Original Research

Comparison of Arthroscopic-Assisted Percutaneous Internal Fixation With a Modified Reducer Versus Open Reduction and Internal Fixation for Schatzker Type II and III Tibial Plateau Fractures

Xingrui Huang,[*†] MD, Song Zhao,[‡] MD, Yuanbin Jiang,[†] MSc, Shuchen Fang,[†] MSc, Hao Xu,[†] MSc, Hanlin Li,[†] MSc, Jinzhong Zhao,[‡§] MD, and Qirong Dong,[*§] MD

Investigation performed at the Department of Orthopedics, Suzhou Wujiang District Hospital of Traditional Chinese Medicine (Suzhou Wujiang District Second People's Hospital), Suzhou, China

Background: Tibial plateau fractures require anatomical reduction and stable fixation to achieve satisfactory results. In addition, addressing any related injuries is of paramount importance. Arthroscopic reduction and internal fixation (ARIF) has been promoted as a possible technique to treat tibial plateau fractures.

Purpose: To compare the effectiveness of ARIF with this modified reducer and open reduction and internal fixation (ORIF) for Schatzker types II and III tibial plateau fractures.

Study Design: Cohort study; Level of evidence, 3.

Methods: We retrospectively reviewed 68 patients who were treated for Schatzker type II or III tibial plateau fractures between August 1, 2014, and October 31, 2018. Patients were categorized into the ARIF ($n = 33$) and ORIF groups ($n = 35$). The groups were compared regarding intra-articular injuries, duration of hospital stay, complications, and clinical outcomes—including the International Knee Documentation Committee (IKDC) score, the Hospital for Special Surgery (HSS) score, and range of motion (ROM). The paired *t* test was used to compare preoperative and postoperative data, and the chi-square test was used to compare the IKDC and HSS scores.

Results: The median follow-up period was 36 months (26-40 months). Additional intra-articular lesions were found in 29 patients—21 in the ARIF group and 8 in the ORIF group ($P = .02$). A significant difference was observed in the duration of hospital stay—3.58 ± 1.46 days for the ARIF group and 4.57 ± 1.12 days for the ORIF group ($t = -3.169$; $P = .002$). All fractures healed within 3 months after surgery. The complication rate for all patients was 11%, with no significant difference between the ARIF and ORIF groups ($t = 1.244$; $P = .265$). At the final follow-up, there were no significant differences between the 2 groups in the IKDC score, HSS score, and ROM ($P > .05$ for all).

Conclusion: ARIF with a modified reducer was found to be an effective, reliable, and safe procedure for the treatment of Schatzker types II and III tibial plateau fractures. Both ARIF and ORIF provided equally good results, while ARIF offered a more precise evaluation and reduced the duration of hospital stay.

Keywords: arthroscopy; open reduction; percutaneous internal fixation; tibial plateau fractures; tunnel

Tibial plateau fractures are intra-articular fractures of the knee joint caused by either a valgus or varus force in combination with axial compression.[30] They represent approximately 1% of all fractures in humans.[5,26] Although tibial plateau fractures are uncommon, they comprise related injuries, with the consequence of potential malfunction if not treated properly.[31] Successful outcomes depend on anatomic reduction, absolutely stable fixation, treatment of concomitant injuries, preservation of the soft tissue envelope, and postoperative unrestricted range of motion (ROM).[2,3] Tibial plateau fractures are typically classified using the Schatzker method: type I, a wedge-shaped pure cleavage fracture of the lateral tibial plateau; type II, a type I fracture with a depressed component; type III, a pure depression of the lateral tibial plateau; type IV, a medial tibial plateau

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fracture with a split or depressed component; type V, a wedge fracture of both the lateral and medial tibial plateau; and type VI, any of the previous types with a transverse tibial metadiaphyseal fracture.[26,27,11]

Open reduction and internal fixation (ORIF) requires extensive soft tissue dissection, which may lead to complications with wound healing, infection, and arthritis.[1,10,13,14,32] In addition, the development of knee osteoarthritis is a common later complication and can be influenced by attached underestimated lesions such as cartilage defects and meniscus and ligament injuries.[33]

In the 1980s, Caspari et al[4] and Jennings[18] recommended arthroscopic reduction and internal fixation (ARIF) to treat tibial plateau fractures, and it is widely used today. ARIF is a minimally invasive procedure and thus has demonstrated a variety of advantages over ORIF, including accurate reduction supervised by direct visualization, lower morbidity, and simplified diagnosis and treatment of intra-articular lesions.[29,37,40] Studies have reported good short- to medium-term functional and radiologic results after ARIF.[7,25,26] However, the actual percutaneous reduction operation lacks appropriate tools, which decreases the effectiveness of anatomical reduction.[8,11,23,41] Moreover, it may lead to prolonged surgical time and increase the incidence of compartment syndrome. Whether ARIF achieves better clinical results than ORIF is still under dispute.[9,19,20]

We have developed a custom reducer to reduce the fracture fragment accurately during ARIF to shorten the operative time and improve surgical outcomes. The purpose of this study was to outline and compare the clinical outcomes of patients who underwent ARIF with this modified reducer and ORIF for tibial plateau fracture. We hypothesized that ARIF with the modified reducer would improve clinical outcomes.

METHODS

We retrospectively evaluated consecutive patients with tibial plateau fractures between August 1, 2014, and October 31, 2018. All patients had radiographs and computed tomography (CT) to demonstrate Schatzker type II or III tibial plateau fractures. Patients were divided into 2 groups: (1) those who underwent ORIF and (2) those treated with ARIF. Institutional review board approval was obtained for this retrospective study, and all patients gave informed consent to participate in the study.

All patients had tibial plateau fractures with a minimum articular depression of 12 mm. Patients with closed tibial plateau fractures and no serious vascular or nerve injury who were aged between 18 and 70 years were included in the study. Patients with (1) open fractures, (2) obvious comorbidities of vascular and nerve damage, (3) severe osteoporosis, and (4) moderate to severe osteoarthritis, local knee infection, or poor joint function and mobility were excluded from the study.

A total of 68 patients with Schatzker type II or III tibial plateau fractures were included. All surgeons involved in treating the enrolled patients had at least 15 years of experience in their specialty. The causes of the tibial plateau fractures were traffic accidents (n = 30 cases), fall injuries (n = 28 cases), and slips while walking (n = 10 cases). Eight patients had associated injuries or fractures—2 patellar fractures, 3 calcaneus fractures, 2 talus fractures, and 1 rotator cuff tear.

Plain radiographs (anteroposterior, lateral, and plateau views), CT, and magnetic resonance imaging (MRI) were performed on each patient (Figure 1). All patients underwent surgery within 10 days of the trauma. In the final follow-up, intra-articular injuries, hospital stay, complications, the International Knee Documentation Committee (IKDC) score, the Hospital for Special Surgery (HSS) score, and postoperative ROM were procured, and clinical outcomes were compared between the 2 groups.

Surgical Procedures

ARIF Group. ARIF was performed with a custom reduction device (Figure 2). The main structures of the modified reducer included the T-handle made of polyvinyl chloride (PVC), a metal connecting rod with a scale, and 4 hollow columnar reset units of different angles. The reduction unit is a hollow structure, and the openings at both ends communicate with the outside world. The inner diameter of the reduction unit is the same as the outer diameter of the connecting rod. The internal thread is coupled with the external thread of the connecting rod. The distal opening of the reduction unit is an inclined plane, and the

[§]Address correspondence to Qirong Dong, MD, Department of Orthopedics, The Second Affiliated Hospital of Soochow University, Suzhou, Jiangsu 215004, China (email: dongqirong@suda.edu.cn); and Jinzhong Zhao, MD, Department of Sports Medicine, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, Shanghai 200233, China (email: zhaojinzhongdoctor@163.com).

*Department of Orthopedics, The Second Affiliated Hospital of Soochow University, Suzhou, China.

[†]Department of Orthopedics, Suzhou Wujiang District Hospital of Traditional Chinese Medicine (Suzhou Wujiang District Second People's Hospital), Suzhou, China.

[‡]Department of Sports Medicine, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, Shanghai, China.

X.H., S.Z., and Y.J. contributed equally to this study.

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The Hospital of Traditional Chinese Medicine of Suzhou Wujiang District provided ethical approval for this study.

Figure 1. Preoperative images of a tibial plateau fracture on the right side of a 62-year-old female patient with a Schatzker type III tibial plateau fracture after a slip and fall. (A, B) Anteroposterior and lateral radiographs. Blue arrows indicate the fracture. (C) Coronal, (D) sagittal, and (E) axial CT scans. (F) Coronal, (G) sagittal, and (H) axial MRI scans. An MRI of the right tibial plateau revealed a Schatzker type III fracture with a grade 1 tear of the lateral meniscus and a grade I injury to the cartilage of the lateral femoral condyle. The integrity and continuity of the ACL, PCL, medial collateral ligament, and lateral collateral ligament were intact. ACL, anterior cruciate ligament; CT, computed tomography; MRI, magnetic resonance imaging; PCL, posterior cruciate ligament.

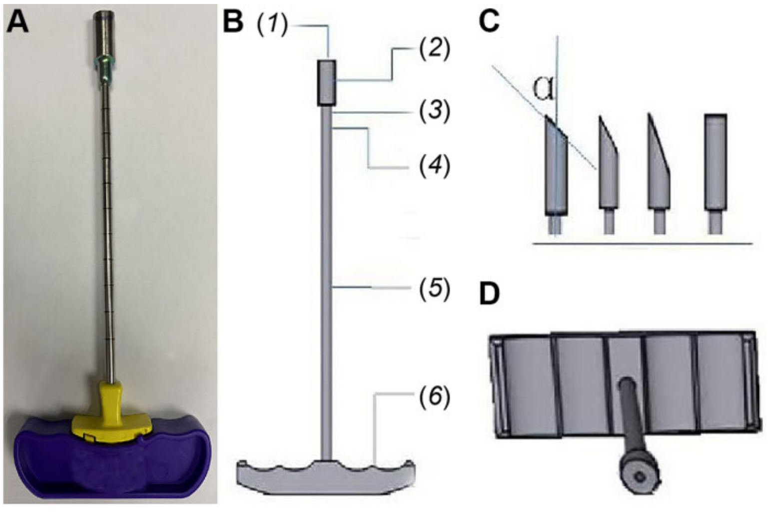

Figure 2. (A) The tibial plateau fracture reduction device. (B) Schematic diagram of: a hollow multiplane columnar reduction unit (*1*); the distal end of the reduction unit (8 mm) (*2*); the proximal end of the reduction unit (with internal thread) (*3*); the distal end of the connecting rod (with external thread matching the internal thread at the proximal end) (*4*); connecting rod (3 mm) (*5*); and a hollow T-handle (*6*). (C) The angles between the distal open inclined plane of the columnar reset element and the axis line are 30°, 45°, 60° and 90°(α). (D) The view of the reduction device from the top.

included angles with the connecting rod are 30°, 45°, 60°, and 90° to meet the requirements of different degrees of collapse in the operation.

All patients were placed supine on the operating table and given general endotracheal anesthesia. A pneumatic tourniquet was applied to the thigh without a leg holder.

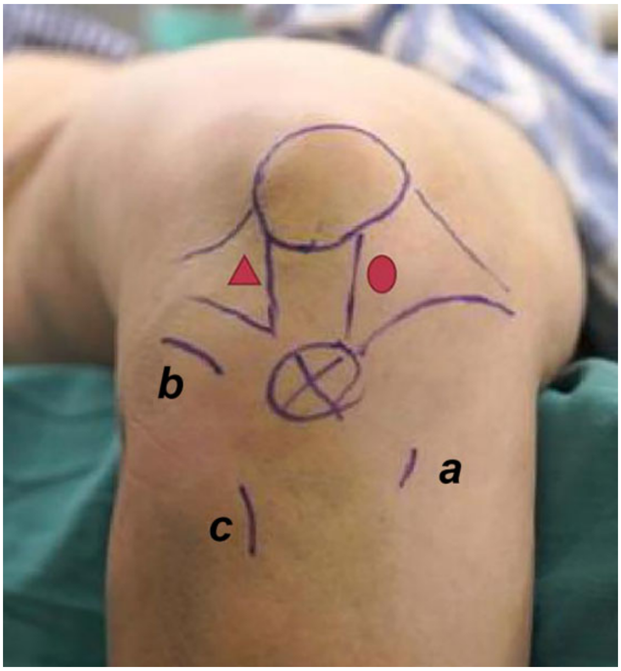

Figure 3. The surgical approach for ARIF. The red triangle shows anterolateral portal; the red circle shows anteromedial portal; "*a*" shows the cortical window for reduction and bone graft; "*b*" shows the insertion port of the plate; and "*c*" shows the incision for locking the distal screw. ARIF, arthroscopic reduction and internal fixation.

Standard anterolateral and anteromedial portals were created (Figure 3). In addition, gravity inflow was used to minimize fluid extravasation. The joint was examined, and the hematoma and any loose particles were removed by an arthroscopic shaver while assessments of the capsule, ligament, and intra-articular damage were completed.

A 2-cm incision was made anteromedially along the tibial crest with an No. 15 blade. A guide pin was inserted into the center of the lateral platform fracture from the anterior medial cortex of the tibial tubercle by an anterior cruciate ligament (ACL) reconstruction locator. Then, a cortical window was made first by drilling a 10 mm–diameter bone tunnel, ensuring that the bit did not cross the depressed fracture block. Afterward, this procedure provided access for the special reduction device to elevate the depressed lateral plateau. The direction and position of the guide pin were adjusted according to the reduction demand of the fracture block, and all collapsed fractures were well reduced (Figure 4). Then, bone grafts of appropriate size were implanted into the bone defect area along the tunnel. The probe was flipped and pried at the same time until the joint surface was flat. After checking that the fracture block was fixed stably and the articular cartilage surface was smooth and flat, the locking compression plate was placed on the lateral side for fixation using the minimally invasive percutaneous plate fixation technique[42] (Figure 5). Final radiographs confirmed the plate placement and restoration of the articular surface.

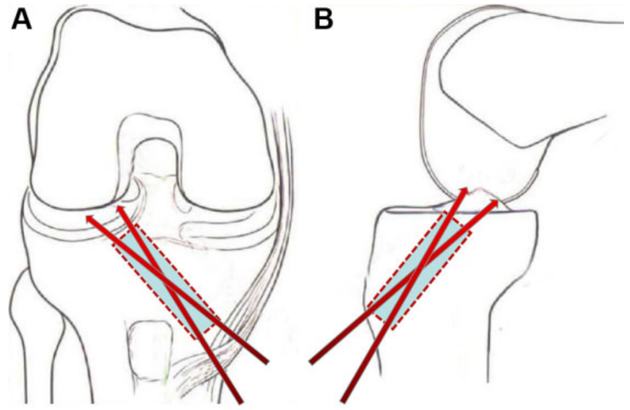

Figure 4. A schematic diagram of the modified reducer adjusting direction and angle in the bone tunnel. (A) Anteroposterior and (B) lateral views. The diameter of the connecting rod of the device is 3 mm, and the angle and direction can be adjusted in a 10-mm bone tunnel. Adjusting the orientation of the reduction device in the tibial tunnel can accurately and adequately reduce the collapsed fracture.

ORIF Group. The anesthesia method and patient positioning were the same as those in the ARIF group. An anterolateral longitudinal incision was made at the proximal end of the tibia, and the joint capsule was opened under the meniscus to expose the tibial plateau fracture (Figure 6). Under direct vision, the tibial plateau fracture was recovered by pushing, drawing, and prying to restore the articular surface. Temporary fixation was performed with Kirschner wires, C-arm fluoroscopy was used to confirm the fracture restoration, and autologous iliac bone was taken and implanted into the bone defect area. After confirming with fluoroscopy that the articular surface of the tibial plateau was flat and the bone plate was in the proper position, screws were inserted one at a time.

Postoperative Management

All patients were treated with a standardized postoperative rehabilitation protocol. Postoperatively, the patient was kept in extension for 1 week, placed in a hinged knee brace, and allowed free ROM. The patients had nonweightbearing exercises for the first 10 weeks after the operation. Partial weightbearing was allowed after 10 weeks, and full weightbearing after 12 weeks, during which patients began physical therapy for quadriceps stretching and strengthening.

Statistical Analysis

Descriptive statistics were reported as means and standard deviations for continuous data and absolute values and percentages for categorical data. The paired t test was used to compare preoperative and postoperative data between the ARIF and ORIF groups, and the chi-square exact test was used to compare preoperative and postoperative IKDC and HSS scores between groups. Statistical analysis was

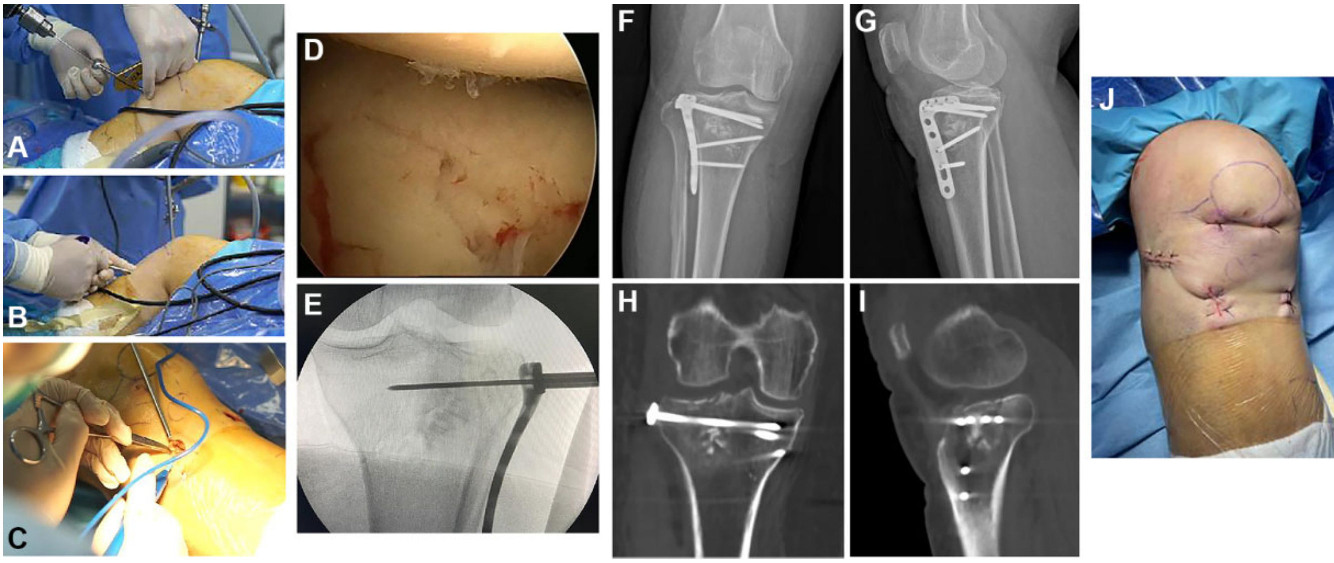

Figure 5. (A) A guide pin was inserted into the center of the lateral platform fracture. (B) The special reduction device elevated the depressed lateral plateau. (C) The locking compression plate was placed on the lateral side for fixation by MIPPO. (D) Arthroscopic examination revealed that anatomical reduction of the depressed fracture and the articular surface was flat. (E) Intraoperative fluoroscopy confirmed plate placement and articular surface restoration. (F and G) Postoperative radiographs and (H and I) CT showed a good anatomical reduction of the depressed lateral condyle in the tibial plateau fracture. (J) View of the knee after surgery. CT, computed tomography; MIPPO, minimally invasive percutaneous plate fixation.

Figure 6. Surgical incision in open reduction and internal fixation surgery.

performed with SPSS software (IBM Corp). The significance level was set at $P < .05$.

RESULTS

The median follow-up period in the 68 patients was 36 months (range, 26-40 months). All fractures healed within 3 months after surgery. The ARIF group (n = 33) included 23 men and 10 women, with a median age of 49 years (range, 25-71 years). The ORIF group (n = 35) included 23 men and 12 women, with a median age of 51 years (range, 21-72 years). Table 1 summarizes the patient and injury characteristics of the 2 groups.

TABLE 1
Characteristics and Injury Details by Treatment Type[a]

Characteristic	ARIF Group (n = 33)	ORIF Group (n = 35)	*P*
Sex			.73
Male	23 (70)	23 (66)	
Female	10 (30)	12 (34)	
Age, y	48.73 ± 7.99	50.69 ± 8.81	.34
Side affected			.82
Right	16 (48)	16 (46)	
Left	17 (52)	19 (54)	
Schatzker type			.83
II	18 (55)	20 (57)	
III	15 (45)	15 (43)	
No. of concomitant lesions	3	5	.51
Patellar fracture	1 (33)	1 (20)	
Calcaneus fracture	1 (33)	2 (40)	
Talus fracture	1 (33)	1 (20)	
Rotator cuff tear	0	1 (20)	
Length of hospital stay, d	3.58 ± 1.46	4.57 ± 1.12	**.04**

[a]Data are reported as n (%) or mean ± SD unless otherwise indicated. The bold *P* value indicates a statistically significant difference between the 2 groups ($P < .05$). ARIF, arthroscopic reduction and percutaneous internal fixation; ORIF, open reduction and internal fixation.

Additional intra-articular lesions were found in 29 patients—21 in the ARIF group and 8 in the ORIF group ($P = .02$) (Table 2). Under normal circumstances, meniscus

TABLE 2
Intraoperative Findings and Postoperative Outcomes by Treatment Type[a]

Characteristic	ARIF Group (n = 33)	ORIF Group (n = 35)	P
No. of intra-articular lesions	21	8	**.02**
Meniscus tear	13 (62)	5 (63)	
ACL rupture	3 (14)	2 (25)	
PCL rupture	1 (5)	0 (0)	
Cartilage contusion	4 (19)	1 (12)	
Length of hospital stay, d	3.58 ± 1.46	4.57 ± 1.12	**.04**
ROM, deg			.82
Flexion	123.63 ± 4.91	120.21 ± 11.61	.25
Extension	0.86 ± 2.1	0.33 ± 1.9	.86
Total arc	124.18 ± 4.43	119.83 ± 11.82	.05
IKDC score	89.09 ± 5.54	88.69 ± 5.23	.65
HSS score	86.21 ± 8.83	85.69 ± 8.30	.66
No. of complications	2	5	.27
Superficial infection	1 (50)	3 (60)	
Valgus deformity	0 (0)	1 (20)	
Deep vein thrombosis	1 (50)	0 (0)	
Knee stiffness	0 (0)	1 (20)	

[a]Data are reported as n (%) or mean ± SD unless otherwise indicated. Bold *P* values indicate statistically significant differences between groups ($P < .05$). ACL, anterior cruciate ligament; ARIF, arthroscopic reduction and percutaneous internal fixation; HSS, Hospital for Special Surgery; IKDC, International Knee Documentation Committee; ORIF, open reduction and internal fixation; PCL, posterior cruciate ligament; ROM, range of motion.

injury was found under the arthroscope, and suture or debridement was performed immediately. If a meniscus or articular cartilage lesion was identified arthroscopically, then either repair or debridement was performed immediately. ACL and posterior cruciate ligament tears were treated in a delayed fashion.

Postoperatively, there was a significant difference between groups in the duration of hospital stay—3.58 ± 1.46 days for the ARIF group and 4.57± 1.12 days for the ORIF group (t = –3.169; P = .04) (Table 2). At the final follow-up, there were no significant between-group differences in the IKDC score, HSS score, or ROM ($P > .05$ for all). The overall complication rate was 11%, with no significant difference between the 2 groups (t = 1.244; P = .265).

DISCUSSION

The most important finding of this study was that in the ARIF group it was easier to detect intra-articular-related lesions than in the ORIF group, and the difference between the 2 groups was significant ($\chi^2 = 6.909$; P = .009). To some extent, ARIF was likely to provide a more accurate diagnostic assessment for Schatzker types II and III tibial plateau fractures than ORIF. An MRI examination can make a precise diagnosis of the knee injury in general. However, interference from a traumatic hematoma of the knee joint may lead to false positive or false negative MRI results. It is well known that arthroscopy is almost the gold standard for examining knee injuries. In other words, the arthroscopic surgery group can detect and manage some diseases promptly and accurately. Furthermore, if a meniscus or articular cartilage lesion was identified with the arthroscope, then either repair or debridement was performed immediately.

In addition, there was a significant difference in the mean duration of hospital stay—3.58 ± 1.46 days for the ARIF group; 4.57 ± 1.12 days for the ORIF group (t = –3.169; P = .002). The results suggest that ARIF may help to shorten the length of hospital stay. In Schatzker types II or III fracture treatment, some scholars have found differences in clinical results in favor of ARIF management; however, these differences were not quite significant.[18,31,34,36] Moreover, no significant differences in clinical outcome were found between the ARIF and ORIF groups. Although arthroscopy may increase the operation time, there was no consequent increase in complications such as compartment syndrome or infection. Wang et al[35] have used a bone impactor as a reduction tool. Impactions were elevated and reduced from below with a bone impactor introduced through the metaphyseal fracture line or a small cortical window. A cannulated impactor or bone tamp was used to elevate the subchondral bone and articular surface by Chiu et al.[8] In this study, we obtained the same findings as the above authors. The function and radiology results measured by the IKDC, ROM and HSS scores were compared between the 2 groups, and no significant differences were observed among the 3 measurement results. This finding indicates that both groups can achieve good results, while there are slight differences between the 2 groups in some aspects.

Previous studies have shown that more than 90% of patients can achieve good results when arthroscopic techniques are used to treat tibial plateau fractures.[7,8,10,12,35,42] However, the visual field under arthroscopy is limited, and special tools are needed for fracture reduction. Most physicians still open the joint capsule and use periosteum strippers for warping reduction under local windowing. Blind reduction of the fracture is prone to deviation and leads to great damage or loss of cancellous bone in the proximal tibia because the periosteum stripper cannot accurately locate the fracture end. This requires more bone grafts and reduces the effectiveness of anatomical reduction. Moreover, this procedure may lead to prolonged surgical time and increase the incidence of compartment syndrome.[8,12,25] Therefore, it is necessary to use a special reduction tool for precise reduction of bone fragments to reduce iatrogenic injuries, thereby shorting the operative time and minimizing the incidence of compartment syndrome. It follows that the tools are just as important as the idea of minimally invasive surgery. Minimally invasive concepts with some appropriate tools may enable orthopaedic surgeons to perform more efficiently and quickly, improving patient outcomes.

In this study, the diameter of the connecting rod of the device is 3 mm, and the angle and direction of the reduction device can be adjusted in a 10-mm bone tunnel. In addition, it is conducive to the full reduction of the collapsed bone mass, depending on the degree of fracture block collapse and will not bring about large iatrogenic injuries. Since the diameter of the head and rod of the fracture reductor is only 10 and 3 mm, respectively, the size of the ordinary periosteal stripper is much larger than the above values, and the reductor may bring less surgical trauma. At the same time, bone particles can be implanted through the established tiny bone tunnel, and fracture blocks can be anatomically reduced.

On the other hand, the overall complication rate in the 2 groups of patients was found to be rather high (11%). This rate is comparable to that reported by other studies and confirms the complication rates found in the literature.[38,39] Nevertheless, there was no significant difference in the complication rate between the 2 groups (t = 1.244; P = .265). Of all the complications, compartment syndrome is the most serious and should be avoided as much as possible, especially during ORIF treatment. Since arthroscopic surgery requires a continuous infusion of normal saline into the knee cavity, the longer the surgery lasts, the greater the infusion pressure, and the greater the risk of compartment syndrome.[24,27,28] Therefore, the surgeon needs to complete the operation as soon as possible to reduce the occurrence of complications. Most of our operation times were controlled at approximately 60 minutes, and generally, few took more than 90 minutes. In addition, no case of compartment syndrome occurred in any of the cases.

Tibial plateau fractures are more common in the productive age group in many clinical results because of the risk of high-energy trauma, such as traffic accidents or falling from heights. Surgical therapy for tibial plateau fractures remains a topical subject because of the complex fracture geometry and rather high complication rates despite the number of different surgical procedures proposed by many authors.[16,20,21,22,28,29] The treatment targets are achieving anatomic reduction, restoration of the axis, and stable internal fixation to ensure early unlimited passive and active ROM. Minimally invasive techniques have been documented to have lower complication rates, faster recovery, and shorter hospital stays while allowing surgeons to manage intra-articular lesions. Studies have shown that more than 90% of patients can achieve good results when selecting arthroscopic techniques for the treatment of tibial plateau fractures.[6,15,17,24] Radiographs and CT are commonly used to diagnose tibial plateau fractures. CT and MRI are more accurate than radiographs in the Schatzker classification of tibial plateau fractures, and cross-sectional imaging can assist in improving surgical planning. The preoperative diagnosis of open surgery mainly depends on MRI to determine whether the internal structures of the knee joint are damaged, such as the meniscus, ligament, cartilage, et cetera. The presence of traumatic hematoma may lead to false positive or false negative MRI results.[16,27] However, we believe that arthroscopic examination is almost the gold standard for detecting injuries, which is unlikely to miss or misdiagnose injuries. Therefore, the combination of MRI and arthroscopic exploration may increase diagnostic accuracy and reduce misdiagnoses and missed diagnoses.

Limitations

The first limitation of this study is that the evaluation criteria for fracture healing after the operation are not uniform. The precise imaging modalities used for fracture healing evaluation were X-ray and CT. Although CT can provide a better assessment of fracture healing, some patients could not afford it due to their poor financial status. The second limitation is the small number of cases and short follow-up period. The third limitation is the retrospective nature of the study and the lack of postoperative CT or second-look arthroscopic assessment. If the opportunity arises in the future, we would like to observe patients over a longer follow-up period to assess the incidence and progression of secondary arthritis.

CONCLUSION

The study findings indicated that ARIF with a modified reducer is an effective, reliable, and safe procedure for the treatment of Schatzker types II and III tibial plateau fractures. Both ARIF and ORIF can provide equally good results, while ARIF seems to offer a more precise evaluation and reduces the duration of hospital stay.

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