REVIEW ARTICLE

Percutaneous Reduction and Internal Fixation for Monocondylar Fractures of Tibial Plateau: A Systematic Review

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Instead of extensive dissection of soft tissue around the fracture site, percutaneous techniques have unique advantages in managing displaced fragments, including preservation of soft tissues, less blood loss, lower risk of complications, and earlier functional rehabilitation. However, there are few systematic reviews on the effects of percutaneous reduction and internal fixation (PRIF) for tibial plateau fractures. A systematic search of Cochrane, EMBASE, and MEDLINE databases was performed for all publicly available data in March 2017 regarding the use of PRIF in treating monocondylar tibial plateau fractures. Basic information of included articles, surgical information, clinical outcomes, and concomitant soft tissue injuries were collected for analysis. Finally, a total of 20 articles including 561 patients were retrieved. Traffic accident was the most common cause of injury. Percutaneous techniques using bone tamp reduction were described in all studies. The majority ($\geq 85\%$) of patients were classified as excellent or good according to clinical and radiological Rasmussen scores. The overall complication rate was 6.6%, with loss of reduction the most frequent complication with an incidence of 2.4%. This systematic review indicated that PRIF was an optimal alternative that physicians should consider for the treatment of monocondylar tibial plateau fractures.

Key words: Fracture; Monocondylar; Percutaneous; Systematic review; Tibial plateau

Introduction

According to the Schatzker and AO/OTA classification system, in which fractures are, respectively, summarized as type I–VI and type A–C, monocondylar fractures (Schatzker type I–IV and AO/OTA type B) account for approximately 64% of all types of tibial plateau fractures^{1–3}. Because the articular surface is not as comminuted as a bicondylar fracture and tibial metaphysis is not involved, many surgical techniques have been developed for the management of monocondylar tibial plateau fractures, in which open reduction and internal fixation (ORIF) and percutaneous reduction and internal fixation (PRIF) are the most well-established techniques for treating certain cases^{4–6}. Successful results depend on anatomic restoration of joint congruity and alignment of the lower extremity with stable fixation allowing early mobilization^{7–9}. In addition, preservation of

the soft-tissue envelope is also important for minimizing the risk of soft tissue complications¹⁰.

For monocondylar tibial plateau fractures, one of the most challenging and crucial processes is anatomic restoration of the displaced intra-articular fragments which are depressed downwards into the metaphysis. Traditional open reduction and internal fixation (ORIF) requires an extensive dissection of soft tissues around the fracture zone to achieve better visualization of the displaced articular surface, which carries numerous complications and risks, especially in terms of operation and wound healing¹¹. Some authors recommend that arthrotomy and transection of the meniscus should be performed for good visualization during open reduction, which may lead to increased pain, proprioception disorders, and joint stiffness¹². Being less invasive, percutaneous reduction and internal fixation (PRIF) has shown unique

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advantages over traditional ORIF treating monocondylar tibial plateau fractures^{13,14}. Evidence suggests that percutaneous techniques could provide precise reduction of depressed fragments and contribute to early mobilization while lowering the overall number of morbidities, particularly in terms of wound complications¹³.

To gain a more comprehensive understanding of this minimally invasive technique, a systematic review was carried out to summarize the surgical methods and clinical outcomes of patients undergoing PRIF, specifically focused on monocondylar tibial plateau fractures. Our hypothesis was that PRIF is an effective method for the treatment of these certain cases with low risk of postoperative complications.

Materials and Methods

Search Strategy

A systematic search of Cochrane databases, Embase, and Medline databases were performed for all publicly available data between March 1997 and March 2017 according to the PRISMA guidelines¹⁵. We used the following keywords and combination: ([tibial plateau fracture*] OR [proximal tibial fracture*]) AND ([lateral] OR [isolate] OR [monocondylar] OR [unicondylar] OR [simple]) AND ([percutaneous] OR [minimally invasive] OR [closed] OR [indirect] OR [arthroscopically] OR [arthroscopic]). The searches were performed independently by two co-authors (Chang and Yu) on 1 March 2017 regardless of language restriction. In addition, the reference lists of the identified articles were manually searched for any further relevant articles.

Inclusion Criteria and Exclusion Criteria

We included studies if the following criteria were met: (i) clinical research; (ii) patients with monocondylar tibial plateau fractures (Schatzker I-IV or AO/OTA type B) treated with PRIF (we defined percutaneous reduction as the process where displaced fragments were indirectly reduced without intruding into the knee joint capsule under the guidance of arthroscopic or fluoroscopic inspection); and (iii) outcomes were assessed using clinical and radiological scales according to the Rasmussen scoring system or another scoring system¹⁶. The exclusion criteria included the following: (i) reduction process or clinical outcomes were not provided; (ii) reviews, meta-analyses, letters to editors, technique notes, perception-based studies, and single case reports; and (iii) articles published before 1 March 1997.

Data Extraction

Two co-authors (Chang and Yu) identified the appropriate studies according to the pre-stated inclusion criteria and extracted relevant data independently. The full text of all the relevant studies was obtained and reviewed. Reference lists of all full-text articles were checked manually to identify additional potential articles for inclusion. In the event of any discrepancy, a third reviewer would have the final decision as to whether the study was included for analysis.

Data extracted from eligible studies included the following: basic information about the article (first author name; patient number; sex distribution; age of patients; and study type); fracture classification (Schatzker or AO/OTA)^{1,2}; the cause of injury; reduction techniques; internal fixation; graft type; length of follow-up; radiologic evaluations, including radiological scoring system and objective satisfaction; clinical scoring system and objective satisfaction; range of motion (ROM); concomitant soft tissue injuries; complications; and the prevalence of secondary osteoarthritis.

Quality Assessment

Similar to the previously published scoring system of Song *et al.*, the methodological quality of the studies was assessed by the two review authors (Chang and Yu) using the modified Coleman Methodology Score (CMS), which was developed on the basis of two-part assessment (Table 1)^{17,18}. Ten critical appraisal criteria are used to score a study, and the final scores ranged from 0 to 100, with a perfect score (100) indicating a study design that completely avoids the influences of chances, various biases, and confounding factors.

Results

Literature Search and Quality Assessment

The search initially identified 90 articles for potential inclusion according to the criteria. A total of 21 duplicates were removed, and, subsequently, 49 articles did not meet the eligibility criteria after abstract and full text review (the specific reasons and numbers are listed in a flow chart (Fig. 1). Finally, 20 papers remained for analysis, of which 17 were in English, 2 in Chinese and 1 in Korean^{8,11,13,14,19-34}. Specifically, there were 2 prospective comparative studies, 2 retrospective comparative studies, 15 case series, and 1 clinical series based on a technique note^{8,11,13,14,19-34}. Levels of evidence (levels I-IV) for each study were examined and distinguished according to the content developed by the OCEBM

TABLE 1 Overall CMS for each criterion

Criteria (maximum score)	Mean $\pm$ SD
Part A	
Study size (10)	4 $\pm$ 2
Mean follow-up (5)	3.8 $\pm$ 1.8
Number of procedures (10)	10
Study type (15)	2.8 $\pm$ 4.9
Diagnostic certainty (5)	5
Surgery procedure (5)	4.9 $\pm$ 0.4
Rehabilitation (10)	2.5 $\pm$ 4.3
Part B	
Outcome criteria (10)	7.8 $\pm$ 1.4
Procedure for outcomes (15)	6.0 $\pm$ 1.8
Selection process (15)	11.9 $\pm$ 2.6
Total score (100)	58.7 $\pm$ 10
CMS, Coleman Methodology Score; SD, standard deviation.	

Fig. 1 The procedure of literature selection. PRIF, percutaneous reduction and internal fixation.

Levels of Evidence Working Group. Specifically, there were 2 Level II studies, 2 Level III studies, and 16 Level IV studies^{8,11,13,14,19–34}. Although 3 studies included a minority (<25%) of patients with complex or bicondylar fractures and should not be included in this review according to the exclusion criteria, the third reviewer finally decided to include these studies considering the fact that the clinical or radiological outcomes of each patient were specifically listed and the data of patients with monocondylar fractures could, therefore, be extracted for analysis^{23,26,34}.

The mean modified CMS value for all included studies was 58.7 (range, 43 to 73) evidencing the overall low quality of the studies. The mean CMS for each criterion is presented in Table 1.

Patient Characteristics

The basic characteristics of the included studies in this systematic review are summarized in Appendix I. The total patient number across all the studies was 561 (range, 14 to 58), 296 of whom were male patients and 265 of whom were female patients. The mean age of patients was 45.5 years (range, 15 to 82 years). The mean follow-up time was reported in 19 of the 20 studies and ranged from 11.5 to 80 months. Six patients were reported as lost to follow-up by Siegler *et al.*³². The tibial plateau fractures were classified by the Schatzker classification system in 18 studies^{11,13,14,19–25,27–34}. Schatzker II and III fractures accounted for the majority of the patients included in these studies, with a proportion of 87.3% (range, 60% to

100%). The AO/OTA (AO-Müller/Orthopaedic Trauma Association) classification system was used in the studies reported by Kiefer *et al.* and Lobenhoffer *et al.* and the majority (>95%) of patients had type B1-B3 fractures^{8,26}. A total of 555 (99%) patients suffered from monocondylar tibial plateau fractures according to these two classification systems. Thirteen studies summarized the cause of the injury and the corresponding case number^{13,21–26,28–31,33,34}. Although the cause of injury was variable between studies, traffic accident (150/351), sport injury (82/351), and fall injury (74/351) were the most frequent etiologies of the fracture.

Surgical Intervention

The percutaneous reduction techniques reported in each study could be summarized as the following categories: indirect reduction with traditional or inflatable bone tamp, percutaneous reduction using bone-holding forceps, the joystick technique, and ligamentotaxis (Fig. 2). The most commonly used method of reduction (20 of 20 studies) was bone tamp reduction (Appendix II). Of the 20 studies, 8 reported a combined of two or three reduction methods for the treatment of tibial plateau fractures^{8,19,25,27,29,30,32,34}. A total of 126 patients were treated with the assistance of intraoperative fluoroscopy, 140 patients were treated with the assistance of arthroscopy, and 235 patients were reduced using both fluoroscopy and arthroscopy^{8,11,19–34}. The type of graft material was variable between studies, including autografts, allografts, and bone substitute (mostly calcium phosphate

Fig. 2 The demonstration of four percutaneous reduction techniques. (A) Bone tamp reduction. (B) Reduction using bone-holding forceps. (C) The joystick technique. (D) Ligamentotaxis.

bone cement). Two studies report that no bone grafts or substitutes were used to fill the bone defects^{19,31}. Screw fixation (mostly 7.3 or 6.5 mm screw) was the most popular fixation technique for the majority (>75%) of all included patients.

Clinical Outcomes

The functional rating system was not unified in each study (Appendix III). The Rasmussen clinical scoring system was reported in 10 of 20 studies ($n = 239$), and the mean score was 27.1 (25.5–29.3)^{8,14,22,25,27,30–34}. In addition, 92.5% (range, 81.0% to 100.0%) of the patients had excellent or good scores according to the clinical Rasmussen classification. The Knee Injury and Osteoarthritis Outcome Score (KOOS) was reported in 5 of 20 studies, and the respective values were: pain score 85.2 (80.0–92.0), activity score 88.6 (80.8–97.0), symptoms score 81.8 (73.0–88.0), quality score 69.6 (61.3–77), and sport score 65.9 (54.4–85.0)^{20,21,24,29,32}. Four articles used at least two clinical rating systems to evaluate the function outcomes, and the majority ($\geq 80\%$) of patients had excellent or good objective scores according to each system^{30–33}. Only Kiefer *et al.* and Horstmann *et al.* report less than 80% satisfactory scores according to the Lysholm scoring system^{23,26}. The ROM was reported in 11 of the 20 studies ($n = 292$). The overall mean flexion

degree was 129.2° (111° – 142°)^{11,13,20,21,23–25,27,29,32,33}. Both Ollivier *et al.* and Suh *et al.* showed relatively poor results of mean flexion ability, which were less than 120° ^{29,33}.

Radiological Outcomes

The Rasmussen radiological score was used to provide objective assessment of the articular surface, the width of the tibial plateau and the alignment of the lower extremity after the operation (Appendix IV). Excellent is indicated by a score of 18, good by a score of 12, fair by a score of 6, and poor by a score of 0. Eight studies ($n = 195$) report the distribution of radiological Rasmussen scores^{8,14,25,27,30–33}. In addition, the proportion of excellent and good scores ($n = 174$) was reported as 89.2% (66.7% to 100%). At least 12 patients with articular incongruence of a more than 5-mm step-off were noted according to the postoperative X-ray examination^{20,23,29}, and the proportion of patients who suffered secondary osteoarthritis reported in 12 articles ranged from 0% to 85.2%^{8,11,20,21,23,25–32}.

Postoperative Complications and Ligament Injuries

A total of 33 patients with postoperative complications were documented in all 20 papers from PRIF ($n = 501$), and the overall complication rate was 6.6% (Appendix V). Loss of reduction was the most common complication, which was presented in a total of 12 patients (2.4%), while the remaining complications all occurred with a frequency less than 1%, including 5 cases of complex regional pain syndrome (CRPS), 4 cases of joint stiffness, 2 cases of chronic pain, 2 cases of deep venous thrombosis (DVT), 1 case of compartment syndrome, 2 cases of superficial infection, and so forth. The frequency of major knee ligament injuries was reported in 14 of 20 studies, with an aggregate patient number of 411^{11,13,14,19,22,24–27,30–34}. The most commonly combined ligament injuries were meniscus injuries, anterior cruciate ligament (ACL) injuries, and medial cruciate ligament (MCL) injuries, with frequencies of 28.0%, 8.8%, and 5.8%.

Discussion

Tibial plateau fractures are typical skeletal injuries around the knee joint, which account for 1.66% of all adult fractures³. With the development of image intensifiers and arthroscopy, percutaneous reduction and internal fixation has become more popular in the treatment of tibial plateau fractures, especially for the cases with only monocondylar involved^{10,21}. This systematic review of the literature showed that, in general, the clinical and radiological results of more than 85% of patients were good to excellent according to the Rasmussen scoring system. The satisfactory results may be a reflection of good reduction in alignment and joint congruity, stable fixation, good soft tissue protection, and early rehabilitation. Three articles compared the clinical outcomes of PRIF to ORIF. However, the benefits from this technique were not as significant as expected^{11,13,14}. Although Ohdera *et al.* reported easier and faster rehabilitation of patients

undergoing percutaneous osteosynthesis with the assistance of arthroscopy, no significant difference was found in terms of clinical results between two groups¹¹. Only Shen *et al.* reported superior average HSS score and ROM in a PRIF group during the follow-up examination¹³. In Wang *et al.*, there was insufficient evidence as well, with only better radiological results reported in the PRIF group¹⁴. Therefore, more comparative studies, especially randomized comparative studies (RCT), should be conducted to give a definite decision about these two techniques.

Reduction Technique

For monocondylar tibial plateau fractures, restoration of articular congruity should be the most important step for acquiring future knee function and preventing post-traumatic arthritis. Although minimally invasive procedures with bone tamp were reported in all the included literature for the reduction of depressed fragments, there were technical differences in the position of the cortex window, the direction of the intramedullary tunnel, and the type of bone tamp. Unlike the laterally based metaphyseal window, Levy *et al.* and other 7 studies recommended the anteromedial approach for the creation of the cortex window^{19–21,23,24,27,28,31}. Considering that the lateral pillar was already broken, making the cortex window from the medial side could protect the lateral plateau from being further disturbed throughout the reduction process. Both Levy *et al.* and Rossi *et al.* reported impressive clinical results of 100% good to excellent objective satisfaction using this technique^{27,31}. After excluding the data of three cases of Schatzker VI fractures, Horstmann *et al.*, however, reported relatively fair results regarding the medial approach in treating lateral tibial plateau fractures²³. Only 53.3% of patients received good to excellent Lysholm knee scores. Koval *et al.* pointed out that the placement of the cortex window depends on the orientation of the depressed fragments.⁶ If the fragments were purely depressed, then the cortex window should be placed on the same side as the fragments. In contrast, if the fragments were rotationally depressed, the cortex window should be made from the opposite side. Lacking evidence from comparative studies, optimal choice could not be decided in terms of the position of the cortex window. With regard to this review, the anteromedial approach was much more popular in recent studies.

Balloon-guided inflation tibioplasty has been described in several studies^{35–37}. However, most studies were limited to case reports and technique notes without postoperative outcomes reported. Ollivier *et al.* first reported the preliminary radiographic and clinical results for the tibioplasty technique at a minimum follow-up of 1 year²⁹. Twenty patients with Schatzker type II and type III fractures were enrolled, and, finally, 95% of patients obtained a step-off ≤ 5 mm with only one specific complication of intra-articular diffusion of bone substitute. Mauffrey *et al.* (2013) reported a single observational retrospective study which only investigated the potential limitations and intra-operative complications of this

technique³⁸. The majority (65%) of patients sustained an adverse intraoperative event. Five cases were major events, including failures to elevate the depressed fragment ($n = 4$) and intra-articular diffusion of calcium phosphate ($n = 1$). The author recommended this technique for Schatzker III fractures or Schatzker II fractures with a small lateral split. At present, it seems that the traditional bone tamp might not be displaced by inflatable bone tamp in elevating depressed fragments according to these clinical findings.

Forceps reduction, ligamentotaxis, and joystick technique were also described for the reduction of, mostly, the laterally displaced fragments. Combining reduction and fixation into one process, percutaneous pinning through the joystick technique was useful not only in treating tibial plateau fractures, but also in talus fractures and femoral shaft fractures^{39,40}. Of note, no one used the percutaneous methods for posterolateral split fragments in this review. The incidence of posterolateral fragments were reported to be 35.9% in AO/OTA type B fractures by Sohn *et al.* Today, treatment is limited to open reduction using the modified anterolateral or L-shaped posterolateral approach, which requires extensive dissection of the soft tissue⁴¹. Chiu introduces a minimally invasive technique for manipulating posteromedial fragments⁴². Through a limited posteromedial approach, a finger passed below the MCL to elevate the subchondral bone and articular surface; then a bone hook and two Kirschner wires were used to hold the reduction and temporarily fix the fragment. Because of the obstruction by fibular head, this technique could not be easily applied for posterolateral fractures. Therefore, minimal osteosynthesis still needs to be explored in the future.

Arthroscopy or Fluoroscopy?

Arthroscopy has been recommended in numerous studies for reduction monitoring by direct visualization of joint surface while depressed fragments are manipulated by bone tamps or other percutaneous osteosynthesis. Moreover, associated injuries inside the knee joint were easily identified and treated during the same procedure for fracture management. However, this process undoubtedly required several experienced surgeons who were not only experts in traumatology but also in sports medicine, which seemed discrepant to the conditions of local hospitals. Fluoroscopy, conversely, could be easily applied in most medical units. In the comparative study by Lobenhoffer *et al.*, no significant benefit from arthroscopy was found compared with fluoroscopic reduction⁸. More than 90% of patients gained good to excellent outcomes in both groups according to Rasmussen's clinical score. Surgical time was significantly longer in the arthroscopic group, with an average of 132 versus 58 min ($P < 0.01$). The question arose as to whether arthroscopy was essential for the reduction control of each monocondylar fracture. Based on MRI or arthroscopic research, several studies concluded that the incidence of ACL injuries was significantly associated with complicated tibial plateau fracture (Schatzker IV–VI fractures)^{43,44}. However, the correlation

between meniscal injury and the different fracture types was seldom reported. Ringus *et al.* pointed out that articular depression was a potential predictor of meniscal injuries in tibial plateau fractures, and patients with more than 10 mm of plateau depression had an eight-fold increase in risk of suffering from lateral meniscus tears⁴⁵. According to these clinical findings, despite the low risk of ACL injuries, monocondylar patients with severely depressed fractures should be examined using arthroscopy during the operation. However, this did not seem necessary for all patients, especially the isolated split fractures without depression.

Complications

Loss of reduction was the most frequent complication in this review. Several factors might have contributed to this, including the fixation method, type of bone graft, and partial weight-bearing time. It is notable that among these 12 cases of reduction loss, 11 patients accepted the fixation using only screws, which might not be sufficient for supporting fragments during the rehabilitation process. However, in the biomechanical study conducted by Koval *et al.*, no difference was found between the buttress plate and 6.5-mm cancellous lag screws in the fixation of lateral split fractures with respect to displacement under cyclic loading or failure strength⁴⁶. Therefore, this hypothesis might not be set up. The incidence of lower than 1% of other complications undoubtedly supported that the PRIF was the ideal method for minimizing the risk of postoperative problems including infection, DVT, and joint stiffness.

The occurrence of postoperative osteoarthritis could be affected by several factors. An anatomical restoration of the articular surface would help prevent or slow down the development of degenerative joint disease^{10,11}. Other factors included postoperative activity level, alignment of the lower limb and integrity of the cruciate ligament and meniscus. Although the prevalence was reported to be quite variable (0% to 85.2%), this issue is one that orthopedic specialists should be aware of. Of note, in this article, only 2 studies reported a >50% OA rate postoperatively^{20,21}. Both of them applied fluoroscopy instead of arthroscopy for the inspection of percutaneous reduction, and both studies revealed more

than 2 patients with >5 mm residual step-off (Appendix V). This result might support the point that arthroscopic-assisted reduction could help achieve better visualization than fluoroscopy, and minimize the risk of osteoarthritis for tibial plateau fracture repair.

Limitations

Although the inclusion criterion was restricted to monocondylar tibial plateau fractures, there are several limitations of this systematic review. First, most of the studies enrolled were retrospective observational studies with low levels of evidence, and only two prospective comparative studies were included in this systemic review. Moreover, the case numbers were quite small (most studies had fewer than 50 cases). The scoring system was obviously different between studies, which made the analysis complicated. These factors clearly affected the outcomes. Undoubtedly, results from studies with higher levels of evidence and of larger-scale as well as prospective studies are required in the future.

Conclusions

The promising results of this systematic review indicated that PRIF was an optimal alternative, which physicians should consider for the treatment of monodondylar tibial plateau fracture. More percutaneous techniques still need to be explored for the reduction of posterolateral fractures.

Appendix

Additional appendix may be found in the online version of this article on the publisher's website:

Appendix I Patient characteristics involved in the systematic review.

Appendix II Summary of surgical information.

Appendix III Summary of clinical results involved in the systematic review.

Appendix IV Summary of radiological outcomes for studies included in the systematic review.

Appendix V Summary of complications and concomitant Ligament injury.

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