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3D printing-assisted osteotomy treatment for the malunion of lateral tibial plateau fracture

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ABSTRACT

Introduction: Osteotomy and internal fixation are usually the most effective way to treat the malunion of lateral tibial plateau fractures, and the accuracy of the osteotomy is still a challenge for surgeons. This is a report of a series of prospectively study of osteotomy treatment for the malunion of lateral plateau fractures with the aid of 3D printing technology.

Methods: A total of 7 patients with malunion of lateral tibial plateau fractures were enrolled in the study between September 2012 to September 2014 and completed follow up. CT image data were used for 3D reconstruction, and individually 3D printed models were used for accurate measurements and detail osteotomy procedures planning. Under the premeditated operation plan, the osteotomy operations were performed. Patients were invited for follow-up examinations at 2 and 6 weeks and then at intervals of 6 to 8 weeks until 12 months or more.

Results: Mean age of the patients was 44 years (range 30–52 years), 3 cases were result of fall injuries, 2 were traffic accidents and 2 were sports injuries. Among the cases, one accompanied with craniocerebra trauma, one with pelvic fracture, one accompanied with both. According to the Schatzker Tibial Plateau classification, the original fracture type were 3 type I, 1 type II and 3 type III. The lateral tibial plateau collapse ranges from 4 mm–12 mm, with an average of 9.4 mm. All the operations were successfully completed, the average operation time was 77.1 min (range 70–90 min), the average intraoperative blood loss was 121.4 ml (range 90–180 ml), the mean follow-up time was 14.4 months (range 12–18 months), and the average healing time of the osteotomy fragments was 12 weeks (range 11–13 weeks). The difference between preoperative and postoperative Rasmussen scores were statistically significant ($P < 0.05$). All the patients were obtained functional recovery, with no complications.

Conclusion: 3D printing technology is helpful to accurately design osteotomy operation, reduce the risk of postoperative deformity, decrease intraoperative blood loss, shorten the operation time, and can effectively improve the treatment effect.

Fracture of tibial plateau (FTP) is a common fracture of lower extremity. Due to the complexity of FTP fractures, surgical treatment is still a clinical challenge. The pathogenesis of FTP is complicated and there exists tibial plateau collapse in most cases. As it is an intra-articular fracture, surgical treatment becomes a better choice for the high quality of reduction [1–4]. However, for some patients could not receive surgical treatment in time with a variety of reasons, such as fail diagnose, ignorance or other objective limitations, thus malunion, long-standing knee joint pain, malformation or limited activity may occur. An osteotomy operation is often necessary for these patients.

There are various surgical methods for the treatment of the lateral FTP malunion, including locking plate technique, minimally invasive percutaneous plate osteosynthesis (MIPPO) and arthroscopy [3,5–7]. What's more, a minimally invasive operation under the guidance of navigation system has also been recently advocated [8]. While choosing a surgical method, there are two key points should be taken into consideration: one is how to select an appropriate method of osteotomy for individualized patients to minimize soft tissue dissection and bone destruction, meanwhile, resume the height of the collapsed tibial plateau [3].

3D printing technology is a new technique recently introduced into the clinical orthopedics. By using the preponderance of reconstructing a full scale model of the fractured plateau, it can be of great help in fully understanding the fracture condition,

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designing a program for surgical osteotomy and even simulating the surgical procedure on the model. With the assist of 3D printing technology, we successfully performed the surgeries by following the preoperative osteotomy programs, thus significantly shortened the operation time, reduced blood loss and improved the accuracy of collapsed plateau reduction.

From September 2012 to September 2014, 7 cases of lateral TFP malunion patients were treated with osteotomy assisted by 3D printing technology in our department. The patients were prospectively followed up for 12–18 months (mean, 14.4 months) in outpatient department, the result is generally satisfactory.

Materials and methods

Preoperative evaluation

A total of 7 patients with malunion of lateral tibial plateau fractures were enrolled in the study between September 2012–September 2014. Demographic characteristics, mechanism of injury, time from fracture to operation, the height of collapsed lateral plateau and concomitances were recorded. Fractures were classified according to the Schatzker Tibial Plateau classification. The study was approved by the Chinese Ethics Committee of Human Resources at the Second Military Medical University. And written informed consent was obtained from each participant. The research was in compliance with the Helsinki Declaration.

Pre-operation preparation and surgery simulation

A 1 mm thickness CT scan of the injured knee joint was taken preoperatively, and the original CT data was imported into the software of Mimics Innovation Suit 16.0 (Materialise company, Belgium), with which a 3D model was reconstructed. The 3D model data was exported as stl format and it was processed and used to rebuilt a full scale model by an FDM 3D printer. After accuracy checking of the model, the planned osteotomy lines were portrayed on the model, after which the measurements were taken.

The aim of measurements is to define the parameters to locate the osteotomy line during the operation, such as the distance from the medial boarder of the osteotomy area to the tibial tubercle, the osteotomy depth along the medial boarder, et al. Then, surgical procedure of osteotomy was simulated according to the osteotomy lines on the model. The height of tibial plateau was resumed by lifting the free fragment, and the amount of bone graft was calculated. Locking plates of different lengths and shapes were compared, from which an optimal plate was selected for the patient, assuring that it can fit the bone surface. Meanwhile, the plate could be slightly contoured as to be fit well sometimes. Finally, the plate was send to be sterilized to be prepared using in the operation.

Surgical methods

After satisfactory anesthesia, the patient was positioned supine with a standard thigh pneumatic tourniquet on the affected limb. Surgery area was routinely sterilized and draped. Then the pneumatic tourniquet was started and time was recorded.

A standard incision about 15 cm was made at the lateral side of the tibial plateau from the skin to deep fascia. The joint capsule was incised along the lateral site where the right tibial tubercle patellar tendon attached to expose the lateral plateau. According to the measurement parameters obtained from the 3D printing model and the preoperative plan, osteotomy was performed along the planned boarder to expose the collapsed fragment. The fragment was reduced and allogeneic bone was grafted to support the collapsed plateau. The osteotomy bone fragments were fixed with Kirschner wire temporarily. The selected locking plate was placed at the lateral side. Locking screws were used to finish the fixation. After checking the stability of the osteotomy and the repositioned fragments, a fluoroscopy was taken to make sure the proper anatomic reduction of the joint surface and the collapsed tibial plateau was resumed to the normal height. Irrigate the incision and close it routinely. At the same time the operation time and intraoperative blood loss were recorded.

The major surgical procedures of all the cases were performed by an experienced surgeon (senior) and assisted by 3 in-training residents (junior).

Postoperative care and follow-up

All patients had to cease smoking and drinking during perioperative period. Intravenous antibiotics were administered pre-operatively and within 24 h postoperatively. Patients were encouraged to perform early passive motion of the knee joints and muscular without weight-bearing from the first day after surgery. Partial weight-bearing was started 6 weeks after operation depending on clinical and radiographic findings and condition of

Table 1
Patients' Characteristics.

NO.	sex	age	injury cause	Fracture classification (Schatzker)	Time from fracture to operation (month)	preoperative lateral plateau collapse (mm)	Concomitance	Rasmussen anatomy score	Rasmussen knee functional score
1	M	30	Fall injury	I	24	5		8	15
2	F	42	traffic accident	II	4	12	craniocerebral trauma	6	12
3	M	52	Sports injury	I	46	7		10	14
4	M	48	traffic accident	III	5	17	craniocerebral trauma, pelvic fracture	10	20
5	F	46	Fall injury	III	86	5		8	16
6	F	38	Fall injury	I	10	14	pelvic fracture	6	16
7	F	52	Sports injury	III	49	6		10	18