

Determinants of functional recovery after tibial plateau fractures: The role of fracture severity, fixation, and complexity

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Abstract

Objective: Tibial plateau fractures are complex intra-articular injuries with variable functional outcomes. While fracture classifications guide management, their ability to predict recovery remains unclear. This study evaluated the impact of fracture severity, treatment variables, and fracture complexity on patient-reported and objective outcomes over time.

Methods: A retrospective cohort of 75 patients who underwent surgical treatment for tibial plateau fractures was analyzed. Functional outcomes were assessed using the Knee Injury and Osteoarthritis Outcome Score (KOOS) and knee flexion at 1 month, 3 months, 6 months, 1 year, and 2 years postoperatively. Fractures were classified using Schatzker and AO/OTA systems. Fixation method, column and segment involvement, and patient factors were recorded. Longitudinal changes were analyzed using generalized estimating equations, and predictors of early improvement were evaluated using robust regression.

Results: KOOS and knee flexion improved significantly over time ($p < 0.001$). Mean KOOS increased from 23.15 ± 5.87 at 1 month to 84.19 ± 8.74 at 2 years, while flexion improved from $74.12 \pm 13.91^\circ$ to $120.91 \pm 17.31^\circ$. Schatzker and AO/OTA classifications were associated with KOOS ($p < 0.001$) but not flexion ($p = 0.160$). Definitive internal fixation method was not significantly associated with KOOS outcomes ($p = 0.817$). In robust regression, male sex ($\beta = 4.146$, $p = 0.042$) and posterior segment count ($\beta = 2.011$, $p = 0.022$) were positively associated with KOOS improvement, whereas comorbidity ($\beta = -7.245$, $p = 0.012$) and provisional external fixation before definitive surgery ($\beta = -8.683$, $p < 0.001$) were associated with less improvement, statistically.

Conclusion: Recovery following tibial plateau fractures is primarily time-dependent, with fracture severity influencing patient perception but not objective motion. No significant associations were identified between functional outcomes and fixation method or the evaluated fracture-complexity parameters in the present cohort.

Keywords: tibial plateau fractures, KOOS, fracture classification, range of motion, outcome assessment

Introduction

Tibial plateau fractures are complex intra-articular injuries that can significantly affect knee function and long-term joint health [1,2]. Restoration of articular

congruity, mechanical alignment, and joint stability are considered essential for optimal recovery [1]. Despite advances in surgical techniques and fixation methods, functional outcomes remain variable, and the factors influencing recovery are not fully understood [2,3].

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Received: April 23, 2026 Accepted: July 23, 2026 Published online: September 30, 2026

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Fracture classification systems such as Schatzker and AO/OTA are widely used to describe injury patterns and guide treatment strategies [1,2]. In general, more severe fractures are thought to be associated with worse clinical outcomes [4,5]. At the same time, considerable emphasis has been placed on surgical technique, with the assumption that fixation method may influence postoperative recovery [3,6]. However, the extent to which fracture severity and fixation strategy independently affect functional outcomes remains unclear [1,2,4].

More recently, concepts such as the 3-column model and ten-segment classification have been introduced to better characterize fracture complexity and guide surgical planning [7-9]. Although these systems provide a more detailed anatomical description, their relationship with clinical outcomes has not been clearly established [8,9]. In addition, it is not well defined whether different outcome domains, such as patient-reported measures and objective range of motion, are influenced by the same factors [9,10].

Therefore, the aim of this study was to evaluate the impact of fracture severity, fixation method, and fracture complexity on functional outcomes following tibial plateau fractures. We hypothesized that fracture severity would negatively affect both patient-reported and objective outcomes, fixation method would have a significant impact on functional recovery.

Methods

The research was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the institutional review board (IRB No: SBA 25/682).

This retrospective cohort study included consecutive patients who underwent surgical treatment for tibial plateau fractures at a single tertiary referral center between 2014-2023. Patients were eligible for inclusion if they were aged ≥ 18 years, had a tibial plateau fracture treated surgically, and had available clinical and radiological follow-up data. Patients with pathological fractures, prior surgery on the affected knee, or incomplete medical records were excluded, Figure 1. All 75 included patients had available KOOS and knee flexion measurements at the predefined follow-up assessments.

Data collection

Demographic and clinical data were obtained from institutional records, including age at the time of surgery, sex, affected side, presence of comorbidities, trauma mechanism. Surgical variables included fixation method, use of bone graft (autograft, allograft, or none), application of external fixation, reoperation status. In the fixation classification, “plate plus screw(s)” indicated plate fixation combined with one or more additional independent lag screws placed outside the plate.

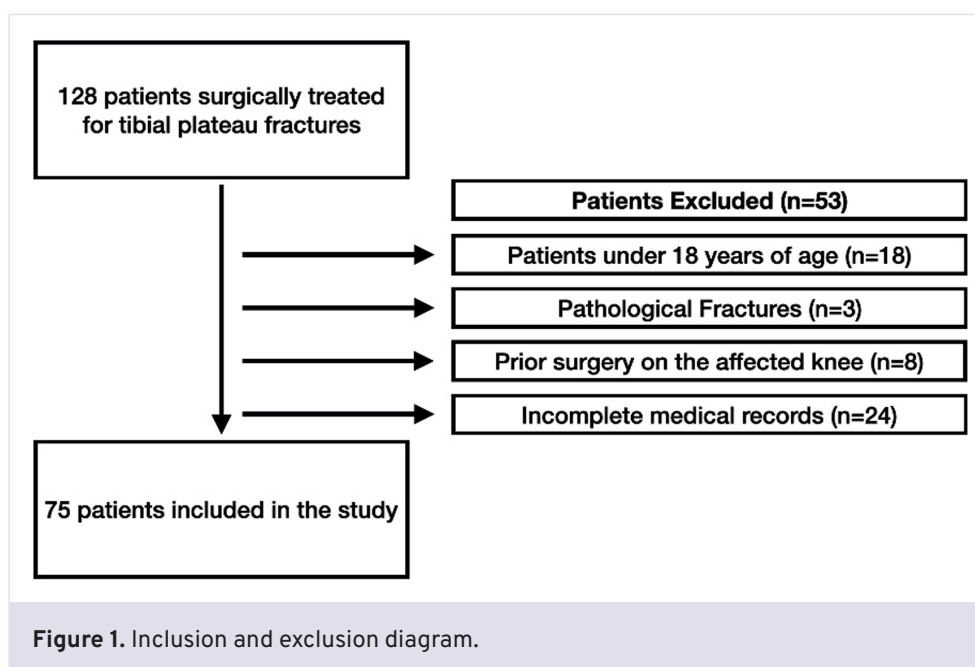


Figure 1. Inclusion and exclusion diagram.

Fracture classification

Fractures were classified using preoperative imaging, including plain radiographs and computed tomography scans. Fracture patterns were categorized according to the Schatzker and AO/OTA classification systems [7-9]. Fracture complexity was further assessed using the 3-column concept and the ten-segment classification. The number of involved columns, as well as anterior and posterior segment involvement, was recorded for each patient.

Radiological assessment

Radiological measurements were performed using the institutional picture archiving and communication system (PACS). Preoperatively measured parameters included articular depression (mm), step-off (mm), plateau widening (mm), fracture gap (mm), varus/valgus alignment (degrees), and posterior tibial slope (degrees). All radiological measurements were performed by a single observer who was blinded to the clinical outcome data. Each parameter was measured independently on two separate occasions, and the mean of the two measurements was used for analysis.

Outcome measures

Functional outcomes were assessed using the validated Turkish version of the Knee Injury and Osteoarthritis Outcome Score (KOOS) and knee flexion range of motion measured in degrees. KOOS was calculated according to the standard scoring instructions, with higher scores indicating better knee-related outcomes. For the present analysis, an overall KOOS score was derived by calculating the global mean of the five individual validated subscale scores. Evaluations were performed at standardized postoperative time points: 1 month, 3 months, 6 months, 1 year, and 2 years [4,10-12]. Change scores for KOOS and knee flexion were calculated as the difference between the 2-year and 1-month postoperative values (2-year value minus 1-month value).

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY, USA) and R software. Normality of continuous variables was assessed using the Kolmogorov-Smirnov

test. Descriptive statistics were presented as mean $\pm$ standard deviation for normally distributed continuous variables, median (minimum-maximum) for non-normally distributed continuous variables, and frequency (percentage) for categorical variables. The effects of independent variables on non-normally distributed change scores were analyzed using robust regression analysis with the MASS package in R. To evaluate the effects of fixation method, Schatzker classification, AO/OTA classification, time, 3-column concept, posterior segment count, and anterior segment count on repeated KOOS and knee flexion measurements, generalized estimating equations (GEE) were used. Both main effects and time interactions were assessed in the GEE models. For variables with significant effects, multiple comparisons were performed using Bonferroni correction. For comparisons of parameters within the same time point based on the multi-response structure of the 3-column concept and ten-segment classifications, Bonferroni-adjusted multiple comparison tests were applied. Longitudinal changes over time were analyzed using generalized estimating equations (GEE), which account for within-subject correlations. A p-value <0.05 was considered statistically significant for all analyses.

Results

A total of 75 patients were included in the study, of whom 55 (73%) were male and 20 (27%) were female. The mean age at the time of surgery was 45.20 ± 16.74 years. The most common trauma mechanism was fall (41%), followed by in-vehicle traffic accidents (33%). The right side was affected in 45% of patients. According to fracture classification, Schatzker type 6 (30%) and AO/OTA type 41-C (35%) fractures were the most frequent. Single plate with additional screw(s) was the most commonly used fixation method (31%). Bone graft was not used in 54.6% of cases. External fixation was applied in 19% of patients (Table 1). The complications were arthrofibrosis, infection, nonunion and implant failure.

Both KOOS and knee flexion improved significantly over time. The mean KOOS increased from 23.15 ± 5.87 at 1 month to 84.19 ± 8.74 at 2 years ($p < 0.001$). Similarly, mean knee flexion improved from $74.12 \pm 13.91^\circ$ to $120.91 \pm 17.31^\circ$ over the same period ($p < 0.001$). Overall, improvements in both KOOS and knee flexion were statistically significant ($p < 0.001$) (Table 2 and Table 3).

Table 1. Demographic characteristics and clinical profile of patients.

Variables		Value
Age		45.20 ± 16.74
Sex	Male	55 (73%)
	Female	20 (27%)
Side	Right	34 (45%)
	Left	41(55%)
Comorbidities	Present	11 (15%)
	None	64 (85%)
Trauma Mechanism	Fall	31 (41%)
	In-Vehicle accident	25 (33%)
	Motorcycle accident	12 (16%)
	Pedestrian traffic accident	5 (7%)
	Scooter accident	2 (3%)
Fixation Method	Single plate with additional screw(s)	23 (31%)
	Single Plate	19 (25%)
	Multiple plates with additional screw(s)	18 (24%)
	Screw fixation alone	8 (11%)
	Multiple Plates	7 (9%)
Bone Graft Used	Autograft	14 (19%)
	Allograft	20 (27%)
	None	41 (54%)
External Fixation Before Definitive Surgery		14 (19%)
Reoperation Occurred		6 (8%)
Schatzker Classification	1	13 (17%)
	2	7 (9%)
	3	16 (21%)
	4	9 (12%)
	5	8 (11%)
	6	22 (30%)
AO/OTA Classification	41-B1	18 (24%)
	41-B2	16 (21%)
	41-B3	15 (20%)
	41-C	26 (35%)
Depression (mm)		5.95 ± 4.73
Step-off (mm)		4.68 ± 3.74
Plateau widening (mm)		5.62 ± 5.84
Gap (mm)		12.93 ± 10.82

Data given as frequencies (percentages) or mean ± standard deviation.

KOOS differed significantly according to fracture severity ($p<0.001$) (Table 2). In contrast, fixation method was not associated with differences in KOOS ($p=0.817$). Additionally, fracture complexity parameters, including the number of involved columns and anterior or posterior segment counts, were not associated with significant differences in overall KOOS values ($p=0.243$, $p=0.316$, and $p=0.067$, respectively) (Table 2). Representative preoperative, postoperative, and follow-up radiographs of a patient treated with plate-and-screw fixation are presented in Figure 2.

Knee flexion also improved significantly over time; however, no significant differences were observed between groups. Flexion values did not differ significantly according to Schatzker classification ($p=0.160$), AO/OTA classification ($p=0.218$), fixation method ($p=0.882$), or fracture complexity parameters ($p>0.05$ for all comparisons) (Table 3).

In the multivariable robust regression analysis, posterior segment count ($\beta=2.011$, 95% CI: 0.306–3.716, $p=0.022$) and male sex ($\beta=4.146$, 95% CI: 0.160–8.131, $p=0.042$) were positively associated with KOOS improvement. The presence of comorbidities ($\beta=-7.245$, 95% CI: -12.852 to -1.638, $p=0.012$) and the use of external fixation before definitive surgery ($\beta=-8.683$, 95% CI: -13.325 to -4.041, $p<0.001$) were associated with less improvement in KOOS (Table 4).

Discussion

In this study, both patient-reported outcomes and objective knee motion demonstrated significant improvement over time following surgical treatment of tibial plateau fractures. However, important differences emerged when outcomes were analyzed in relation to fracture characteristics. Both the AO/OTA and Schatzker classifications were significantly associated with KOOS scores ($p<0.001$ for both), whereas neither classification showed a statistically significant association with knee flexion ($p=0.218$ and $p=0.160$, respectively). In contrast, fixation method and fracture complexity, including column and segment involvement, were not associated with either functional or objective outcomes. These findings suggest that recovery after tibial plateau fractures is multifactorial and not solely determined by fracture morphology or surgical technique.

Table 2. KOOS outcomes.

Variables	1 month	3 months	6 months	1 year	2 years	p-values
Total KOOS Scores	23.15 ± 5.87	38.13 ± 11.96	53.32 ± 13.33	67.72 ± 14.36	84.19 ± 8.74	<0.001
Schatzker Classification						<0.001
1	25.08±6.20 ABC, a	42.38±13.31 AB, a	56.54±12.67 AB, b	72.46±14.02 AB, c	86.31±9.11 AB, d	
2	22.71±4.86 ABC, a	40.29±11.21 A, b	55.86±8.11 AB, c	70.71±10.37 AB, c	85.14±8.47 AB, d	
3	26.81±5.19 A, a	44.13±9.22 A, b	59.38±12.99 A, c	74.31±11.71 A, d	89.81±8.26 A, d	
4	24.89±4.73 AB, a	39.78±15.60 AB, a	54.00±15.96 AB, b	68.22±19.36 AB, c	86.11±9.92 AB, c	
5	19.00±5.24 BC, a	33.63±10.39 AB, a	52.88±15.83 AB, b	64.25±15.11 AB, b	76.38±6.70 B, c	
6	20.27±5.17 C, a	31.55±9.11 B, a	46.09±11.08 B, b	60.23±12.40 B, c	80.59±5.88 B, d	
AO/OTA Classification						<0.001
41-B1	26.61±6.10 A, a	44.89±12.59 A, b	59.28±12.57 A, c	74.83±12.97 A, c	88.50±9.31 A, d	
41-B2	24.25±4.70 B, a	38.38±10.41 A, a	54.06±15.02 A, b	67.63±16.35 A, b	86.75±9.37 A, c	
41-B3	21.73±4.83 A, a	34.53±9.61 A, b	52.07±11.02 A, c	66.60±12.02 A, d	81.80±8.08 A, e	
41-C	20.88±5.87 A, a	35.38±12.25 A, b	49.46±13.13 A, c	63.50±14.11 A, d	81.00±6.82 A, d	
3- Column	25.91±5.12	40.65±8.30	56.65±9.89	72.70±9.65	88.87±7.40	0.243
2 columns	22.71±5.75	38.35±13.44	52.74±14.14	68.29±15.03	83.74±9.45	
3 columns	20.76±5.83	35.05±12.84	50.52±15.10	61.43±15.86	79.71±6.48	
Fixation Method						0.817
Single plate with additional screw(s)	24.91±4.69	39.65±12.21	54.30±11.85	68.52±14.57	86.57±8.51	
Single plate	24.26±4.85	39.58±9.28	55.42±12.13	72.26±10.78	87.16±7.68	
Multiple plates with additional screw(s)	20.17±5.60	33.39±10.82	50.17±14.05	63.61±15.90	80.44±6.78	
Screw fixation alone	25.75±8.86	44.75±16.70	58.38±15.30	69.38±18.04	84.50±12.26	
Multiple Plates	19.00±4.69	33.86±11.78	46.71±16.40	61.43±12.41	77.57±7.16	
Affected						0.316
Posterior	24.25±5.80 a	40.25±14.34 a	51.50±17.71 b	71.00±15.77 c	86.25±12.01 c	
Segment	26.25±5.88 a	39.08±11.22 b	58.25±16.76 c	72.92±15.89 d	88.83±9.43 e	
Count	23.96±4.80 a	38.96±10.70 b	53.08±10.01 c	69.58±11.58 d	86.00±7.98 e	
3	22.67±5.98 a	37.50±13.09 b	52.63±13.10 c	65.71±13.94 d	82.25±7.72 e	
4	17.75±7.93 a	35.75±16.15 b	45.75±14.24 c	56.75±21.96 c	78.50±10.85 d	
5	19.14±5.15 a	36.00±13.64 b	53.43±16.84 c	63.71±16.37 d	78.71±6.73 e	
Affected						0.067
Anterior	23.88±5.59 a	41.38±11.61 b	57.75±10.66 c	73.25±10.25 d	85.88±8.10 e	
Segment	25.20±5.36 a	38.80±10.47 a	53.20±11.65 b	73.20±13.41 c	90.20±10.11 c	
Count	24.67±5.76 a	40.77±11.02 b	56.30±11.25 c	70.97±12.08 d	86.80±8.58 e	
3	22.80±5.43 a	35.50±13.89 b	50.30±16.12 c	63.50±17.67 d	81.60±7.69 e	
4	19.80±6.98 a	39.80±14.13 b	56.20±15.97 c	69.40±15.44 d	80.60±9.86 d	
5	17.71±4.89 a	29.00±5.45 b	42.14±10.40 c	54.43±7.98 d	76.71±4.89 e	

Values are presented as mean ± standard deviation. Analyses were performed using generalized estimating equations. The reported p-values represent the overall effect of the corresponding variable in the GEE model. Different uppercase letters indicate statistically significant differences between groups at the same follow-up point, while different lowercase letters indicate statistically significant differences between follow-up points within the same group. Post hoc comparisons were adjusted using the Bonferroni method. A p-value <0.05 was considered statistically significant.

Table 3. Knee flexion outcomes.

Variables	1 month	3 months	6 months	1 year	2 years	p-values
Total flexion range	74.12 ± 13.91	96.67 ± 17.21	111.20 ± 15.25	117.01 ± 16.25	120.91 ± 17.31	<0.001
Schatzker						
1	77.15±14.92 a	102.08±17.76 b	114.15±13.97 c	120.31±13.43 d	125.69±15.18 e	0.160
2	76.00±10.57 a	96.71±10.63 b	110.29±9.14 bc	115.86±12.44 b	119.71±12.98 c	
3	81.44±11.49 a	103.56±13.20 b	117.19±13.99 c	122.38±13.93 d	126.94±14.73 e	
4	76.89±15.69 a	99.67±21.09 b	112.44±18.60 c	117.44±21.17 d	121.44±22.20 e	
5	69.50±14.38 a	93.38±21.98 b	109.63±20.01 c	114.00±21.83 d	117.38±22.66 d	
6	66.95±12.35 a	88.41±15.58 b	105.45±14.49 c	112.45±16.14 d	115.14±16.72 e	
AO/OTA						0.218
41-B1	78.78±13.95 a	101.50±16.49 b	113.06±14.49 c	118.83±15.25 c	124.28±17.30 d	
41-B2	77.31±14.23 a	101.00±16.18 b	115.19±15.22 c	120.19±15.55 c	124.31±15.84 d	
41-B3	73.80±13.22 a	94.93±17.26 b	110.73±15.65 c	117.07±17.38 d	120.73±17.95 e	
41-C	69.12±13.13 a	91.65±17.65 b	107.73±15.62 c	113.77±17.01 d	116.58±17.81 e	
3- Column						0.410
1 column	79.04±11.75 a	102.04±14.74 b	114.35±13.62 c	120.65±13.51 d	125.00±14.54 e	
2 columns	75.42±13.91 a	98.90±16.75 b	113.00±15.16 c	118.84±16.29 d	123.10±17.28 e	
3 columns	66.81±13.68 a	87.48±17.50 b	105.10±16.00 c	110.33±17.64 d	113.19±18.40 e	
Fixation Method						0.882
Single plate with additional screw(s)	75.91±11.80 a	98.17±13.11 b	111.78±10.43 c	117.00±12.25 d	121.04±13.07 e	
Single plate	80.47±13.04 a	103.95±14.78 b	116.26±14.57 c	122.42±14.24 d	126.11±14.15 e	
Multiple plates with additional screw(s)	66.83±13.57 a	89.72±20.05 b	106.00±17.58 c	112.28±19.19 d	115.72±20.46 e	
Screw fixation alone	74.13±19.28 a	93.13±23.34 b	108.13±21.42 c	114.88±22.36 d	119.75±25.25 e	
Multiple Plates	69.71±9.34 a	93.86±15.69 b	112.43±15.59 c	117.00±17.44 c	121.00±19.24 d	
Affected						0.217
Posterior	79.75±15.37 a	104.25±15.41 b	116.75±17.61 bc	120.00±19.49 c	123.50±20.07 d	
Segment Count						
1	78.92±13.51 a	105.58±14.49 b	117.92±15.98 c	124.67±16.63 d	129.83±17.78 e	
2	76.54±9.70 a	99.54±11.35 b	112.67±9.28 c	119.50±10.73 d	123.71±11.65 e	
3	73.17±15.61 a	94.50±19.18 b	109.79±16.25 c	114.54±17.16 d	117.92±17.99 e	
4	63.75±18.19 a	87.00±29.20 b	103.00±26.62 cd	109.75±27.98 c	112.00±30.28 d	
5	63.57±13.30 a	80.14±13.77 b	101.00±15.96 c	106.29±15.99 d	109.86±16.38 e	
Affected Anterior						0.557
Segment Count						
0	72.88±6.42 a	97.63±12.24 b	112.38±9.53 c	119.13±11.01 d	124.00±14.00 e	
1	77.40±9.40 a	101.60±8.38 b	111.40±8.29 c	117.80±8.76 d	124.60±11.67 e	
2	77.53±13.81 a	99.80±16.66 b	114.03±14.87 c	119.47±15.66 d	123.20±15.97 e	
3	73.70±15.63 a	95.70±20.02 b	109.85±17.41 c	115.60±18.66 d	119.15±19.86 e	
4	70.20±15.85 a	93.40±21.03 b	108.60±17.78 bc	114.80±17.81 c	118.00±19.17 d	
5	62.57±13.31 a	83.71±15.73 b	103.29±18.71 c	109.14±21.07 d	112.00±22.08 e	

Values are presented as mean ± standard deviation. Analyses were performed using generalized estimating equations. The reported p-values represent the overall effect of the corresponding variable in the GEE model. Different uppercase letters indicate statistically significant differences between groups at the same follow-up point, while different lowercase letters indicate statistically significant differences between follow-up points within the same group. Post hoc comparisons were adjusted using the Bonferroni method. A p-value <0.05 was considered statistically significant.

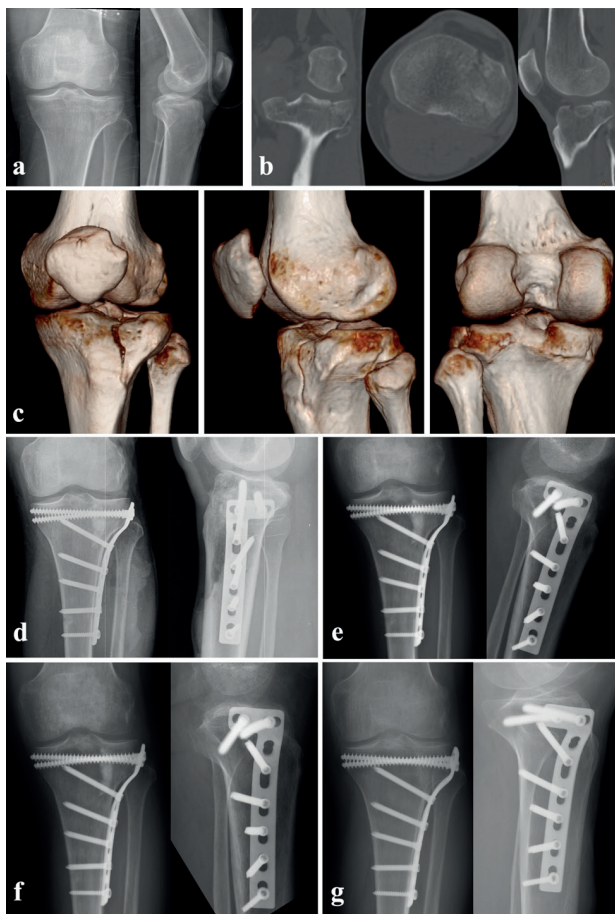


Figure 2. A 51-year-old male patient sustained a left tibial plateau fracture (Schatzker type 2, AO/OTA 41-B3) following a pedestrian traffic accident.

(a) Anteroposterior and lateral radiographs obtained at emergency department presentation. (b, c) Preoperative computed tomography (CT) images in coronal, axial, and sagittal planes and three-dimensional CT reconstructions demonstrating the fracture pattern. (d) Immediate postoperative radiographs showing reduction and fixation with a proximal tibial plate and screws, with use of allograft. (e) One-month, (f) six-month, and (g) two-year anterior-posterior and lateral follow-up radiographs demonstrating maintained reduction, fracture healing, and stable fixation over time.

The progressive improvement observed in both KOOS and knee flexion over time is consistent with previous literature. Lang et al. 2025 demonstrated that longer follow-up duration is associated with significantly better patient-reported outcomes, reflecting ongoing biological healing and functional adaptation [10]. Similarly, several longitudinal cohort studies have shown that functional recovery continues beyond the early postoperative period, often extending up to two years and even up to five years in some domains [13,14].

However, certain basic outcomes such as range of motion may plateau earlier, typically between 6 and 12 months [15]. Our findings support this pattern, emphasizing that recovery following tibial plateau fractures follows a gradual and domain-dependent trajectory rather than reaching an early universal plateau.

Fracture severity remains an important determinant of outcome; however, its effect appears to be domain specific. In the present study, KOOS scores differed significantly according to both the Schatzker and AO/OTA classifications, whereas knee flexion did not differ significantly between classification groups. This is consistent with previous reports showing that complex fracture patterns (Schatzker IV–VI) are associated with worse patient-reported outcomes, particularly in KOOS sports and QoL domains [10]. However, objective range of motion may remain comparable across fracture severities, as demonstrated in mid-term follow-up cohorts reporting no significant differences in knee flexion between simple and complex fractures [16]. In addition, Madi et al. demonstrated that greater postoperative articular step-off is associated with worse patient-reported outcomes, while Sadighi et al. reported that increased depression correlates with inferior clinical scores, with minimal impact on ROM [5,17]. Our findings extend this knowledge by demonstrating that the impact of fracture severity may be more pronounced in patient perception than in objective range of motion, suggesting that different outcome domains capture distinct aspects of recovery.

The discrepancy between patient-reported outcomes and objective knee motion represents one of the most important findings of this study. While KOOS scores were influenced by fracture severity, knee flexion was not, indicating that subjective and objective measures of recovery do not necessarily align. This observation is supported by previous literature. Elsoe et al. found that MRI-verified soft tissue injuries did not significantly affect KOOS scores at one year, highlighting the complex and multifactorial nature of patient-reported outcomes [18]. Likewise, Vaartjes et al. demonstrated in a large multicenter cohort that although many patients regain functional independence in pain and ADL domains, deficits in KOOS sports and QoL often persist, particularly in higher-demand activities [3]. These findings suggest that pain, perceived instability, activity modification, and psychosocial factors play a critical role in subjective recovery. Furthermore, mental health status has been shown to significantly influence

Table 4. Multivariable robust regression analysis of independent predictors of change in KOOS score.

Variables		β_1 (95% CI)	SE	β_2	t	p
Constant		15.812 (-1.377 - 33.001)	8.558	---	1.848	0.071
Age at surgery (year)		-0.091 (-0.214 - 0.033)	0.062	-0.185	-1.472	0.147
Male Sex		4.146 (0.16 - 8.131)	1.984	0.230	2.089	0.042
Presence of comorbidities		-7.245 (-12.852 - -1.638)	2.792	-0.328	-2.595	0.012
Articular surface depression (mm)		0.143 (-0.628 - 0.914)	0.384	0.086	0.373	0.710
Articular step-off (mm)		0.155 (-0.883 - 1.194)	0.517	0.073	0.301	0.765
Absolute plateau widening (mm)		0.167 (-0.168 - 0.502)	0.167	0.123	1.003	0.321
Fracture gap (mm)		0.113 (-0.157 - 0.382)	0.134	0.147	0.839	0.405
Fracture varus/valgus angle (°)		-0.14 (-0.31 - 0.03)	0.084	-0.206	-1.658	0.104
Posterior tibial slope (°)		0.092 (-0.037 - 0.221)	0.064	0.180	1.435	0.158
Number of involved columns (3-column concept)		0.952 (-2.197 - 4.1)	1.568	0.092	0.607	0.547
Number of involved posterior segments		2.011 (0.306 - 3.716)	0.849	0.311	2.369	0.022
Number of involved anterior segments		-0.148 (-2.069 - 1.774)	0.957	-0.025	-0.155	0.878
Fixation method (reference: Single Plate)	Single plate with additional screw(s)	-1.139 (-6.103 - 3.824)	2.471	-0.066	-0.461	0.647
	Multiple Plates	-4.625 (-12.333 - 3.082)	3.837	-0.173	-1.205	0.234
	Multiple plates with additional screw(s)	-2.462 (-8.39 - 3.466)	2.952	-0.133	-0.834	0.408
	Screw fixation alone	3.415 (-2.879 - 9.708)	3.134	0.133	1.090	0.281
Graft use (reference: none)	Allograft	0.12 (-4.75 - 4.99)	2.425	0.007	0.050	0.961
	Autograft	-5.504 (-11.04 - 0.033)	2.756	-0.257	-1.997	0.051
External fixation occurred before definitive surgery		-8.683 (-13.325 - -4.041)	2.311	-0.443	-3.757	<0.001
Reoperation occurred		-5.724 (-13.163 - 1.715)	3.704	-0.190	-1.546	0.129

β_1 represents the unstandardized regression coefficient with 95% confidence interval (CI), and β_2 represents the standardized regression coefficient. Analyses were performed using robust multivariable linear regression. Standard errors (SE), t-values, and p-values are reported for each predictor. Categorical variables were entered into the model using dummy coding, with the specified reference categories. A p-value < 0.05 was considered statistically significant.

long-term outcomes after tibial plateau fractures [19]. Therefore, evaluation of outcomes after tibial plateau fractures should incorporate both subjective and objective measures to provide a comprehensive assessment.

Another notable finding of this study is that no statistically significant association between fixation method and clinical outcomes was identified in the present cohort. This aligns with current evidence suggesting that surgical technique may be less important than achieving adequate reduction and stability. A recent meta-analysis by Tay et al. found no significant differences in functional outcomes or complication rates between arthroscopy-assisted and conventional open reduction techniques [20]. While some studies, such as van der

Linden et al., have suggested that greater fracture extent may be associated with worse patient-reported outcomes, the overall prognostic value of classification systems remains limited [21]. This is further supported by systematic reviews highlighting the variability and moderate reliability of commonly used classification systems, as well as their limited ability to predict clinical outcomes [22]. Taken together, these findings suggest that although classification systems remain valuable for describing fracture morphology and guiding surgical planning, their additional prognostic value remains debatable.

The regression analysis in this study further supports the multifactorial nature of recovery. Comorbidities were associated with worse early functional

improvement, which is consistent with existing literature demonstrating the negative impact of patient-related factors on recovery. Studies evaluating clinical outcomes and quality of life after tibial plateau fractures have shown that factors such as increased body weight and general health status negatively influence both physical and psychological recovery [23]. Additionally, injury-related factors such as polytrauma and fracture complexity have been associated with reduced range of motion at one year [4]. Interestingly, posterior segment involvement was associated with greater early improvement in our cohort; however, this finding contrasts with some previous reports suggesting worse high-demand functional outcomes and limited sports participation in such cases, often due to pain and fear of reinjury [24]. Therefore, this result should be interpreted cautiously. The use of external fixation before definitive surgery was also associated with less early improvement in KOOS. However, external fixation is generally used in patients with more severe injuries or greater soft-tissue compromise. Therefore, this association may reflect the initial injury severity rather than an independent adverse effect of external fixation itself. Overall, these findings underscore the importance of considering both patient-related and injury-related factors when evaluating prognosis and reinforce the need for a multidimensional assessment of recovery.

This study has several limitations. First, its retrospective design introduces the potential for selection bias. Second, all radiographic measurements were performed by a single observer, and interobserver reliability was not assessed. Third, stratifying our 75 patients into multiple classification and fixation categories created small subgroups. This may have introduced statistical power constraints and a risk of Type II errors. Fourth, the cohort was heterogeneous with respect to fracture pattern, associated injuries and treatment, and the fixation method was selected by the treating surgeon according to fracture morphology and soft-tissue condition rather than at random; residual confounding by indication therefore cannot be excluded. Fifth, because several subgroups were small, some statistically significant associations may not be clinically meaningful and should be regarded as exploratory; larger, preferably prospective studies are needed to confirm these findings.

Conclusion

Functional recovery after surgically treated tibial plateau fractures continued throughout the two-year follow-up period. Fracture severity was associated with patient-reported KOOS outcomes but not with knee flexion, statistically. No statistically significant associations between the evaluated fixation methods or fracture-complexity parameters and functional outcomes were identified in this cohort. These findings support the combined use of patient-reported and objective measures when evaluating recovery after tibial plateau fractures.

Author contributions

Conception: G.A., B.Y., O.M.K., U.C.K.; Design: G.A.; Data acquisition: B.Y., O.M.K., U.C.K.; Data analysis: B.Y., O.M.K.; Data interpretation: B.Y., O.M.K.; Drafting of the manuscript: B.Y., O.M.K., U.C.K.; Critical revision of the manuscript: G.A., U.C.K. All authors reviewed the results, approved the final version of the manuscript, and agreed to be accountable for all aspects of this study.

Ethical approval

This study was approved by the Hacettepe Üniversitesi Sağlık Bilimleri Araştırma Etik (Date: 22 July 2025, IRB No: SBA 25/682). Informed consent was obtained from all participants involved in this study.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that this study was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Funding

The authors declare that this study received no funding.

Generative AI statement

The authors declare that no generative AI or AI-assisted technologies were used in the writing or preparation of this study.

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