Original Article

Complex Tibial Plateau Fractures Treated by Hybrid External Fixation System

A correlation of followup computed tomography derived quality of reduction with clinical results

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Abstract

Background: Tibial plateau fractures are common due to high energy injuries. The principles of treatment include respect for the soft tissues, restoring the congruity of the articular surface and reduction of the anatomic alignment of the lower limb to enable early movement of the knee joint. There are various surgical fixation methods that can achieve these principles of treatment. Recognition of the particular fracture pattern is important, as this guides the surgical approach required in order to adequately stabilize the fracture. This study evaluates the results of the combined treatment of external fixator and limited internal fixation along with the advantages using postoperative computed tomography (CT) scan after implant removal. **Materials and Methods:** 55 patients with a mean age of 42 years (range 17–65 years) with tibial plateau fracture, were managed in our institution between October 2010 and September 2013., Twenty fractures were classified as Schatzker VI and 35 as Schatzker V. There were 8 open fractures (2 Gustilo Anderson 3A and 6 Gustilo Anderson 2). All fractures were treated with closed reduction and hybrid external fixation (n = 21/38.2%) or with minimal open reduction internal fixation and a hybrid system (n = 34/61.8%). After the removal of the fixators, CT-scan was programmed for all the cases, for correlation with the results. At final followup, the American Knee Society Score (AKSS) was administered. **Results:** All patients were evaluated with a minimum of 12 months (range 12–21 months) followup. Average time to union was 15.5 weeks (range 13–19 weeks). The postoperative joint congruity as evaluated in the postoperative CT-scan was <2 mm of articular step-off in 8 patients (14.5%), between 2 and 4 mm in 18 patients (32.7%) and over 4 mm in 29 (52.7%). The injured limb mechanical axis was restored within 5° compared to the contralateral limb in 36 cases (65%) and with an angulation >5° in 19 cases (35%). Patients with residual joint depression <3.5 mm had a 95% chance of having excellent AKSS knee score results and 80% chance of having excellent AKSS function scores. On the other hand, residual joint depression of >4.5 mm displayed a 100% chance of getting poor-fair scores both in AKSS knee and AKSS function score. The association of a postoperative mechanical axis within 5° of the contralateral limb and improved knee scores was statistically significant for the AKSS function and total scores but not for the AKSS knee score. The AKSS was negatively correlated with postoperative joint depression magnitude which was statistically significant. Only the amount of joint collapse was verified as a prognostic factor in a multivariate logistic regression analysis. **Conclusions:** The postoperative CT-scan shows important information about bone healing, and an exact image of the reduction and the shaft alignment. Postoperative radiographs may have led to an underestimation of the degree of residual displacement. On the contrary, CT-scan demonstrates the exact grade of articular displacement and depending on CT-scan results one can better manage the postoperative rehabilitation.

Keywords: *Joint congruity, postoperative computed tomography scan, tibilal plateau fractures, hybrid fixation*

MeSH terms: *Tibial fractures, CAT scanners, x-ray, Ilizarov technique*

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Access this article online

Website: www.ijoonline.com

DOI: 10.4103/ortho.IJOrtho_300_16

Quick Response Code:

Introduction

Complex tibial plateau fractures are usually high energy injuries presenting with significant articular and soft tissue damage in a major weight bearing joint. The restoration of the articular surface, joint stability, and axis is technically demanding. The soft tissue damage associated with the injury severity, only adds to the challenge of optimizing outcomes for these injuries.[1]

The original approach to these injuries was an open reduction of the fragments and

How to cite this article: Kateros K, Galanakos SP, Kyriakopoulos G, Papadakis SA, Macheras GA. Complex tibial plateau fractures treated by hybrid external fixation system: A correlation of followup computed tomography derived quality of reduction with clinical results. Indian J Orthop 2018;52:161-9.

internal fixation with plates and screws.[2,3] The advantage of anatomic reduction and stable fixation that allows early joint motion is, however, frequently overshadowed by soft tissue complications.[4-6] The effect of the surgical trauma on compromised soft tissues leads to wound infection, a devastating complication associated with an increased reoperation rate and poor outcomes.[7,8] To address these concerns, the use of a closed or limited open reduction with a hybrid ring fixator or ring frame has been advocated.[9-12]

The purpose of this prospective case series was to evaluate the radiological and clinical outcomes after treatment of complex proximal tibial fractures with the use of a hybrid external fixator utilizing a pre- and postoperative computed tomography (CT) scan and the American Knee Society Score (AKSS).

Materials and Methods

55 consecutive patients with 55 complex tibial plateau fractures treated by a hybrid external fixator between October 2010 and September 2013 in our institutions were enrolled in this study. All the cases were operated by senior surgeons (KK, PS).

All patients over 17 years of age with Schatzker Type V or VI tibial plateau fractures were included in the study. Exclusion criteria were multi-ligamentous instability that required a knee-spanning external fixator, patients that required a damage control approach due to vascular insult, bilateral injury, ipsilateral femoral fracture, preexisting knee arthritis, pathological fractures, and nonindependent preinjury ambulatory status.

64 fractures in 64 patients were identified during this period. Six patients had preexisting knee arthritis, two had impaired knee function due to previous strokes and one had vascular injury. These 9 patients were excluded from the study. There was a male predominance in the group with 31 male and 24 female patients and the mean age was 42 years (range 17–65 years). Twenty fractures were classified as Schatzker type VI and 35 as Schatzker type V. There were 8 open fractures (2 Gustillo Anderson 3A and 6 Gustillo Anderson 2) [Table 1]. The study protocol was approved by our institutions' ethics and scientific boards.

All patients underwent standard anteroposterior and lateral knee radiographs, performed in the emergency department [Figure 1a]. In addition, all patients underwent CT scans with coronal [Figure 1b] and axial [Figure 1c] reconstruction to evaluate the degree and location of articular comminution and joint depression, articular step-off, and identify main fragments on which to build a stable construct and place wires.

Operative procedure

Prophylactic antibiotics were administered intravenously in all cases. All open fractures (n = 8) received antibiotic doses like this for the first day, a combination of the second generation cephalosporin with an aminoglycoside and subsequently replaced according to the culture results. Both open and closed fractures received preoperatively a single dose of teicoplanin. Patients who had an open wound received antibiotic treatment for a minimum of 5 days.

Surgery was performed under spinal or general anesthesia. Closed reduction was attempted under fluoroscopic guidance with ligamentotaxis either by means of fracture table traction or by an assistant, and gentle direct pressure and where needed, minimal open reduction or articular

Figure 1: Preoperative radiograph in anteroposterior view (a) and computed tomography in coronal (b) and axial view (c) showing proximal tibial fracture

Table 1: Clinical details of patients

Case number	Age (years)	Schatzker type	Open fracture	Preoperative step (mm)	Joint alignment	Joint collapse (mm)	AKSS total
1	21	V	No	14	4° Varus	5	141
2	43	V	No	12	10° Varus	2	180
3	23	VI	Gustilo 2	13	4° Varus	6	139
4	41	V	No	11	3° Valgus	3	172
5	27	VI	No	12	11° Valgus	5	130
6	57	V	No	10	3° Varus	5	125
7	24	VI	No	9	8° Valgus	2	164
8	21	V	No	12	4° Varus	5	138
9	37	V	No	10	5° Varus	5	146
10	34	V	No	9	3° Valgus	<2	180
11	41	VI	Gustilo 2	11	8° Varus	5	145
12	51	VI	No	12	7° Varus	6	110
13	35	V	No	9	4° Varus	3	171
14	19	V	No	8	2° Varus	5	151
15	28	VI	No	11	10° Varus	6	144
16	55	V	No	8	2° Varus	<2	183
17	58	V	No	7	2° Varus	<2	184
18	47	VI	No	13	3° Valgus	6	126
19	45	V	Gustilo 2	10	10° Varus	5	123
20	51	VI	No	11	3° Varus	5	119
21	49	VI	No	10	8° Varus	5	131
22	50	V	No	9	4° Varus	3	171
23	29	V	Gustilo 2	10	5° Valgus	6	161
24	57	VI	No	11	7° Varus	5	138
25	61	V	No	10	2° Varus	6	129
26	48	VI	No	13	8° Valgus	7	119
27	49	V	No	9	2° Varus	2	174
28	53	VI	No	9	3° Valgus	3	176
29	31	V	No	8	2° Varus	<2	190
30	56	VI	No	11	4° Varus	6	107
31	49	V	Gustilo 2	10	8° Varus	5	115
32	41	V	No	9	5° Varus	<2	172
33	40	VI	No	7	2° Varus	2	163
34	43	VI	No	12	5° Valgus	6	124
35	41	V	No	8	9° Varus	2	164
36	29	V	No	9	4° Varus	3	156
37	65	VI	Gustilo 3A	14	7° Varus	8	109
38	49	VI	No	12	6° Valgus	6	128
39	34	VI	No	11	3° Varus	6	139
40	59	V	No	8	2° Varus	<2	177
41	60	V	No	9	5° Varus	3	164
42	61	V	No	8	4° Valgus	3	172
43	39	V	No	8	8° Varus	4	160
44	48	VI	No	12	4° Varus	6	148
45	33	V	No	8	8° Varus	4	164
46	37	V	No	7	5° Varus	3	170
47	52	V	No	8	2° Valgus	3	166
48	41	V	No	6	2° Varus	<2	192
49	26	V	No	7	6° Varus	<2	185
50	27	VI	Gustilo 3A	14	4° Varus	8	101
51	42	V	No	9	2° Varus	4	146
52	23	V	No	10	6° Varus	7	126
53	37	V	No	10	2° Varus	4	145

Contd...

Table 1: Contd...

Case number	Age (years)	Schatzker type	Open fracture	Preoperative step (mm)	Joint alignment	Joint collapse (mm)	AKSS total
54	52	V	No	11	4° Varus	7	125
55	41	V	Gustilo 2	12	8° Valgus	8	121

AKSS=American Knee Society Score

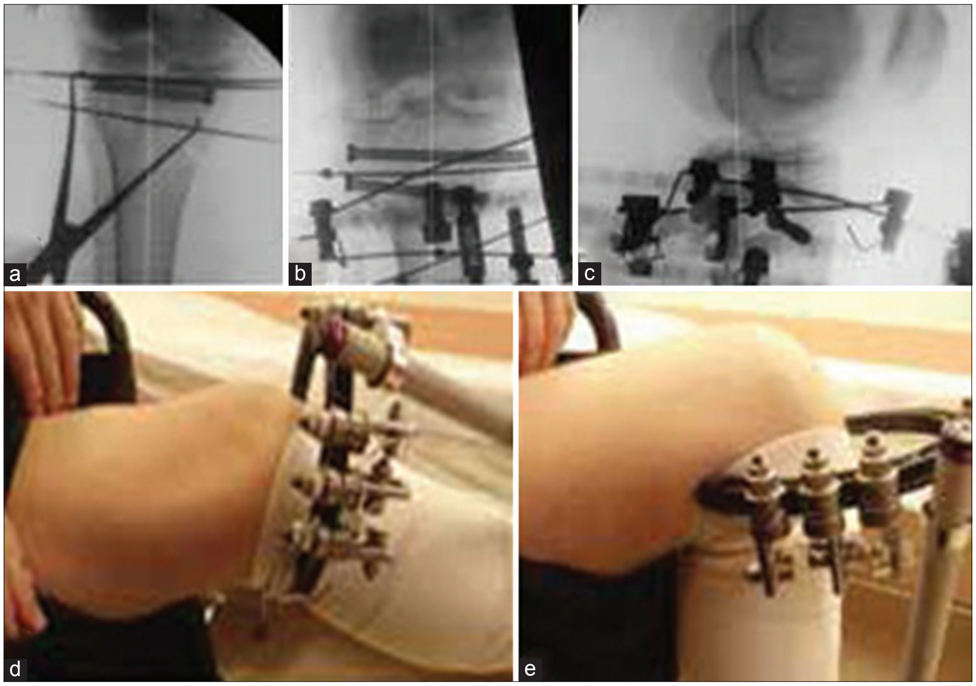

Figure 2: (a,b,c) Fluoroscopic images showing minimal invasive internal fixation and hybrid fixation in proximal tibial fracture and clinical photographs (d,e) showing fixation *in situ*

Figure 3: Preoperative radiographs anteroposterior (a) and lateral view (b) showing proximal tibial fracture Schatzker type VI (c,d) Anteroposterior and lateral view radiographs after hybrid external fixator and minimal internal fixation removal

surface elevation with a tamp through a cortical window, followed by lag screw insertion. The articular blocks were then fixed to the shaft by a hybrid external fixator with a standard Ilizarov ring proximally and Schanz screws distally [Figure 2].

Each limb was strictly elevated until soft tissue edema was no longer a concern. Postoperatively, patients were encouraged to begin range of motion exercises immediately and physiotherapy was initiated during instay and continued postdischarge. Patients and caretakers were trained and instructed on pin toilette. All patients were nonweight bearing for 6 weeks postoperatively, and depending on articular surface comminution, were allowed to weight bear progressively from the 6th or 8th week. Full weight bearing was deferred until radiological or clinical signs of healing were observed.

Patients were followed up with serial radiographs in the outpatient department until clinical and radiographic union as defined by pain-free weight bearing and callus on three of four cortices. After fracture healing, the external fixator was removed and the postoperative CT-scan performed. All patients were followed up at weekly postoperative visits until fixator removal and at monthly intervals thereafter for a minimum of 1 year postoperatively (range 12–21 months) when the knee score evaluation was performed [Figures 3a-d].

Subsequently, the fixator was removed and they had a CT-scan of their knee. At their final appointment, they were evaluated with the AKSS scores.[13]

The radiographs and CT-scans were reviewed documenting: alignment, articular depression in millimeters and step-off by the senior authors (KK, PS) along with a senior radiologist.

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) statistical package version 17 (SPSS Inc., Chicago, IL, USA). Data are expressed as mean ± standard deviation or median (interquartile range) for quantitative data and as percentages for qualitative data. The Kolmogorov–Smirnov test was utilized for normality analysis of the parameters. The analysis of quantitative variables between compared groups was performed using the one-way ANOVA model. Pairwise comparisons performed using the Bonferroni test. Kruskal–Wallis test and Mann–Whitney test were used in case of violation of normality. The correlation between qualitative variables was performed using the Chi-square test. Correlation between quantitative variables was examined using the Pearson's or Spearman's correlation coefficient. A receiver operating curve (ROC) analysis was conducted to determine the diagnostic ability and obtain cut off levels of joint collapse number for the classification of patients as excellent and no excellent according to AKSS knee and AKSS function scores by calculating the respective areas under the curve with their standard error and 95% confidence interval. The diagnostic ability of the joint alignment for the classification of patients as excellent and no excellent according to AKSS knee and AKSS function scores was evaluated using the sensitivity and specificity values multiple linear and logistic regression analysis with enter method was performed using as dependent variables the AKSS knee and AKSS function scores in quantitative

Table 2: Patient knee scores distribution

AKSS knee score category				AKSS function score category			
Poor (<60)	Fair (60-69)	Good (70-79)	Excellent (80-100)	Poor (<60)	Fair (60-69)	Good (70-79)	Excellent (80-100)
4 (7.2%)	18 (32.7%)	13 (23.6%)	20 (36.4%)	7 (12.7%)	13 (23.6%)	7 (12.7%)	28 (50.9%)

AKSS=American Knee Society Score

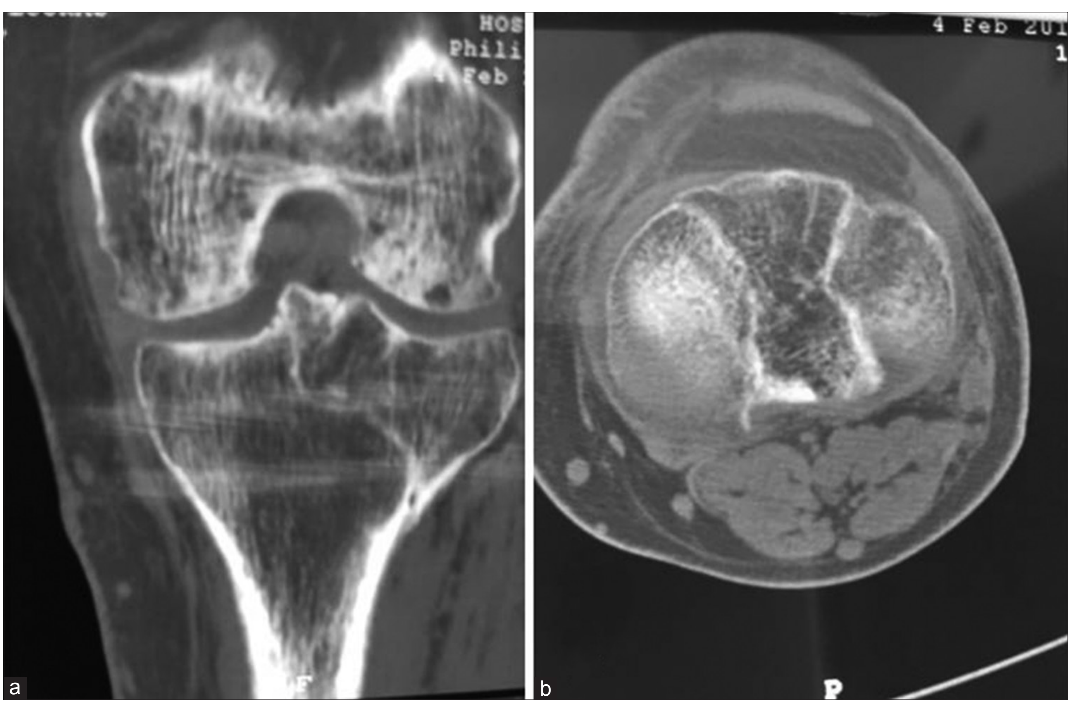

Figure 4: Postoperative CT scan in coronal (a) and axial plane (b) showing united proximal tibial fracture

and qualitative form and as independent variables the joint collapse number and joint alignment. All tests were two-sided, statistical significance was set at $P < 0.05$.

Results

All fractures were treated with closed reduction and hybrid external fixation (21 fractures38.2%) or with minimal open reduction and a hybrid system (34 fractures/61.8%). Postoperative length of stay at hospital average was 4.2 days (range 3 to 6 days). Union was defined as pain-free weight bearing, and radiographs showing callus in minimum 3 cortices was observed. Average time to union was 15.5 weeks (range 13–19) [Figure 4a and b]. There were 9 cases of pin tract infection treated with oral antibiotics and aggressive pin toilette but no deep wound infections or septic arthritis. We observed no compartment syndromes or deep vein thrombosis.

The AKSS knee score was good or excellent in 22 patients overall (40%) and poor or fair in 23 patients (60%) with a mean value of 73. The AKSS function score was good or excellent in 35 patients (64%) and poor or fair in 20 (36%) with a mean value of 75 [Table 2].

The postoperative joint congruity as evaluated in the postoperative CT-scan was <2 mm of articular step-off in 8 patients (14.5%), between two and four mm in 18 patients (32.7%) and above 4 mm in 29 (52.7%). The injured limb joint alignment was restored within 5° compared to the contralateral limb in 36 cases (65%) and with an angulation >5° in 19 cases (35%). The AKSS was negatively correlated with postoperative joint depression magnitude was statistically significant [Table 3].

ROC analysis showed that patients with residual joint depression <3.5 mm had a 95% chance of having excellent AKSS knee score results and 80% chance of having excellent AKSS function scores. On the other hand, residual joint depression of >4.5 mm displayed a 100% chance of getting poor fair scores both in AKSS knee and AKSS function score.

The association of a postoperative joint alignment within 5° of the contralateral limb and improved knee scores was statistically significant for the AKSS function and total scores but not for the AKSS knee score [Table 4].

Patients with postoperative joint alignment within 5° of the contralateral limb were associated with better knee function score category (good-excellent vs. poor-fair). Sensitivity: 77%, Specificity: 55%, $P = 0.021$ [Table 5]. However, only the amount of joint collapse was verified as a prognostic factor in a multivariate logistic regression analysis (excellent vs. no excellent and poor-fair vs. excellent).

Open fractures had on average lower AKSS scores (Gustillo Anderson 2 134 vs. 149 overall), but this did not reach statistical significance due to the small number of cases.

Table 3: Correlation of the American Knee Society Score with postoperative joint depression

Scores	Joint depression (mm)	*n*	Mean value	SD	*P*
AKSS knee	<2	8	8788	3182	<0.0005
	2-4	18	7989	4042	
	>4	29	6528	5457	
AKSS function	<2	8	95	378	<0.0005
	2-4	18	8556	6157	
	>4	29	64,31	10,583	
AKSS total	<2	8	18,288	6556	<0.0005
	2-4	18	16,544	9376	
	>4	29	12,959	14,319	

AKSS=American Knee Society Score, SD=Standard deviation

Table 4: Correlation of the American Knee Society Score with postoperative joint alignment

Scores	Angulation	*n*	Mean value	SD	*P*
AKSS knee	<5°	36	7494	10,057	0.107
	>5°	19	7032	9787	
AKSS function	<5°	36	7903	14,678	0.025
	>5°	19	6947	14,327	
AKSS total	<5°	36	15,397	23,974	0.040
	>5°	19	13,979	23,446	

AKSS=American Knee Society Score, SD=Standard deviation

Table 5: Correlation of the American Knee Society Score function score categories with postoperative joint alignment

Joint alignment	AKSS function score category	
	Poor-fair, *n* (%)	Good-excellent, *n* (%)
Anglulation		
<5°	9 (25.00)	27 (75.00)
>5°	11 (57.9)	8 (42.1)
P	0.021	

AKSS=American Knee Society Score

Discussion

The treatment of complex proximal tibial fractures is challenging, and till date, there is no clear consensus as to the ideal method of treatment. Data suggesting that minimally invasive or closed reduction and ring or hybrid external fixation is a safer equivalent to open reduction and internal fixation of Schatzker Type V and VI fractures have accumulated in the past decade.[11,12,14,15]

The need of preoperative detailed imaging especially for these specific types of injuries has been mentioned by many authors.[16-18] Yang *et al*.[16] proposed a CT-based three-column classification system (TCCS) where posterior tibial plateau fractures were defined as a fracture with an independent fragment of the posterior column. The authors stated that the TCCS gives a better understanding of the fracture morphology and the injury mechanism, which determines the appropriate surgical management.[16] Furthermore, other investigators agree that this classification system demonstrates a higher reliability and it can be used as a supplement to the conventional Schatzker classification, especially for complex and posterior comminuted tibial plateau fractures.[17,18]

Various surgical techniques and approaches have been described, all with their own advantages and disadvantages. Likewise, numerous fixation options and devices are available, all with their own indications, contraindications, and potential problems.[19]

Open reduction and internal fixation with plates and screws has been termed as the "gold standard" treatment for these fractures so as to achieve a precise anatomic reduction of the joint surface which is solid enough to allow early mobilization; but these modalities of internal fixation, especially with a compromised soft tissue envelope and bulky metallic hardware, have been associated with complications.[8]

The role of external fixators, either half-pin or ring and wire, has been evaluated in various studies of comminuted complex tibial plateau fractures, and quite encouraging results have emerged.[9-12,15] To address reduction issues, several authors reported good results using a hybrid or circular frame combined with minimal open reduction and percutaneous screw fixation or even grafting, through a small skin incision in cases with severe comminution and metaphyseal osseous gap.[20-22]

Minimally invasive procedures with bone allograft and percutaneous screw fixation may be a treatment option with low risk of complications and a high level of satisfactory clinical and patient-reported outcomes for a selected patient group.[23] In a recent study by Elsøe *et al*.[23] 82% of the patients achieved anatomical reduction, which is in line with, or better than, other studies reporting this surgical method.[24,25]

Moreover, no significant advantage of the newer open techniques has been reported in studies of sufficient power, as reflected in the recent review study by McNamara *et al*.[26] where patients treated with hybrid fixation were less likely to undergo secondary unplanned surgery.

In the present study, the postoperative joint depression showed a statistically significant correlation with the AKSS. Patients with residual joint depression >4.5 mm had poor or fair results, whereas all patients with joint depression <4 mm had good or excellent results. In the literature, there has been a wide range of residual displacement from 2 to 10 mm that has been considered acceptable.[27-30] In a retrospective study by Rademakers *et al*.[31] the authors fractures found that an articular step-off of up to 4 mm did not differ statistically with a step-off less than 2 mm in radiographic and clinical outcomes at a mean followup of 14 years.[31] This is in accordance with our findings, but the study included all types of tibial plateau fractures and possibly does not account for the cartilage damage seen in higher energy fractures as in those of the present study. Kumar and Whittle[22] found better knee scores in short and midterm followup in patients that had a near anatomic restoration of the articular surface compared to patients with joint incongruity but did not quantify the amount of joint depression in their cases. An experimental study in sheep models by Trumble *et al*.[30] suggests that articular step-off of less than 2 mm is critical for good outcomes. They found that joint contour improvement is possible in displaced articular fragments if the displacement is less than the articular cartilage thickness.[30] The importance of articular congruity restoration is highlighted in the study by Blokker *et al*.[32] where a residual step-off >5 mm was associated with unsatisfactory results. Bai *et al*.[33] performed a cadaveric biomechanical study loading lateral tibial plateau fracture models with varied degrees of articular showed the importance of reducing articular step-off and retaining the menisci.[33] Honkonen, on the other hand, found a poor correlation between articular irregularities and development of osteoarthritis highlighting the role of meniscal retention or repair and anatomical axis restoration in the optimization of oucomes.[27]

Our data show a statistically significant decrease in knee scores in patients with a nonanatomic restoration of the joint alignment, defined as a 5° change from the contralateral limb, but disagree with the effect of joint congruency on outcomes with the previous author. The weaker statistical correlation of the mechanical axis and outcomes compared to joint congruity could, however, be due to the shorter followup in our study; although, we are not aware of any high powered study comparing the relative importance of mechanical axis alignment versus joint congruity in terms of mid to long term outcome.

The effect of residual joint depression in the long term outcomes of patients treated with tibial plateau fractures has not been resolved in the literature. Houben *et al*.[34] demonstrated a bimodal distribution of knee function deterioration following a tibial plateau fracture. Their patients reported the most functional complaints in the first 3 years or after 6 years from treatment, with an improvement in subjective knee scores in years 3–6. Therefore, the duration and timing of followup play a critical role in the reported outcomes.

The value of radiographic arthritis measurements has been challenged in a study by Katsenis *et al*.[15] who followed up patients treated with small wire circular frames at 3 and 5 years postoperatively and found radiographic deterioration of the knee joint without significant deterioration of functional results. Conserva *et al*.[14] with a mean followup of 3 years (38 months) noticed a higher incidence of radiographic osteoarthritis in patients treated with external fixation for complex tibial plateau fractures than in patients treated with internal fixation. However, patients treated with external fixation had higher WOMAC scores, although this did not reach statistical significance.

The major strength of the present study is the elimination of methodological issues with radiographic measurements and interobserver variability by means of postoperative CT-scans. To assess the effect of articular congruity on outcomes, fracture reduction has to be measured in an accurate and reproducible manner. Plain radiographs have not been shown to allow for an accurate and reproducible measurement of articular joint depression and joint alignment. To our knowledge there has been no similar study correlating functional outcomes with CT-derived radiographic measurements for complex tibial plateau fractures.

The main limitation of the study is the relatively short followup of our patients, which does not allow for long term outcome prognosis.

Conclusions

Based on our results, the use of hybrid external fixator for the treatment of complex tibial plateau fractures is safe and effective in terms of low rates of complication and good functional results. Attempts to restore the articular congruity and anatomical axis should be made, as an articular step-off of more than 4 mm is strongly correlated with worse outcomes. Malalignment in the coronal plane should be <5° compared to the contralateral limb to improve short-term functional outcomes.

We feel that further studies of higher power are needed to determine the effect of smaller articular step-off on short and midterm functional outcomes, and help elucidate the effect of level of surgeon and center expertise in the treatment outcomes of these challenging injuries.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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