1	Experimental group (n=28)	20 (71.4%)	6 (21.4%)	2 (7.1%)	0	26 (92.9%)
	Control group (n=36)	18 (50%)	7 (19.4%)	11 (30.6%)	0	25 (69.4%)
<i>P</i> =0.028						
10	Experimental group (n=28)	18 (64.3%)	6 (21.4%)	4 (14.3%)	0	24 (85.7%)
	Control group (n=36)	18 (50%)	6 (16.7%)	12 (33.3%)	0	24 (66.7%)
<i>P</i> =0.144						

**Table 5.** Comparison of postoperative complications (n, %)

Complications	Experimental group (n=28)	Control group (n=36)	<i>P</i>
Total number	1 (3.6%)	3 (8.3%)	0.625
Incision infection	0	1	
Nerve injury	1	1	
Hip joint osteoarthritis	0	1	

which had lasted for 7 days after falling from a 5-meters height. No anomaly was found in the examination of spine or head. His vitals were stable, too. X-ray plain film and 3D reconstruction of the CT scan showed severely comminuted fracture of the left pelvis (**Figure 1A**). The preoperative surgical planning was performed along with the following steps: 3D reconstruction of the CT scan data (**Figure 1B**), production of the 3D printing model (**Figure 1C, 1D**), simulation of the surgical procedure including precontouring of reconstructive plates and determination of the screw sizes and trajectories (**Figure 1E**). Then the selected plates and screws were sent for sterilization in order to be used in the actual operation.

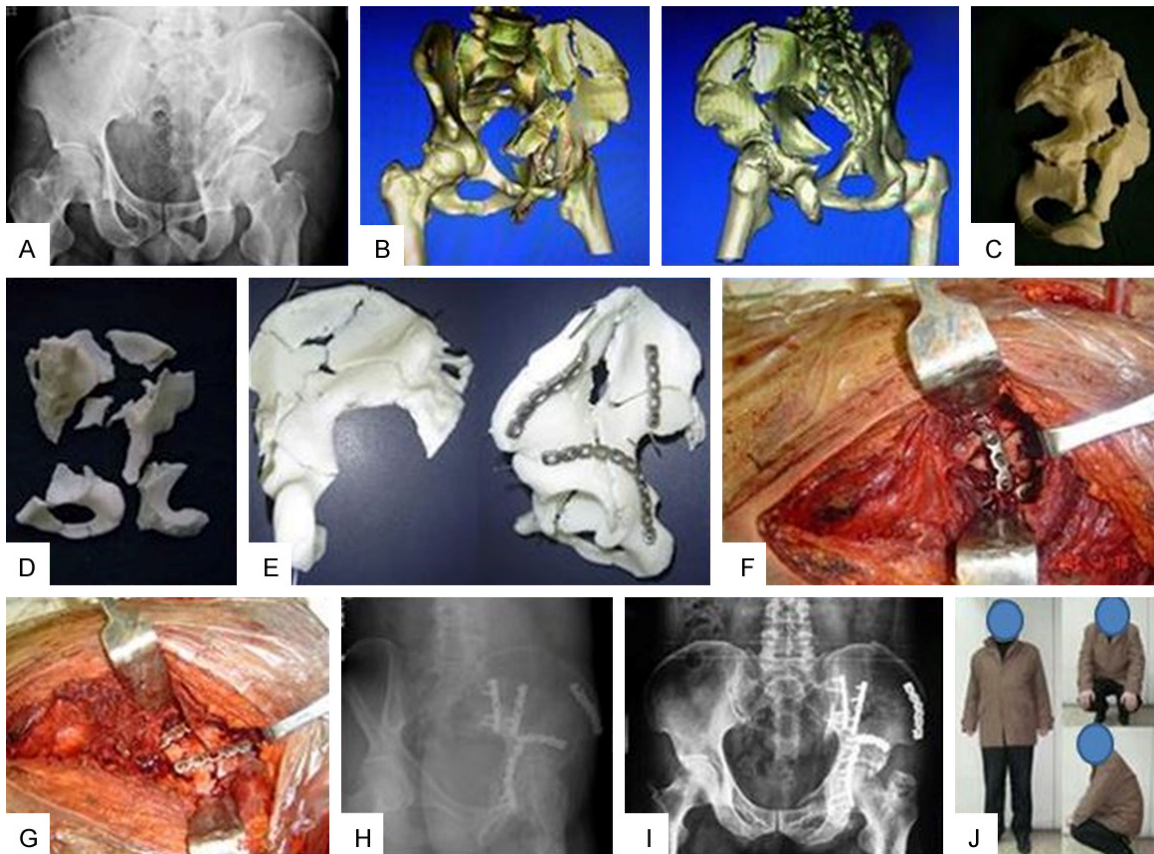
In the actual surgery, the fracture was exposed anteriorly through the ilioinguinal approach and posteriorly through the Kocher-Langenbeck approach. After successful reduction of the fragments, the left iliac crest was fixed with a 6-hole reconstructive plate according to the simulated operation. However, because of the

limited length of the posterior incision, the roof and posterior column of left acetabulum were separately fixed with 5-hole and 6-hole reconstructive plate in practice (**Figure 1F**), instead of being jointly fixed with a 11-hole plate in the simulation. Similarly, the left iliac ala was actually fixed with 2 pieces of 5-hole reconstructive plates instead of one in the simulated surgery, partly due to its severe fragmentation (**Figure 1G**). The process of the surgery went smoothly with a total operation time of 3 h 50 min, of which the instrumentation took 40 min. The intraoperative blood loss and blood transfusion were 450 mL and 300 mL, respectively. The anteroposterior pelvic X-ray plain film showed anatomic reduction with a displacement of 1 mm at POD 2 (**Figure 1H**) and completely normal at 10 years post the operation (**Figure 1I**). At 1 year after the surgery, the patient's pelvic function reached normal, with a Majeed score of 88. At 10 years post the operation, the patient showed excellent pelvic functional recovery (**Figure 1J**) with a Majeed score of 90.

### Discussion

Reconstructive surgeries of pelvic fracture are always complex and difficult, mainly due to its complicated anatomic structure, irregular shape, and the risk of injury to adjacent important vessels and nerves. Serious complications including lower limb shortening, pelvic deformity

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**Figure 1.** A 45-years-old male with severe comminuted fracture of the left pelvis. A. Preoperative pelvic anteroposterior plain film; B. 3D reconstruction of the preoperative CT scan data; C, D. 3D printing model of the severely fractured pelvis; E. 3D model of the pelvis after surgical simulation; F. Place plates in the roof and posterior column of left acetabulum; G. Place plates in the left iliac ala; H. Pelvic anteroposterior plain film at POD 2; I. Pelvic anteroposterior plain film at 10 years after the operation; J. Functional recovery of case 2 at 10 years after the operation.

and nerve injury may subsequently occur, leading to a dramatically influenced aesthetic appearance as well as the quality of life [9]. Thus, it is of great importance for surgeons to have full understanding of the fracture, making detailed and reliable preoperative plan and performing individualized treatment to the patient.

In recent years, the combination of rapid prototyping technique and high-accuracy imaging modalities, namely the 3D printing technique, has been shown to play an important role in the surgical treatment of complex fractures [10, 11]. Comparing with the other traditional methods, the 3D printing assisted operation can improve the treatment of these fractures based on the following reasons. First, an accurately printed full-scale model of the fracture enables the surgeons to observe, touch and measure its details. Therefore, the surgeon's

understanding of these fractures could be improved, leading to a better prognosis of the patient and more intuitive doctor-patient communications [12]. Second, since these fractures are highly heterogenous, there is no universal surgical method for them. So it is necessary to design individualized surgical plan for each patient. Based on the printed 3D fracture model of one specific patient, an optimized custom-made surgical plan could be established and used to improve the outcome of the treatment [13]. Third, with a tangible 1:1 model of the fracture, surgeons can repeatedly practice the pre-planned operative procedures, choose the most appropriate way for internal fixation, and bend the plates to accurately fit the surface of fracture site before the actual surgery. These are all helpful for the reduction of operation time and minimization of intraoperative radiation dose, blood loss and soft tissue injury [14].

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Recently, there has been several studies about the application of 3D printing assisted surgery in the treatment of pelvic or acetabular fractures. The preliminary results of these researches are predominantly promising [15, 16]. However, as this method still being in its infancy, few studies about its long-term effect have been reported. For this reason, we carried out a retrospective long term follow-up study about 3D printing assisted surgery in the treatment of Tile C pelvic fractures.

The two groups were homogeneous in terms of age, sex, weight and ISS. Comparing with the control group, the experimental group showed significantly reduced operation time ( $191.4 \pm 85.1$  vs.  $128.9 \pm 59.2$  min), decreased intraoperative blood loss ( $771.1 \pm 114.4$  vs.  $481.4 \pm 103.2$  mL) and blood transfusion ( $736.6 \pm 125.9$  vs.  $345.1 \pm 75.4$  mL). The proportion of anatomic or satisfactory reduction in experimental group (92.9%) was also significantly higher than that in control group (66.7%). These findings are consistent with previous studies, suggesting that the assistance of 3D printing model are helpful for the surgical process as well as the improvement of diaphysis accuracy in complex pelvic fractures [17].

During the perioperative period, only one case of incision infection was found in the control group. This could be attributed to the relatively extended operation time of the control group [18]. There was one case in each group suffering from postoperative injury of the femoral anterolateral nerve, which was usually caused by unclear understanding of the regional anatomy and inappropriate operative procedure [19]. However, there were no significant differences between the incidence of complications as well as fracture healing time of the two groups, indicating that the assistance of 3D printing in the surgical procedure does not play a conclusive role in the postoperative healing process of complex pelvic fractures.

At 10 years post the operation, there was only one case in the control group suffering from hip osteoarthritis. None of the patients in experimental group was observed to have similar symptoms. This could be attributed to better reduction of intra-articular fractures achieved in the experimental group. At 1 year post the operation, the proportion of Majeed score

with excellent or good in experimental group (92.9%) was significantly higher than that in control group (69.4%). However, at 10 years post the operation, the difference between that proportion in experimental group (85.7%) and in control group (66.7%) was not significant. This suggests us that, comparing with conventional imaging method guided surgery, the 3D printing assisted surgery could improve the long-term functional recovery of patients with complex pelvic fractures. However, further studies are required to clarify this effect for a period up to 10 years.

The limitation of our study is its limited case number and retrospective character. Thus, we need to conduct a large scale prospective study to improve the reliability of our results.

In summary, the use of 3D-printing models in the preoperative planning and surgical simulation of complex pelvic fractures can improve the short-term outcome by shortening the operation course, reducing the intraoperative injury and enhancing the accuracy of reduction. The same trend also holds true for the postoperative long-term improvement of patient's functional recovery. Surgical treatment with the assistance of 3D-printing technology will provide the surgeon a simpler treatment method with more safety and efficiency, therefore possessing great promise in the forthcoming future.

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### Disclosure of conflict of interest

None.

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