The Application of 3D Printing Technology in the Classification and Preoperative Planning of Complex Tibial Plateau Fractures

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Abstract

Background: Tibial plateau fracture is one of the common intra-articular fractures in clinic. And its accurate classification and treatment is a difficult problem for orthopedic surgeons. Our research aims to investigate the application value of 3D printing in the classification and preoperative planning of complex tibial plateau fractures.

Methods: 28 cases of complex tibial plateau fractures diagnosed and treated in our hospital from January, 2017 to January, 2019.01 were analyzed. Preoperative spiral CT scan was performed and then DICOM data were input into the computer. We use Mimics to process data. And 3D printing technology was applied to print the 3D model of fracture (1:1). Combined with the 3D printed model, the tibial plateau fractures were subdivided into seven types according to the geometric plane of the tibial plateau. The surgical approach was determined on the 3D printed model. And then simulated operations such as accurate reduction of fracture and selection of plate placement were performed.

Results: The reconstructed 3D model of tibial plateau fracture can accurately reflect the direction of fracture components displacement and the degree of plateau collapse. Also, it can help with the preoperative reconstructive plan for the tibial plateau fracture. The intraoperative fracture details were basically the same as the 3D printed model. And The fracture surface of the tibial plateau of all 28 patients was well improved in terms of restoring the anatomical structure.

Conclusion: 3D printing technology can be used to guide the classification and preoperative planning of complex tibial plateau fractures.

Background

Tibial plateau fracture is one of the common intra-articular fractures in clinic. And its accurate classification and treatment is a difficult problem for orthopedic surgeons[1]. At present, the commonly used clinical classification method of tibial plateau fracture was put forward by Schatzker et al. [2] in 1949, which is based on X-ray. It does not consider the displacement of fracture in sagittal position. So sometimes the classification can not effectively guide the formulation of treatment plan, especially in the case of posterior tibial plateau. In 2009, Professor Luo Congfeng [3] proposed a three-column classification method of tibial plateau fractures based on CT, which divides the tibial plateau into lateral column region, medial column region and posterior column region. However, this classification method can not directly reflect the degree of comminution and collapse of the articular surface of the fracture. Also, this classification method can not guide the design of preoperative operation well. Complex tibial plateau fractures are often associated with two-column or three-column fractures. Good preoperative planning can greatly shorten the operation time and improve restoration effect. With the emergence of 3D printing digital medical technology, accurate and individualized treatment has become the trend of orthopaedic trauma surgery[4]. Different literature reviews have revealed an increasing use of 3D-printed models in surgery [5], orthopedics [6] and orthopedic trauma [7], interventional radiology [8], surgical

teaching and assessment [9], etc. The reported advantages of 3DP-based approaches refer to the strong capabilities of customization based on patient imagistic data (computer tomography (CT), magnetic resonance imaging (MRI)), improved visualization of anatomy allowing better diagnosis evaluation, a decrease in operating time and radiologic exposure during surgery, improved intervention accuracy, and enhanced communication among physicians and with patients [5,7]

1. Methods

1.1 Inclusion and exclusion criteria for cases.

Inclusion criteria: ☐cases of unilateral closed tibial plateau fracture treated by surgery in the department of orthopaedics of our hospital during 2017.01-2019.01. ☐ complex tibial plateau fractures with double-column or three-column injuries. ☐The time from injury to operation was less than 14 days.

Exclusion criteria: ☐patients with chronic lesions of knee joint and knee joint dysfunction before injury. ☐complicated with vascular and nerve injury on the affected side. ☐those with serious underlying diseases or unable to cooperate with treatment.

1.2 General information.

A total of 28 patients were included in this study, including 20 males and 8 females, with an average age of 49.5 ± 2.5 years old. According to the theoretical basis of three-column classification of tibial plateau, combined with 3D printing model classification, there were 9 cases of type ☐ fracture, 7 cases of type ☐ fracture, 4 cases of type ☐ fracture and 8 cases of type ☐ fracture. All cases were treated with internal fixation. The time from injury to operation was 12 days, with an average of 6.5 ± 1.3 days. This study has been approved by the Ethics Committee of our hospital. All patients have signed the informed consent form for the operation.

1.3 Using 3D printing model to refine the classification of plateau fractures from the geometric plane 3-column 3-zone typing method

3D model printing: all the 28 cases underwent 64-slice spiral CT thin-slice scanning (0.6mm) before operation, and the DICOM data were input into the computer. The Mimics software was used to process the data. And the 3D printing technique was used to print the three-dimensional model of the fracture (1:1).

Based on the classification of the geometric plane of the platform (Fig. 1), the overlooking view of the tibial plateau shows that the O point is the midpoint of the tibial spine line. The A' point is the tibial tubercle. The B' point is the medial crest of the tibial plateau. And the C' point is the anterior edge of the fibular head. The tibial plateau is divided into three plane parts by OA', OB' and OC', which are defined as A zone, B zone and C zone respectively.(Table 1)

Table 1
Three-column and three-zone classification of tibial plateau fractures

Classification	Zone	Position	Approach
□	A	Supine position	Anterolateral approach
□	B	Supine position	Anteriomedial approach
□	C	Prone position	Posterior approach
□	A + B	Supine position	Combined medial and lateral approach
□	A + C	Supine position	Anterolateral peroneal approach
□	B + C	Supine position	Posteromedial approach
□	A + B + C	Floating position	Anterolateral approach + posteromedial approach
Type IV-VII are included in this project			

1.4 Preoperative planning and surgical simulation steps.

- ☒ The CT data of patients with quasi-fracture were processed on a special computer platform. And then the tibial plateau fracture model was printed 1:1 (Fig. 2). The printing machine is the selective laser sintering equipment Farsoon401. The printing material is nylon powder material for laser sintering.
- ☒ The fractures were re-classified by three-column classification according to the fracture imaging data and 3D visual model so as to achieve accurate classification according to the principle.
- ☒ Evaluate the displacement direction of the bone fracture block. And through the direction, distribution and movement of the fracture block, we can accurately evaluate the displacement direction of the bone fracture block.
- ☒ Evaluate the collapse site of the articular surface. And through the detailed analysis and observation of the articular surface, we can determine the actual collapse site of the articular surface.
- ☒ Establish the surgical approach. Through the analysis of the fracture mass and articular surface of the complex tibial plateau fracture, the intraoperative approach can be established to create conditions for reducing trauma injury.
- ☒ Determine the position and the number of steel plate implantation. Predicting the position and number of steel plate implantation and the pre-bending data of steel plate before operation can effectively reduce the operation time, trauma injury and the use of anesthetic drugs.
- ☒ Simulate the operation. The reduction of the fracture block and the placement of the steel plate can be performed on the 3D model according to the operation plan, so as to improve the proficiency of the operation.

1.5 Preoperative scheme design of complex tibial plateau fracture (type Ⅴ-VII).

Type IV: supine position, choice of surgical approach: combined medial and lateral approach. (Fig. 3).

Type Ⅴ: supine position, choice of surgical approach: anterolateral peroneal head approach to fix the lateral column, and whether to fix it according to the stability of the posterior column (Fig. 4).

Type VI: supine position, choice of surgical approach: modified posterior medial approach (Fig. 5).

Type Ⅶ: floating position, choice of surgical approach: the meniscus was repaired by the anterolateral approach, the lateral column was fixed by the anterolateral approach, and the medial column and the posterior column were fixed by the posteromedial approach. (Fig. 6)

1.6 Surgical methods and postoperative management.

All patients were treated with general anesthesia or combined block anesthesia. After successful anesthesia, the affected limb was bound with a tourniquet with a pressure of 50 KPA for 90 minutes. Antibiotics were routinely used before operation. Combined with preoperative classification, the operation was performed according to the surgical approach, fracture reduction mode, plate preshaping, screw direction and length designed before operation. During the operation, the mode and amount of bone graft were determined according to the collapse of the articular surface. Explore the articular surface to repair meniscus and ligament injuries that need one-stage surgical repair as far as possible [10]. Intraoperative C-arm fluoroscopy confirmed the degree of fracture reduction and articular surface elevation. After operation, the negative pressure drainage tube was routinely indwelled and removed within 48 hours. Prophylactic use of antibiotics was used within 48 hours after operation. The contraction exercise of quadriceps femoris was performed on the 3rd day after operation. The flexion and extension function of knee joint began to exercise 1 week later and partial weight-bearing began to be carried out 6 weeks after operation. And after the fracture healing was confirmed by X-ray 3 months after operation, patients began to bear weight completely gradually.

1.7 Observation indicators.

1.7.1 The coincidence rate between the preoperative planning and the final surgical plan.

Each case of complex platform fracture was designed according to the 3D printing model before operation. The specific surgical approach and implant scheme were designed. The specific operation plan was recorded. The consistency rate between the final operation plan and the preoperative plan was obtained.

1.7.2 Knee joint function score.

The patients were followed up for 1 year. During the follow-up, the anterior and lateral films of the knee joint were taken and the knee joint function was evaluated by HSS score [11]. HSS score>85 was excellent, 70–84 was good, 60–69 was fair, and score<59 was poor.

1.7.3 Fracture healing time and postoperative complications.

The fracture healing time of each case was recorded in the follow-up. And whether there were postoperative complications such as infection, screw fracture and other complications were recorded.

1.8 Statistical processing.

The above data were analyzed by SPSS18.0 statistical software. χ^2 test was used for the comparison of counting data. T test was used for the comparison of measurement data. The difference was statistically significant ($P < 0.05$).

2. Results

2.1 The coincidence rate between the preoperative planning and the final surgical plan.

The classification of tibial plateau fracture combined with 3D printing is basically consistent with what was seen during the operation. The fracture type and articular surface collapse seen during the operation are basically the same as the model, which is of great help to the understanding and operation of the operation. In all 28 cases, the final operation plan of 26 cases was consistent with the design before operation. And 2 cases of them are type VII fracture. Before operation, the lateral column was fixed by anterolateral approach and the medial column and posterior column were fixed by posteromedial approach. The bone mass of lateral column was reduced and fixed by anterolateral approach. It was found that the stability of posterior column was good. The coincidence rate between the preoperative planning and the final surgical plan was 92.8% (the final plan was consistent with the preoperative planning and design of the number of cases / total number of cases * 100%). The postoperative CT results showed that the collapse of the articular surface of the platform was well reduced in all 28 patients.

2.2 Knee joint function score.

During the follow-up 6 months after operation, the excellent and good rate of knee joint function was 85.7%. And the excellent and good rate of knee joint function 12 months after operation was 89.3%. Only one patient had poor knee joint function at 6 months after operation. And his knee joint function was improved after functional rehabilitation exercise.(Table 2)

Table 2
Comparison of knee joint function

		6 month after the surgery	12 month after surgery
case numbers		28	28
HSS score		87.3 ± 6.2	88.1 ± 7.1
	Excellent	19(68%)	22(80%)
knee joint function	Good	5(18%)	3(10%)
	Average	3(10%)	3(10%)
	Bad	1(4%)	0

(P>0.05)

2.3. Fracture healing time and postoperative complications.

Postoperative follow-up showed that all 28 patients healed well. And the average healing time was 3.2 ± 0.6 months. All 28 patients had no infection and no internal fixation loosening.

3. Discussion

3.1 The importance of correct classification of tibial plateau fractures and preoperative planning

The treatment of complex tibial plateau fractures has always been a difficult problem in orthopaedics [12]. It is often accompanied by ligament, meniscus injury and serious damage of nerve, blood vessel and soft tissue, which makes the treatment of fracture more difficult [13]. Patients often have varying degrees of dysfunction after operation, which seriously affects their ability to work. How to deal with complex tibial plateau fractures, reduce fracture complications, and make a good recovery of knee joint function is particularly important.

The correct classification and preoperative planning of tibial plateau fractures are very important for the selection of surgical approaches and fixation methods. CT scanning can scan the tibial plateau in axial, coronal and sagittal planes to show the full picture of the tibial plateau[18-20]. While 3D printing can have a more intuitive understanding of the whole tibial plateau and the details of the fracture, which makes various measurements more convenient. Thus, we can have a quantitative understanding of the degree of fracture collapse and splitting. Also, it can provide a better reference for surgical approach and internal fixation placement [14].

3.2 Development of classification methods for tibial plateau fractures

A good classification method of tibial plateau fracture not only needs to accurately reflect the degree of fracture injury, but also needs to guide clinical treatment. Hohl-Moore classification is a classification

method based on X-ray, which divides tibial plateau fractures into 5 kinds of primary fractures and 5 kinds of fracture and dislocation. However, this method can not accurately reflect the degree of soft tissue injury during fracture, and it is difficult to guide clinical treatment. Schatzker classification increases the type of VI fracture with separation of metaphysis and diaphysis, which is widely used in clinic. However, it also has disadvantages. In practical clinical application, simple collapse fracture is rare and can not be effectively distinguished. The fracture of the posterior lateral column of tibial plateau is not distinguished, which is easy to cause missed diagnosis and affect the choice of surgical treatment. The content of AO classification is detailed, which is conducive to academic research and communication. However, the content is too complex to remember. Also, it can not accurately reflect the relationship between articular surface collapse and fracture severity. Thus, it is not competent to guide the choice of clinical treatment and prognosis [15]. On the basis of the above, Luo Congfeng et al suggested the classical three-column classification method based on three-dimensional CT and analyzed the shape and location of the fracture from a three-dimensional point of view for the first time[3]. It is divided into internal, external and posterior three columns according to the division, which can accurately guide the surgical approach. But this classification did not put forward the concept of posteromedial and posterolateral tibial plateau fractures. Mao Yujiang et al put forward the theory of "four columns and four quadrants" on the basis of three columns. This classification distinguishes the morphological differences between posteromedial and posterolateral column fractures, and is of great significance for the guidance of clinical posterior column fractures [17].

With the emergence of 3D printing technology, we can better obtain the solid model of the fracture site before operation. Compared with the solid model, the surgeon has a deeper understanding of the local structure of the fracture. On the basis of accurate classification, it is of greater significance to guide clinical surgery[21-23].

3.3 Advantages of 3D printing technique in classification and preoperative planning of complex tibial plateau fractures

Compared with CT scanning, 3D printing provides more details about proximal tibial bone and fracture, even the internal details of fracture[6-7]. 3D printing can intuitively classify and fix the fracture as a more detailed preoperative plan, guide the mode of operation, surgical approach and fixation, which can provide better preoperative guidance for clinical practice[24]. And it can provide the possibility to better improve the classification of tibial plateau fracture. It has the following three advantages:

Psychological advantage: After the 3D model of complex tibial plateau fracture is printed, the operator can intuitively understand the fracture state and displacement. So that the surgeon can have more time and more intuitive to design the operation plan, so as to get twice the result with half the effort.

Operational advantages: According to the operation on the simulated 3D model before operation, the plates and screws can be implanted smoothly during the operation. For medial and lateral plateau fractures, we can often see the articular surface of the plateau, the reduction of the articular surface is not very difficult, but in complex plateau fractures involving posterior column fractures, it may not be easy to

see the posterior articular surface during operation. Therefore, the preoperative surgical design, the pre-shaping of the steel plate and the direction and length of the screw are of great help to the operation. It greatly simplifies the difficulty of the operation, shortens the operation time and reduces the surgical trauma injury[25-26].

Communication advantages: before operation, we use 3D printed models to communicate with patients. So that patients have a better understanding of the severity of their own fractures, as well as a certain understanding of the surgical plan and the expected effect of treatment. In this way, it can also eliminate the patients' fear. And the compliance will be better.

In summary, 3D printing technology can be used to further refine the classification of complex tibial plateau fractures. The surgical approach and internal fixation plan are planned through the solid model, which is intuitive and accurate. And the preoperative planning scheme is feasible, which greatly simplifies the operation and reduces the surgical trauma injury. Also, it can be used as a routine item of preoperative preparation. In the future, under the guidance of 3D printing template, the optimized preoperative planning of tibial plateau fracture and accurate internal fixation operation will be better applied into clinic.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Consent for publish

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

CYH and CFY contributed to the study design and the drafting of the article. JMZ contributed to the implementation. BZ, HJ and XMX collected CT data and CAD. BJ and FYM performed 3D printing. XJ, FYC and LMW contributed to all surgical procedures. The authors read and approved the final manuscript.

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Figures

Figure 1

O: Midpoint of tibial spine line A':Tibial Tuberosity B':Medial spine of tibial plateau C': Anterior margin of fibular head

Figure 2

3D printed tibial plateau fracture model

Figure 3

Type IV tibial plateau fracture A: 3D printed model B: Approach C,D: X-rays after the operation

Figure 4

Type V tibial plateau fracture A: 3D printed model B: Approach C,D: X-rays after the operation

Figure 5

Type VI tibial plateau fracture A: 3D printed model B: Approach C,D: X-rays after the operation

Figure 6

Type VII tibial plateau fracture A: 3D printed model B: Approach C,D: X-rays after the operation