Systematic Review

External fixation versus open reduction and internal fixation in the treatment of Complex Tibial Plateau Fractures: A systematic review and meta-analysis

Sujit Kumar Tripathy1, Paulson Varghese1, Sibasish Panigrahi1, Bijnya Birajita Panda2, Anand Srinivasan3, Ramesh Kumar Sen4

1Department of Orthopedics, All India Institute of Medical Sciences, Bhubaneswar, India
2Sir Chandra Bhanj Medical College & Hospital, Cuttack, India
3Department of Pharmacology, All India Institute of Medical Sciences, Bhubaneswar, India
4Max Super Speciality Hospital, Mohali, India

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ORCID iDs of the authors:
S.K.T. 0000-0003-0179-9510;
P.V. 0000-0002-2323-4880;
S.P. 0000-0003-1339-2405;
B.B.P. 0000-0002-0887-1690;
A.S. 0000-0002-0663-0922;
R.K.S. 0000-0002-2428-1105.

Abstract

Objective: The aim of this meta-analysis was to compare the functional outcomes and complications of external fixation (EF) versus open reduction and internal fixation (ORIF) in the treatment of complex tibial plateau fractures.

Methods: Based on a comprehensive search of major databases through PubMed, Embase, and Cochrane Central Register of Controlled Trials (CENTRAL), 19 studies comparing EF versus ORIF in treatment of complex tibial plateau fractures (Schatzker V-VII/OTA C1, C2, and C3) were included in the studies. There was one randomized controlled trial, two prospective comparative studies, 14 retrospective comparative studies, and two conference papers. From these studies, the data regarding functional and surgical outcomes as well as complications were obtained and pooled to conduct a comparison between the two methods of treatment.

Results: 1191 tibial plateau fractures were determined by the systematic review. Of those fractures, 541 were treated using EF, and 648 were treated using ORIF with plate and screws. All the studies included the young patients with traumatic tibial plateau fractures with mean ages from 40 to 60 years. The analysis of pooled data revealed significantly better functional outcome in patients operated with EF (standard mean difference [SMD] = 0.29, 95% confidence interval [CI] = 0.04-0.55, P = 0.02, I² = 0%). However, according to categorical functional outcomes, no significant differences were found (OR 0.80, 95% CI: 0.47, 1.34, P = 0.39, I²= 31%). The range of movement at the knee joint was significantly better in patients treated by EF (mean difference [MD] = 7.86, 5% CI: 3.56 - 12.17, P = 0.0003). The surgical time in the EF group was significantly shorter compared to the ORIF group (MD = 52.11, 95% CI: -99.62-(-4.60), P = 0.03). Similarly, the intraoperative blood loss was significantly lesser in the EF group (MD = -341.53, 95% CI: -528.18-(-154.88), P = 0.0003). Although the superficial infection was more frequent in the EF group (odds ratio [OR] = 3.22, P = 0.0002), there were no differences in the deep infection and overall infection rates. Also, there were no differences in reoperation rate, knee stiffness, compartment syndrome, and venous thromboembolism. The radiographic osteoarthritis was more common in the EF group (OR = 1.56, P = 0.04); however, there was no difference in the need for total knee arthroplasty between the two treatment modalities.

Conclusion: EF provides better functional outcomes and range of motion compared to ORIF in the treatment of complex tibial plateau fractures. With shorter surgical time and lesser intraoperative blood loss, EF can be considered as a definite treatment method in open injuries, polytrauma patients, and chronically morbid patients who cannot withstand prolonged surgery.

Level of Evidence: Level III, Therapeutic Study

Introduction

Tibial plateau fractures are uncommon injuries accounting for 1.2% all fractures. Although fragility fracture of the tibial plateau is increasing, still a majority of these fractures are because of high-velocity trauma seen in the young adults following a road traffic accident or fall from height.1,2 Fractures involving both the condyles of the tibial plateau (Schatzker type V and VI or the AO/OTA type C1, C2 and C3) are considered as complex fracture because of its association with high-velocity trauma, articular/periarticular comminution, associated soft tissue damage and articular cartilage involvement.3,4 These patients may present with compartment syndrome or open injuries and thus, compromise the functional outcomes.5

The management principle in such fractures aims at restoring the articular congruity and axial alignment with stable fixation, but with a minimal iatrogenic soft-tissue damage.5 Accordingly, the trend of open reduction and internal fixation with a locked plate and screws was shifted to the minimally invasive percutaneous fixation technique.5,7 Nevertheless, articular congruency restoration is the priority, and it should not be compromised at the cost of minimally invasive surgery.5,7 Long-term sequelae of poor joint

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A literature search was performed on 31st August 2020 by two authors. This systematic review was registered in PROSPERO before data views and Meta-analyses (PRISMA) and Meta-analyses and Systematic recommendations of Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA). Nevertheless, these devices may not be cosmetically appealing, and there are reports of higher incidence of pin tract infection and delayed fracture union.

Few systematic reviews and meta-analyses have compared both external and internal fixations in complex tibial plateau fractures. The last one published in the year 2017 by Zhao and colleagues did not report any difference in the complication rates between these two modalities of fixation other than an increased risk of infection in the external fixation group which was primarily because of increased incidence of superficial infection. However, the previous meta-analyses have not performed the quantitative synthesis of data on functional outcome and intraoperative surgical parameters such as bleeding and surgical duration. Many new studies have also been published since 2017. This updated meta-analysis was conducted accordingly to evaluate the functional outcome and complications of external and internal fixations in the complex tibial plateau fractures.

Materials and Methods

This systematic review/meta-analysis was performed following the recommendations of Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) and Meta-analyses and Systematic Reviews of Observational Studies statement standards (Figure 1). This systematic review was registered in PROSPERO before data collection. The registration number was CRD42020206780.

Literature search strategy

A literature search was performed on 31st August 2020 by two authors to identify studies that have evaluated External Fixation (EF) and Open Reduction Internal Fixation (ORIF) in complex tibial plateau fractures. The electronic databases of PubMed/Medline, Embase and the Cochrane Central Register of Controlled Trials (CENTRAL) were searched using the keywords “external fixation,” “plate,” “external fixation,” “Ilizarov fixator,” “tibial plateau fracture,” “Schatzker VI,” “Schatzker 6,” “Schatzker V,” “Schatzker 5” and “knee-fracture dislocation.” The search was limited to English literature and human beings.

Open reduction or percutaneous fixations with locked plate and screws have resulted in early aggressive physical therapy in the postoperative period with minimal risk of knee stiffness. However, the soft-tissue problem such as skin necrosis, infection and hardware prominence could not be resolved. There are certain conditions such as the open fracture, compartment syndrome, infection and poor soft tissue conditions, where internal fixation is not recommended. External fixation, like hybrid fixator, Taylor spatial frame, Ilizarov circular frame and Monticelli-Spinelli circular fixator are viable alternatives in such compromised soft-tissue conditions that can provide rigid stability to the fracture site and allow early movement. Nevertheless, these devices may not be cosmetically appealing, and there are reports of higher incidence of pin tract infection and delayed fracture union.

The title and abstract of retrieved articles were assessed carefully for possible inclusion in this review. The references of the relevant articles and reviews were also searched to get more studies related to the review. If there was any discrepancy in study selection, it was resolved by a discussion between the authors. When there was no consensus, the opinion of a third author was sought (Figure 1).

Study selection

Any Randomized Controlled Trial (RCT) or observational study that reported the outcome and complications of external fixation and open reduction internal fixation in complex tibial plateau fracture of adults (≥18 years) were included. Studies that reported on pathological fracture were not considered.

Methodological quality and risk of bias assessment

Two authors evaluated the methodological quality and risk of bias of the randomized controlled trial using Cochrane Collaboration Risk of Bias Tool. This risk of bias assessment tool has seven components: random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment data (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias) and other bias. Each item is categorized as “high risk,” “low risk” or “unclear risk.” The quality of the observational studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS) scale. There are 12-items in MINORS scale for comparative study. The items are scored as 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate) with a maximum possible score of 24 for an ideal comparative study. The discrepancy in ascertaining points for the items was resolved by discussion between the two authors. If no agreement could be reached, the opinion of a third author was sought.

Data extraction

Two authors extracted the data from the included studies and the details (author, year of publication, study design, demographic line restoration and axial mal-alignment lead to postramatic arthritis. Besides, the initial traumatic injury of the articular cartilage is also one of the causative factors.

Radiographic osteoarthritis is more common in the external fixation group; however, the conversion total knee arthroplasty rate is not different from the internal fixation group.
properties, surgical details, follow-up, functional outcome and complications) were filled up in a Microsoft Excel sheet. Any disagreement was resolved through the discussion with a third author.

The primary objective of this study was to compare the functional outcome of complex tibial plateau fracture after external fixation and open reduction internal fixation. The secondary objectives were to compare the complications, length of hospital stay, surgical duration and intraoperative blood loss.

Statistical analysis
Data were analyzed using Review Manager (RevMan) V.5.3.23 Studies, where the Standard Deviation (SD) was not mentioned, it was calculated with the RevMan calculator from the available data (P and t-value). The mean and standard deviation value was calculated from the median and IQR following the recommendation of Wan et al. and Luo et al.14,25 Whenever feasible, data were pooled for analysis. For comparison of binary data, the Odds Ratio (OR) and 95% Confidence Interval (CI) were calculated; for continuous data, Mean Difference (MD) with 95% confidence interval were estimated. While evaluating the continuous data if different scales were used for outcome assessment, the Standard Mean Difference (SMD) was calculated. $P < 0.05$ was considered as statistically significant. The heterogeneity among the cohort studies was assessed by Cochrane’s $Q$ ($P < 0.10$) and quantified by $I^2$. $I^2$ statistics with values of 25%, 50%, and 75% were considered as low, moderate, and high heterogeneity, respectively.26 The random-effects model was applied to address the high degree of heterogeneity ($I^2 > 50$%).27

Results
Selection of the study, quality assessment, and patient demographics
The search of electronic databases and manual search retrieved 923 articles, of which 19 articles were selected for final review (Figure 1).13-19,28-40 Two articles were from the same study reported from the Canadian Orthopaedic Trauma Society (COTS 2006)21,22 and another two were from the same institute of Boston (Boston 1994)29,30 There was one RCT, two prospective studies13,19 and 14 retrospective studies.14,16,20,29,33-40 Two of the studies were published in conference proceedings.23,30

The COTS 2006 study was a multicentre RCT.31,32 There was low risk in all domains of the Cochrane Collaboration Risk of Bias Tool except for blinding of the assessor and reporting bias (Table 1). The researchers were not blinded for the study, and the protocol was not published prior to patient recruitment. The quality score for Non-RCTs ranged from 17 to 22, with a mean of 19.47 (SD 1.627) (Table 2).

There were 1191 tibial plateau fractures in this review; 543 fractures were treated with EF, and 648 fractures were treated with open reduction and internal fixation with plates/screws. All these studies evaluated traumatic tibial plateau fracture in young patients as the mean age was ranging between 40 and 60 (Table 3).

Functional outcome
Four studies ($n = 244$) reported the functional outcome in both the treatment groups.19,31,33,35 As various functional outcome scores were used in these studies (Conservav 2015: Rasmussen score, COTS 2006: Hospital for special surgery knee score, Kartheek 2017: Modified Rasmussen clinical assessment score, Wu 2019: Rasmussen Knee Clinical Functional Score, Table 3), the pooled analysis was performed with the Standard Mean Difference (SMD). There was significantly better functional outcome in patients operated with EF, as revealed from the forest plot analysis (SMD: 0.29, 95% CI: 0.04, 0.55, $P = 0.02$, $I^2 = 0$%) (Figure 2). Four studies ($n = 332$)14,18,26,46 described the functional outcome in categorical grades (excellent, good, fair and poor). Excellent and good outcomes were considered a satisfactory outcome; accordingly, the data were pooled. As per the categorical functional outcome, there was no difference in satisfactory outcome between both the treatment modalities (OR: 0.80, 95% CI: 0.47, 1.34, $P = 0.39$, $I^2 = 31$%). Evangelopoulos et al. reported Lysholm’s score of 83.2 in the ORIF group vs 85.8 in the EF group.15 The mean KOOS score was 81.4 in the ORIF group vs 89.6 in the EF group. The pain was evaluated by Ahearn et al. using VAS and Conservav et al. using NRS; there was no significant difference between the two groups in their studies.26,45

Three studies ($n = 233$) provided the total arc of motion in their patients.14,19,31 There was a significantly increased range of movement at the knee joint in the EF treated group (MD: 7.86, 95% CI: 3.56, 12.17, $P = 0.0003$).

Hospital parameters
Five studies ($n = 397$) reported the time between injury and surgery (in days).10,19,31,33,36 The patients managed with EF were operated earlier than the ORIF group (MD: -0.87, 95% CI: -1.66, -0.09, $P = 0.03$, $I^2 = 43$%). However, there was no difference in the length of hospital stay between the groups. Six studies ($n = 329$) reported the length of hospital stay (in days), but there was no difference (MD: -0.66, 95% CI: -12.87, 0.75, $P = 0.08$, $I^2 = 97$%).13,16,19,33,35,36 There was significant heterogeneity among the studies; hence, a random effect model was applied (Figure 3).

Three studies ($n = 245$) reported the surgical duration (in minutes) for both the treatment groups.5,16,17,21 There was a significant difference in surgical time between both the groups. The EF group needed significantly lesser time compared to the ORIF group (MD: -52.11, 95% CI: -99.62, -4.60, $P = 0.03$). The mean intraoperative blood loss (in mL) was also significantly less in patients operated with EF (MD: -341.53, 95% CI: -526.18, -154.88, $P = 0.0003$, $I^2 = 92$, $P < 0.00001$).15,17,18 Exclusion of study by Xu et al. decreased the heterogeneity to 17% (MD: -450.35, 95% CI: -533.09, -367.62, $P < 0.00001$, $I^2 = 17$, $P = 0.27$).

Four studies provided the data of consolidation time/healing time (in weeks).16,17,35,36 There was no difference in time for healing between the two groups (MD: -1.74, 95% CI: -6.52, 3.04, $P = 0.48$).

Table 1. Quality Assessment of the Randomized Controlled Trials (the Cochrane Collaboration Risk of Bias Tool)

| Quality Assessment for RCT | Random Sequence Generation (Selection Bias) | Allocation Concealment (Selection Bias) | Blinding of Participants and Personnel (Performance Bias) | Blinding of Outcome Assessment (Detection Bias) | Incomplete Outcome Data (Attrition Bias) | Selective Reporting (Reporting Bias) | Others |
|---------------------------|------------------------------------------|----------------------------------------|----------------------------------------------------------|-----------------------------------------------|---------------------------------------|--------------------------------------|--------|
| COTS 2006                 | Low risk                                 | Low risk                               | High risk                                                | Low risk                                     | Unclear risk                          | Low risk                             |        |
| McKee et al.13            |                                         |                                        |                                                          |                                               |                                       |                                      |        |
| Pirani et al.25           |                                         |                                        |                                                          |                                               |                                       |                                      |        |

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| Study                        | A Clearly Stated Aim | Inclusion of Consecutive Patients | Prospective Data Collection | Endpoint is Appropriate to the Aim of the Study | Unbiased Assessment of the Study Endpoint | Follow-up Period Appropriately to the Aims of Study | Less than 5% Loss to Follow-up | Prospective Calculation of the Sample Size | An Adequate Control Group | Contemporary Groups | Baseline Equivalence of Groups | Adequate Statistical Analyses | Total Score |
|-----------------------------|----------------------|---------------------------------|------------------------------|-----------------------------------------------|-------------------------------------------|---------------------------------------------|-------------------------------|---------------------------------------------|-----------------------------|---------------------------|-----------------------------|----------------------------------|-----------|
| Ahearn 2014                  | 2                    | 0                               | 2                            | 2                                             | 2                                         | 1                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 1                                 | 9         |
| Bertrand 2017                | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |
| Berven 2018                  | 2                    | 0                               | 2                            | 2                                             | 1                                         | 1                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 1                                 | 7         |
| Boston 1994 (Covall et al. 29 and Mallik et al. 30) | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 9         |
| Bove 2018                    | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 1                                 | 9         |
| Chan 2012                    | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 0         |
| Conservav 2015               | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 0         |
| Evangelopoulos 2020          | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 7         |
| Guryel 2010                  | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 0         |
| Jansen 2012                  | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 0         |
| Karthick 2017                | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |
| Krupp 2009                   | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |
| Pan 2014                     | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |
| Tahir 2019                   | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |
| Wu 2019                      | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |
| Veri 2000                    | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |
| Xi 2018                      | 2                    | 0                               | 2                            | 2                                             | 2                                         | 2                                           | 0                             | 2                                            | 2                          | 2                         | 2                          | 2                                 | 2         |

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### Table 3. Demographic Characteristics of the Included Studies

| Study               | Study Design | No. of Cases | Age (years) | Gender | Fracture Type                          | Intervention                                                                 | Outcome Measure                                      | Follow-up |
|---------------------|--------------|--------------|-------------|--------|----------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------|-----------|
| Ahearn 2014**        | Retrospective| 21/34        | 44          | 40:15  | C3-30, others were unknown             | EP: Taylor spatial frame IF: lateral locking plate ± medial plate fixation    | Primary: WOMAC and SF-36                             | EP: 31 months | IF: 40.5 months |
| Bertrand 2017**      | Retrospective with prospectively collected data | 67/26        | 46.71       | 66/27  | V: 31 VI: 62                          | EF: hybrid external fixator IF: dual plating by anterolateral incision and peroperative fixation | Complications, ROM, reoperations, time of healing, hospital parameters | 3, 6, 18 months | and 24 months |
| Boven 2018**         | Retrospective | 62/68        | 55.74 ± 14.3/50.44 ± 14.7 | 66/64  | A2: 3 C1: 9, C2: 16, C3: 34 IF: A2: 9, A3: 3, C1: 5, C2: 8 | EF: Ilizarov ring fixator IF: ORIF with locked plate                           | ROM, complications and re-operations                  | 6 months |
| Boston/Covall et al. 1994** | Retrospective | 10/7         | 45          | 43.85  | EF: Monticelli-Spinelli circular fixator IF: Bilateral buttress, semi-tubular plates, or cannulated screws | Complications and reoperations                                                | EP: 10 months | IF: 33 months |
| Bove 2016**          | Retrospective | 14/14        | 51/43       | 24/4   | VI: 28                                 | EF: conventional Ilizarov frame by Plastek-1 case, the TrueLoc device by Orthofix-2 cases, the Ring Rod system by Diamedical-2 cases, Taylor Spatial Frame (TSF) by Smith & Nephew-0 cases, IF: Fixed angle locking plate using LISS Synthes, Switzerland | Complications, hospital parameters, Functional and bone scoring systems described by Paley and Maar, ASAMI outcome score | 24 months |
| Chan 2012**          | Retrospective | 35/34        | 52.03 ± 3.441/45.04 ± 3.538 | 28/31  | OTA C1: 18, C2: 2, C3: 9              | EF: Ilizarov circular frame, Hoffman II with limited internal fixation       | Complications, reoperations                            | 3, 6, 12 months | and 24 months |
| Conservav 2015**     | Retrospective | 41/38        | 54.1        | 46.33  | IV: 23 V: 29 VI: 27                   | EF: Percutaneous lag screw + Hybrid external fixator                         | Rasmussen, WOMAC, NRS, complications and reoperations                    | EP: 39.4 months | IF: 35.1 months |
| COTS 2006**          | RCT (multicentre) | 43/40       | 43.4/46.24  | 52/30  | V: 18 VI: 65                          | EF: Ilizarov’s circular external ring fixator IF: ORIF with medial and lateral non locking buttress plating ± bone grafting | Primary: HSS                                           | 6, 12 months | and 24 months |
| Evangelopoulos 2020** | Retrospective | 6/16         | 47.6        | 10/12  | IV: 2 V: 9 VI: 11                    | EF: Circular external fixator IF: ORIF with dual plating                     | Clinical outcome: Lysholm’s knee score, knee injury, and osteoarthritis outcome score (KOOS), EuroQol-5D, Radiological outcome: arthritis | 56 months |
| Garryel 2010**       | Retrospective | 78/45        | -           | -      | Valgus: 62 Varus: 14 Axial: 48         | EF: Ilizarov circular frame IF: ORIF                                         | IOWA knee score, ROM and complications                  | -         |
| Jansen 2012**        | Retrospective | 2/20         | 46          | 17/5   | OTA C1: 7, C2: 7, C3: 9               | EF: Ilizarov circular frame IF: Liss ± additional plates ± artificial bone substitute | KOOS, IKDC, Lysholm score, complications and ROM | 67 months |
| Kartheek 2017**      | Non-RCT, Prospective | 15/15       | 43.20 ± 10.98/44.73 ± 10.64 | 13/2   | V: 5 VI: 10 IF: V: 8 VI: 7           | EF: Ilizarov’s ring fixator IF: ORIF with Locking plate                     | ROM, complications, Rasmussen’s radiological scoring and modified Rasmussen clinical assessment score | 6 and 12 months |
| Krupp 2009**         | Retrospective | 30/28        | 48.8/46.64  | 23/35  | V: 37 VI: 21                          | EF: Hoffman II Hybrid, circular frames IF: Dual plating ± V: lateral locking plate medical screws or buttress plate | Clinical outcomes: union rate, time to union, malunion, ROM, complications and reoperations | EP: 16.4 months | IF: 10.2 months |
| Pun 2014**           | Retrospective | 12/9         | 43.85       | 20/1   | V: 11 VI: 10                          | EF: Circular frame + medial percutaneous screws IF: Dual plate               | IJS (clinical, functional and radiological outcomes), WOMAC and infection rates | 30 months |
| Tahir 2019**         | Retrospective | 69/68        | 45 ± 10.52  | 107/30 | V: 63 VI: 74                         | EF: Ilizarov’s external ring fixator IF: Dual plating                      | ROM, IJS (clinical, functional and radiological outcomes)                  | 24 months |
| Wu 2019**            | Non-RCT, Prospective | 34/35       | 48.56 ± 11.67/48.51 ± 9.98 | 46/23  | V: 21 VI: 48                         | EF: Limited open reduction or percutaneous screw/plate followed by hybrid external fixator IF: Single anterior incision or combined anterolateral and medial incision with dual plating | Rasmussen functional score, radio graphical parameters, complication rates, hospital days and operative parameters | 3, 6 and 24 months |
Table 3. Demographic Characteristics of the Included Studies (Continued)

| Study       | Study Design          | No. of Cases | Gender (M:F) | Fracture Type | Intervention                                                                 | Outcome Measure                                      | Follow-up          |
|-------------|-----------------------|--------------|--------------|---------------|------------------------------------------------------------------------------|------------------------------------------------------|--------------------|
| Veri 2000   | Retrospective matched- | 34/17        | -            | EF/IF         | EP: Hybrid ring fixator                                                       | Infection, re-operation, wound complications and time to healing/return to activity | EF: 15 months      |
|             | cohort design          |              |              |               | IF: ORIF with plates                                                         |                                                      | ORIF: 17 months    |
| Xu 2013     | Retrospective study    | 89/23        | 66/46        | aV: 58        | EF: Close reduction/minimal incision with hybrid external fixation           | Operative parameters, wound complications, Radiological assessment of reduction and fixation failure, SF-36 | 36.5 months        |
|             |                       |              |              | VI: 54        | IF: ORIF with one plate via anterolateral incision; ORIF with dual plating via anterolateral and posteromedial incisions; ORIF with dual plating via single midline incision; ORIF with dual plating via combined anterior and posterior approaches |                                                      | (range, 26–110 months) |

*Schatzker classification.
†Orthopaedic Trauma Association (OTA) classification.
The Chertsey classification of tibial plateau fractures.
KODS, Knee Injury and Osteoarthritis Outcome Score; IKDC, International Knee Documentation Committee scores; LCP, Locking Compression Plate; NRS, Numeric Rating Scale; HSS, Hospital for Special Surgery Knee score; WOMAC, Western Ontario and McMaster Universities Arthritis Index; ROM, Range Of Motion; HJS, Honkonen and Jarvinen Score; SF-36, Short Form 36; VAS, Visual Analogue Score; LISS, Less Invasive Stabilization System; COTS, Canadian Orthopaedic Trauma Society; EF, External Fixation; IF, internal fixation; ORIF, Open Reduction and Internal Fixation; RCT, Randomized Control Trial; Non-RCT, Non-Randomized Control Trial.

Figure 2. Forest-plot analysis of functional outcome and range of motion between the EF and ORIF group.
Figure 3. Forest-plot diagram analysis of delay in surgery, length of hospital stay, surgical time, intraoperative blood loss and consolidation time.
Complications
Fifteen studies (n = 920) reported rates of superficial and deep infection. The superficial infection rate in the EF and ORIF groups were 16.07% and 4.17% (OR: 3.22, 95% CI: 1.75, 5.93, \(P = 0.0002, I^2 = 36\%\), respectively. But there was no difference in deep infection rate between the group (5.51% vs. 4.17%, OR: 1.07, 95% CI: 0.55, 2.09, \(P = 0.84, I^2 = 16\%\)). Pooled results of 16 studies for any kind of infection revealed no difference in infection.

Figure 4. Forest-plot diagram showing infection rate in both the groups.
1. **Nonunion**

| Study or Subgroup | Ex-fix Events | Ex-fix Total | ORIF Events | ORIF Total | Weight | Odds Ratio | Odds Ratio IV, Fixed, 95% CI |
|-------------------|---------------|--------------|-------------|------------|--------|------------|-------------------------------|
| Berven 2018       | 3             | 62           | 9           | 66         | 46.6%  | 0.33 [0.09, 1.29] |
| Bove 2018         | 1             | 14           | 1           | 14         | 10.4%  | 1.00 [0.08, 17.75] |
| Evangelopoulos 2020 | 0         | 6            | 0           | 16         | Not estimable |
| Jansen 2013       | 1             | 2            | 3           | 20         | 9.3%   | 5.67 [0.27, 117.45] |
| Krupp 2019        | 4             | 30           | 3           | 28         | 33.7%  | 1.28 [0.26, 6.31] |
| **Total (95% CI)**| **9**         | **114**      | **146**     | **100.0%** | **0.77** | **[0.30, 1.93]** |

Total events: 9

Heterogeneity: Chi² = 3.56, df = 3 (P = 0.31); I² = 16%
Test for overall effect: Z = 0.56 (P = 0.57)

2. **Reoperation rate**

| Study or Subgroup | Ex-fix Events | Ex-fix Total | ORIF Events | ORIF Total | Weight | Odds Ratio | Odds Ratio IV, Fixed, 95% CI |
|-------------------|---------------|--------------|-------------|------------|--------|------------|-------------------------------|
| Ahearn 2014       | 0             | 21           | 4           | 34         | 2.7%   | 0.16 [0.01, 3.08] |
| Bertrand 2017     | 22            | 67           | 5           | 32         | 19.8%  | 2.05 [0.68, 6.17] |
| Berven 2018       | 8             | 62           | 10          | 68         | 23.9%  | 0.86 [0.32, 2.34] |
| Conservav 2015    | 3             | 41           | 1           | 38         | 4.5%   | 2.92 [0.29, 29.37] |
| COTS 2006         | 15            | 43           | 18          | 40         | 30.7%  | 0.65 [0.27, 1.58] |
| Evangelopoulos 2020 | 0         | 6            | 0           | 16         | Not estimable |
| Krupp 2019        | 10            | 30           | 7           | 28         | 18.3%  | 1.50 [0.48, 4.71] |
| **Total (95% CI)**| **58**        | **270**      | **250**     | **100.0%** | **1.05** | **[0.64, 1.71]** |

Total events: 58

Heterogeneity: Chi² = 5.37, df = 5 (P = 0.37); I² = 7%
Test for overall effect: Z = 0.19 (P = 0.85)

3. **Knee stiffness**

| Study or Subgroup | Ex-fix Events | Ex-fix Total | ORIF Events | ORIF Total | Weight | Odds Ratio | Odds Ratio IV, Fixed, 95% CI |
|-------------------|---------------|--------------|-------------|------------|--------|------------|-------------------------------|
| Berven 2019       | 7             | 62           | 9           | 68         | 55.0%  | 0.83 [0.29, 2.39] |
| Conservav 2015    | 3             | 41           | 0           | 38         | 6.8%   | 7.00 [0.35, 140.13] |
| Kartheek 2017     | 1             | 15           | 4           | 15         | 11.3%  | 0.20 [0.02, 2.02] |
| Krupp 2019        | 4             | 30           | 1           | 28         | 12.0%  | 4.15 [0.43, 39.87] |
| Wu 2019           | 2             | 34           | 2           | 35         | 15.0%  | 1.09 [0.14, 7.77] |
| **Total (95% CI)**| **17**        | **182**      | **184**     | **100.0%** | **1.03** | **[0.47, 2.24]** |

Total events: 17

Heterogeneity: Chi² = 5.14, df = 4 (P = 0.27); I² = 22%
Test for overall effect: Z = 0.06 (P = 0.95)

4. **Venous thromboembolism**

| Study or Subgroup | Ex-fix Events | Ex-fix Total | ORIF Events | ORIF Total | Weight | Odds Ratio | Odds Ratio IV, Fixed, 95% CI |
|-------------------|---------------|--------------|-------------|------------|--------|------------|-------------------------------|
| Ahearn 2014       | 1             | 21           | 0           | 34         | 9.1%   | 5.05 [0.20, 129.81] |
| Berven 2018       | 2             | 62           | 1           | 68         | 16.3%  | 2.23 [0.20, 25.26] |
| Chan 2012         | 0             | 35           | 2           | 24         | 10.1%  | 0.13 [0.01, 2.76] |
| Gurel 2019        | 4             | 45           | 2           | 79         | 31.8%  | 3.76 [0.66, 21.38] |
| Wu 2019           | 2             | 34           | 5           | 35         | 32.7%  | 0.38 [0.07, 2.08] |
| **Total (95% CI)**| **9**         | **197**      | **240**     | **100.0%** | **1.18** | **[0.44, 3.16]** |

Total events: 9

Heterogeneity: Chi² = 6.47, df = 4 (P = 0.17); I² = 38%
Test for overall effect: Z = 0.34 (P = 0.73)

Figure 5. Forest-plot diagram showing nonunion rate, reoperation rate, knee stiffness and venous thromboembolism rate in EF and ORIF groups.
rate between the two fixation groups (OR: 1.64, 95% CI: 0.76, 3.57, \( P = 0.21, I^2 = 61\% \)). There was significant heterogeneity \( (I^2 = 61\%, \ P = 0.001) \) among the studies. Exclusion of study by Berven et al.\(^{17} \) significantly lowered the heterogeneity (OR: 1.39, 95% CI: 0.84, 2.31, \( Z = 1.27, P = 0.20, I^2 = 46\%, P = 0.03 \)), but there was no difference in overall infection rate (Figure 4). Five studies \( (n = 260) \) reported on non-union following tibial plateau fracture fixation.\(^{15,17,18,36,37} \) The nonunion rate was lower in the EF than the ORIF, but it was not significant (7.89% vs 10.96%, OR: 0.77, 95% CI: 0.30, 1.93, \( I^2 = 16\%, P = 0.57 \)). The reoperation rate in the EF group was 21.48%, whereas in the ORIF group, it was 18%; the difference was not significant (OR: 1.05, 95% CI: 0.64, 1.71, \( P = 0.85, I^2 = 7\% \))\(^{15}–^{17,28,31,35,37} \) (Figure 5).

Five studies \( (n = 366) \) described the incidence of knee stiffness.\(^{13,17,19,35,37} \) There was no significant difference in the knee stiffness rate between the EF and ORIF groups (9.34% vs 8.69%, OR: 1.03, 95% CI: 0.47, 2.24, \( P = 0.95 \)). There was no difference in venous thromboembolism rate between the groups (OR: 1.18, 95% CI: 0.44, 3.16, \( P = 0.73 \))\(^{13,17,28,31,34} \). The rate of development of compartment syndrome in both the fixation groups was not different (OR: 0.65, 95% CI: 0.12, 3.35, \( P = 0.60 \))\(^{15,17,24,36} \).

Figure 6. Forest-plot diagram showing compartment syndrome, radiographic OA and TKA rate between both the groups.

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| 1. Compartment syndrome |
|-------------------------|
| **Study or Subgroup** | **Ex-fix Events** | **ORIF Events** | **Total Events** | **Total** | **Weight** | **Odds Ratio** | **IV, Fixed, 95% CI** |
|-------------------------|
| Berven 2018 | 0 | 62 | 68 | | | Not estimable | |
| Chan 2012 | 3 | 35 | 38 | | | 0.42 | [0.07, 2.76] |
| Evangelopoulos 2020 | 0 | 6 | 16 | | | Not estimable | |
| Jansen 2013 | 2 | 2 | 4 | | | 2.73 | [0.09, 86.92] |
| Total (95% CI) | 105 | 129 | 100 | 0.05 | [0.12, 3.35] |
| Heterogeneity: Chi\(^2\) = 0.86, df = 1 (P = 0.35); P = 0% | | | |
| Test for overall effect: Z = 0.52 (P = 0.60) | | | |

| 2. Radiographic OA |
|---------------------|
| **Study or Subgroup** | **Ex-fix Events** | **ORIF Events** | **Total Events** | **Total** | **Weight** | **Odds Ratio** | **IV, Fixed, 95% CI** |
|---------------------|
| Berven 2018 | 42 | 62 | 104 | 36.5% | | 2.10 | [1.03, 4.29] |
| Chan 2012 | 11 | 41 | 52 | 13.8% | | 0.84 | [0.26, 2.69] |
| Consenav 2015 | 13 | 24 | 37 | 13.2% | | 3.12 | [0.90, 10.83] |
| COTS 2006 | 11 | 21 | 32 | 12.0% | | 0.45 | [0.04, 5.19] |
| Gurlay 2019 | 3 | 5 | 8 | 9.1% | | 0.80 | [0.06, 5.67] |
| Krupp 2017 | 5 | 30 | 35 | 10.7% | | 0.50 | [0.20, 1.35] |
| Total (95% CI) | 260 | 286 | 100 | 1.56 | [1.02, 2.41] |
| Heterogeneity: Chi\(^2\) = 5.55, df = 6 (P = 0.48); P = 0% | | | |
| Test for overall effect: Z = 2.03 (P = 0.04) | | | |

| 3. TKA |
|--------|
| **Study or Subgroup** | **Ex-fix Events** | **ORIF Events** | **Total Events** | **Total** | **Weight** | **Odds Ratio** | **IV, Fixed, 95% CI** |
|--------|
| Chan 2012 | 4 | 35 | 39 | 10.9% | | 0.49 | [0.12, 2.06] |
| Consenav 2015 | 1 | 43 | 44 | 9.0% | | 0.30 | [0.01, 7.62] |
| COTS 2006 | 1 | 4 | 5 | 9.0% | | 0.20 | [0.01, 3.97] |
| Gurlay 2019 | 1 | 45 | 46 | 9.0% | | 0.45 | [0.04, 5.19] |
| Krupp 2017 | 1 | 30 | 31 | 9.0% | | 0.50 | [0.20, 1.35] |
| Total (95% CI) | 194 | 209 | 100 | 0.51 | [0.20, 1.35] |
Radiographic osteoarthritis was reported in 32.69% of patients in the EF group compared to 23.07% of patients in the ORIF group. The odds of development of posttraumatic OA were significantly higher in the EF group (OR: 1.56, 95% CI: 1.02, 2.41, \( P = 0.04 \)). Despite that, there was no difference in the need for TKA between the groups (3.6% vs 5.74%, OR: 0.51, 95% CI: 0.20, 1.35, \( P = 0.18 \)) (Figure 6).

Discussion

The major finding of this meta-analysis is that external fixation in complex tibial plateau fracture provides a better functional outcome than internal fixation. As the surgical time and intraoperative blood loss are less, it can be safely considered as a definite surgical fixation method in open injuries, polytrauma patients and chronically morbid patients who cannot withstand prolonged surgery.

It is believed that external fixation in tibial plateau fracture can result in a better functional outcome as it preserves the soft tissue and restores the limb alignment and articular surface until the fracture is healed.44–46 Several independent series of tibial plateau fractures reported good outcome in patients treated with external fixation. Catagni et al. reported a good-to-excellent outcome in 97% of patients treated with an external fixator in high energy complex tibial plateau fractures.47 Weiner et al. had 82% good or excellent outcome, but they could achieve a closed reduction in two-third of their patients, and the remaining one-third patients needed knee arthrotomy to obtain an acceptable reduction.48 Comparing the ORIF and EF in high-grade tibial plateau fractures, Veri et al. noted high rates of wound complications and reoperations in the ORIF group who were operated with single or double incisions and dual plate fixation.49 Their results also suggested that hybrid external fixation was an effective and safe method with a low wound complications rate. The findings of this meta-analysis had a similar conclusion as the functional outcome was significantly better in the EF group.11,12,13,15,20 Some studies reported their result as good/excellent/fair or poor outcome.14,16,28 It was observed that there was no statistically significant difference in the proportion of patients with good-to-excellent outcome in both treatment modalities. However, this categorical functional outcome evaluation included a wide range of patients in a particular category and probably comparing the two treatment groups with the exact value of their functional outcome more accurately rated the outcome in this meta-analysis. Consequently, it could be concluded that the patients treated with EF had a better functional outcome.

Similar to the previous meta-analyses, the superficial infection rate was more in patients treated with EF compared to ORIF.8,10 Pin tract infection is very common in the EF patients, but it is not a major concern for the patients as most of them respond to proper pin tract care and local/systemic antibiotic administration.41–44 Keightley et al. reported pin-site infections in half of their patients treated with Lizarov’s fixator in high-energy tibial plateau fractures, but there was no deep infection.44 Many authors had similar observations. The deep infection in tibial plateau fracture is worrisome; it can cause nonunion and may lead to osteomyelitis unless controlled early.5 In most hospitals, implant removal is delayed, and thus the deep infection in tibial plateau fracture is often delayed because of the associated open wound, fracture blisters, subcutaneous haemorrhage, or extensive bruising.16,18,31,32 Benirschke et al. reported 30% incidence of deep infection following ORIF, and it was much lower in patients treated with EF.45,46 Many previous studies reported a higher incidence of deep infection following ORIF in the tibial plateau fracture. This meta-analysis failed to see any difference in deep infection and overall infection rates between patients treated with ORIF and EF. Dual plating, longer operative time, increased intraoperative blood loss, smoking, and open fractures are independent risk factors of infection after ORIF.47–49 Young and his associates reported 88% deep infection in tibial plateau fracture treated with dual plating.47 Similarly, McKee et al. and Jensen et al. had a higher incidence of deep infection in the plate fixation group of their comparative studies.41,46 Many researchers believed that EF would not induce deep infection unless the fracture sites were opened.46–48 Bertrand et al. reported that opening up the fracture together with the use of permanent pins encouraged contamination and hence subsequent infection. They reported an infection rate of 62.5% in patients treated with open reduction and external fixation compared to 37.5% in patients treated with a closed reduction and external fixation.46

This meta-analysis did not find a significant difference in nonunion rate, reoperation rate and venous thromboembolism between EF and ORIF. The reoperation surgeries included bone grafting, readjustment of fixation, osteotomy, pin-track debridement, screw pull-out, fasciotomy, arthrolysis and knee amputation. However, no study took the planned frame removal into account during analyses. Posttraumatic osteoarthritis of the knee has been reported in 25–45% of patients following tibial plateau fracture at long-term follow-up.13,20,24 This incidence increases with the severity of the fracture, loss of reduction and in malalignment of more than 5°. We observed a significantly higher incidence of radiographic osteoarthritis in the external fixation group; however, it did not affect the functional outcome and conversion TKA. Several studies reported that residual tibial plateau articular incongruity did not compromise long-term functional outcomes.26,43 Many surgeons used the wire and frame device as a minimally invasive procedure for the complex tibial plateau fractures where the intrarticular reduction was achieved either by ligamentotaxis or by indirect methods (thumping, K-wire joystick or reduction clamp).51–54 Although few lag screws were fixed before the wire application in many patients, all the comminuted bony fragments might not have been stabilized adequately. These fragments held by the smooth wires of the external fixator probably failed to maintain the reduction until healing and hence resulting in joint incongruence. Nevertheless, there was no difference in the need for TKA between EF and ORIF. Literature supports that the proportion of patients who need TKA after the development of posttraumatic OA is low, and it may range from 3% to 7% at 10 years.51–53

Knee stiffness was reported in approximately 15% of patients after tibial plateau fracture.44–46 Reahl et al. identified two risk factors for the development of arthrofibrosis, the bicondylar fracture and time spent in an external fixator.55 However, these are the spanning external fixator which limits the movement of the knee. The external fixator, as discussed in this meta-analysis, was applied only in the tibia, and it spared the knee joint; hence it allowed early ROM. The other variables, like an open fracture, orthopaedic polytrauma, and tibial spine involvement, have been reported to be associated with knee stiffness in short-term follow up.48 Deep infection, non-white ethnicity and increasing age are also proposed as the risk factors for knee arthrofibrosis in tibial plateau fracture at long term follow-up.47 There were no such differences among the treatment groups in these studies. In agreement with the literature, this meta-analysis showed significantly better ROM (7.86° extra ROM) among patients treated with EF.

Open reduction and internal fixation with single or double plates in complex tibial plateau fracture are often delayed because of the associated open wound, fracture blisters, subcutaneous haemorrhage, or extensive bruising.16,18,31 Benirschke et al. reported 30–35% incidence of open injury in complex tibial plateau fracture; 86% of the remaining fractures were associated with significant closed injuries to the soft tissue.26 In the presence of severe soft tissue compromise, the EF in contrast to the traditional methods of ORIF, allow for early surgery with adequate stabilization of the fracture and minimal soft tissue devitalization.13,19–20,29–31 The pooled assessment of the available

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The main advantages of EF were lesser intraoperative bleed and decreased surgical time. Surgical time has been consistently reported to be an independent risk factor of infection in tibial plateau fracture.45-47 It has been reported that for every extra 30 min of surgery time, the incidence of infection increases by 2.5%.48 Colman et al. reported that every extra hour of operative time increased the risk of surgical site infection by approximately 78%.49 Longer surgical time results in increased exposure of the surgical field to airborne pathogens, and increased tissue ischemia and necrosis; these factors contribute to the incidence of surgical site infection. Prolonged surgery leads to increased intraoperative bleed, which is an independent risk factor for infection.46,48-50 In severely morbid or polytrauma patients, surgical time is crucial.49 Accordingly, Ilizarov external fixator was used in many studies in the principle of damage control orthopedics.46-48 Removal of the external fixator and subsequent internal fixation as reported in the staged procedure of tibial plateau fracture is associated with inferior outcome compared to primary ORIF.46 It is probably better to retain the external fixator as a definite fixation method till fracture healing because it has a better functional outcome and similar complications to that of primary internal fixation.

It is indeed challenging to design RCT in tibial plateau fracture as the literature supports the use of external fixator in specific conditions like compartment syndrome, open fracture, poor soft tissue envelope and extremely comminuted intraarticular fracture. Accordingly, the retrospective studies are the strength of this meta-analysis because the patients could be treated with appropriate fixation devices as per the decision of the surgeons. We believe that the surgeon must have considered the soft tissue condition, associated injuries and bone comminution while deciding the treatment towards external fixation.

There were certain limitations to this meta-analysis. Most of the studies were retrospective in design; hence missing of the data could not be overlooked. Small patient cohorts, short follow up, and different assessment tools were other drawbacks. Different surgical settings and comorbidities might have affected the outcome. A major drawback of this meta-analysis was that none of the studies evaluated the cost-effectiveness of the treatment modalities in these patients. The patient compliance and acceptability of the procedure were other variables that needed evaluation. Despite these limitations, the strength of this meta-analysis was that most of the studies were designed appropriately, and there was no significant heterogeneity among the studies.

Based on the current evidence, the meta-analysis revealed that external fixation in complex tibial plateau fracture provides a better functional outcome and range of motion than the internal fixation. As the surgical time and intraoperative blood loss are less, it can be safely considered as a definite treatment method in open injuries, polytrauma patients and chronically morbid patients who cannot withstand prolonged surgery. Further randomized clinical trial and multicentre studies can clarify the results more reliably.

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