Injury, Int. J. Care Injured 48 (2017) 2221–2229

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Complications and unplanned outcomes following operative treatment of tibial plateau fractures

David Kugelman*, Abdullah Qatu, Jack Haglin, Phillip Leucht, Sanjit Konda, Kenneth Egol*

NYULMC Hospital For Joint Diseases, 301 E 17th St., New York, NY 10003, United States

ARTICLE INFO

Keywords:
Tibial plateau
Tibial plateau complications
Knee fracture
Orthopaedic complications
Tibial plateau outcomes
Orthopaedic complication predictor

ABSTRACT

Introduction: The operative management of tibial plateau fractures is challenging and post-operative complications do occur. The purpose of this study was three-fold. 1). To report complications and unplanned outcomes in patients who had sustained tibial plateau fractures and were operatively managed 2). To report predictors of these post-operative events 3). To report if differences in clinical outcomes exist in patients who sustained a post-operative event.

Methods: Over 11 years, all tibial plateau fractures were prospectively followed. Clinical outcomes were assessed using the validated Short Musculoskeletal Functional Assessment (SMFA) score. Demographics, initial injury characteristics, surgical details and post-operative events were prospectively recorded. Student's *t*-tests were used for continuous variables and chi-squared analysis was used for categorical variables. Binary logistic regression and multivariate linear regression were conducted for independent predictors of post-operative events and complications and functional outcomes, respectively.

Results: 275 patients with 279 tibial plateau fractures were included in our analysis. Ten patients (3.6%) sustained a deep infection. Six patients (2.2%) developed a superficial infection. One patient (0.4%) presented with early implant failure. Two patients (0.7%) developed a fracture nonunion. Eight patients (2.9%) developed a venous thromboembolism. Seventeen patients (6.2%) went on to re-operation for symptomatic implant removal. Nine patients (3.3%) underwent a lysis of adhesions procedure. Univariate analysis demonstrated bicondylar tibial plateau fractures ($P < 0.001$), Moore fracture-dislocations ($P = 0.005$), open fractures ($P = 0.022$), and compartment syndrome ($P = 0.001$) to be associated with post-operative complications and unplanned outcomes. Long-term functional outcomes were worse among patients who developed a post-operative complication or unplanned outcome ($P = 0.031$).

Conclusion: Orthopaedic trauma surgeons should be aware of complications and unplanned outcomes following operatively managed tibial plateau fractures, along with having the knowledge of factors that are associated with development of post-operative events.

Introduction

Tibial plateau fractures constitute 1% of all fractures and 8% of fractures in the elderly [1]. These fractures occur when varus or valgus stress is applied to the knee, coupled with axial loading. The incidence of such fractures follows a bimodal distribution, primarily occurring in either younger individuals due to higher energy mechanisms such as motor vehicle accidents, or elderly patients with osteoporotic bone following a low energy fall [1]. The operative management of tibial plateau fractures proves challenging, as good outcomes may not always be achievable [2,3].

Operative fixation of a tibial plateau fracture is performed with the goals of reconstructing the articular surfaces of the tibia, stabilizing the joint, restoring alignment, and repairing concomitant soft tissue injuries of the knee [4]. Decreased knee stability and failure to restore joint alignment are the most significant factors that lead to poor long-term outcomes [2,5,6].

In 1979 Schatzker et al. synthesized modern management of these injuries, and developed the most utilized classification system [5]. One of the earliest studies to look at complications and clinical results following operatively-managed tibial plateau fractures was performed by Moore et al. [7]. This study found that a majority of operatively treated Schatzker I–IV fractures had

* Corresponding author.
E-mail addresses: davidnkugelman@gmail.com, ljegol@att.net (D. Kugelman), Abdullah.qatu@nyumc.org (A. Qatu), jack.haglin@nyumc.org (J. Haglin), Phillip.leucht@nyumc.org (P. Leucht), Sanjit.konda@nyumc.org (S. Konda), Kenneth.egol@nyumc.org (K. Egol).

http://dx.doi.org/10.1016/j.injury.2017.07.016
0020-1383/

good functional results at long-term follow-up, while bicondylar fractures (Schatzker V, VI), had worse functional results. The overall complication rate in this study was 19% for operatively managed fractures. Moore reported infection to be the most common complication following operative fixation of these injuries. Post-operative complications are most prevalent in high-energy bicondylar fractures of the tibial plateau, with recent studies reporting complication rates among these injuries to be as high as 28% [8]. Since these early reports, our understanding of the soft tissue anatomy about the knee, and its management, has helped diminish the rate of complications following tibial plateau fractures [9–15].

Although complications following operative management of tibial plateau fractures can not be completely avoided, their incidence can be reduced by utilizing certain strategies such as: staged management, gentle tissue handling, and limited incisions with less subcutaneous dissection [2,9–16]. Over the last century, research has contributed to advancements in surgical techniques, approaches, implant technology, and post-operative management, which have led to improved functional results [16]. The purpose of this study is three-fold: 1). To report the complications and unplanned events of a large prospective series of patients who sustained tibial plateau fractures and underwent open reduction and internal fixation (ORIF) at a single academic institution. 2). To determine if there are injury characteristics, patient demographics, or surgical details that may predict a post-operative complication or unplanned outcome (post-operative event). 3). To determine if differences in long-term functional outcomes exist between patients who sustained a post-operative complication or unplanned outcome, and those whom did not.

Patients and methods

Over an 11-year period, from April 2006 to March 2016, all tibial plateau fractures treated by one of three surgeons at a single academic institution were prospectively followed in an institutional review board approved database. Patients were screened and identified on presentation to the emergency department or in the outpatient clinic for inclusion in the registry. Following attainment of history and physical examination, standard radiographs including anteroposterior, lateral, and 10° caudal tilt plateau views of the knee were obtained for all patients. A computed tomography (CT) scan was obtained to further elucidate the fracture morphology and allow for the planning of surgical intervention in all cases.

Inclusion criteria for this study were as follows: operatively managed tibial plateau fractures with a minimum of 12-months post-surgical intervention, age 18 years or older, and complete post-operative follow-up data. Patients were excluded if they had insufficient documentation for review, or were followed at another institution following initial operative fixation. Patient-related factors and demographics (age, gender, race, body mass index (BMI), tobacco use, alcohol use, illicit drug use), comorbidities (diabetes mellitus, renal disease, pulmonary disease, cardiovascular disease, neurologic disease), injury characteristics (open fracture, compartment syndrome, poly trauma, AO/OTA classification, Schatzker classification, Moore fracture-dislocation) and surgical information (application of external fixator, locked or unlocked plating, single or dual plating, number of incisions, bone graft use) were recorded. Schatzker fractures were further divided into unicondylar (Schatzker I–IV) and bicondylar (Schatzker V, VI) tibial plateau fractures [5]. In regards to the AO/OTA classification system, partial articular fractures (41-B1, 41-B2, 41-B3) fall under the unicondylar tibial plateau fracture group, while AO/OTA complete articular fractures (41-C1, 41-C2, 41-C3) are considered bicondylar tibial plateau fractures [17]. The system of Moore was used when applicable or the pattern did not fit the Schatzker classification.

Surgical indications, operative fixation, and post-operative management

Patients were generally indicated for surgical management if they had >2 mm articular incongruence, open fracture, condylar widening >5 mm, or knee varus/valgus instability >5° on physical exam, and were medically stable to undergo surgical intervention [1,6,16,18]. The knee was examined for varus or valgus stress at 0 and 30° of flexion [19]. The principles of definitive fixation aimed for restoration of the articular surface and proper mechanical alignment, balanced fixation using appropriate implants with raft support of subchondral bone, and buttress plating or bridge plating with single or dual implants [16]. Bridge plating was used for cases in which metaphyseal-diaphyseal dissociation existed. Intervention generally followed a period of waiting to operate until the soft tissue envelope was ready, using percutaneous and minimally invasive techniques when appropriate [16]. Our standard protocol for high-energy tibial plateau fracture was based on a staged management protocol that utilized knee-spanning external fixation followed by definitive repair when the soft tissue allowed [9].

Thromboprophylaxis was administered in the form of low molecular weight heparin (LMWH) at 12 h post-operatively and prescribed for a minimum of 4 weeks, unless contradicted. If the patient required a subsequent procedure, LMWH was discontinued at least 12 h before surgery [9]. Mechanical prophylaxis utilized compression devices while the patient was in the hospital. All patients were routinely screened for a VTE using doppler ultrasonography, multiple times while in the hospital. Patients who developed a VTE were managed with anticoagulation therapy for 3–6 months following the event. Upon discharge, all patients were provided thromboprophylaxis in form of LMWH or aspirin one time daily, depending on physician and patient choice. Patients with closed injuries received intravenous antibiotics for 24 h post-operatively. Patients who sustained an open fracture received 48 h of antibiotics (cephalosporin and aminoglycoside), followed by 24 h of antibiotics after each operation. Patients who developed a deep wound infection were given a 6-week course of culture-directed intravenous antibiotics.

Surgeons' had an agreed upon post operative protocol. Patients' knees were generally kept immobilized for 3–7 days post-operatively. Patients' knees were in extension initially, then transitioned to an unlocked hinged knee brace. Patients began physical therapy for range of knee motion exercises in addition to quadriceps and hamstring strengthening. All patients remained non-weight bearing until they had achieved radiographic and clinical signs of union, at approximately 10–12 weeks as this was the treating surgeons' standard for all articular fractures of the lower extremity. Physical therapy was then continued with an advancement to weight-bearing as tolerated, including continued emphasis on range of motion and muscle strengthening exercises. Post-operative complications and re-operations were documented at follow-up and recorded contemporaneously at each post-operative visit. Clinical outcomes were assessed using the validated Short Musculoskeletal Functional Assessment (SMFA) score, Visual Analog Scale (VAS) pain scores and range of motion (ROM) at 3-month, 6-months and long-term (12-month's or greater) follow-up.

Patient analysis

Patients were divided post-hoc into a post-operative event group and non-event group. Post-operative events included;

superficial infection, deep tissue infection, fracture nonunion, venous thromboembolic events, painful implants, or knee arthrofibrosis. Each event was defined, and patients were categorized accordingly based off the specific event sustained.

Deep tissue infection was defined as the occurrence of any infection necessitating reoperation in the form of irrigation and debridement. Superficial infection was defined as localized surgical site infections, which did not require reoperation, but were treated with antibiotics. Patients categorized with non-union were those who failed to demonstrate evidence of radiological or clinical healing of their fracture at a minimum of six months post-operatively. This non-union diagnosis was further confirmed for such patients with a CT scan demonstrating a lack of bone bridging at the fracture site in multiple planes. Patients categorized with venous thromboembolic events, such as deep venous thrombosis, were diagnosed through utilization of a doppler ultrasound, in which if confirmed, patients were given subsequent anticoagulation for 3–6 months. If any symptoms of pulmonary embolism were noted such as shortness of breath or tachycardia, a definitive diagnosis was made by obtaining a spiral CT imaging or ventilation/perfusion nuclear scan for confirmation. Removal of surgical implants were not a standard part of the treatment protocol. Diagnosis of painful implants was considered an unplanned outcome, and included all patients who returned to the operating room after complete fracture union for implant removal due to increased pain that could not be contributed to any other pathology. Finally, those patients categorized with knee arthrofibrosis demonstrated a knee range of motion of less than 90°, and underwent subsequent lysis of adhesions procedure.

Statistical analysis was used to assess if patient reported factors and demographics, initial injury characteristics, or surgical details were associated with a complication or unplanned outcome (as described above) following a tibial plateau fracture. Further analysis was conducted to assess predictors of specific complications. Long-term functional outcomes were compared between the group who sustained a post-operative event following a tibial plateau fracture and the group who did not sustain any events following surgical management. Lastly, long-term functional outcomes were compared between patients who sustained specific complications or unplanned outcomes following a tibial plateau fracture and patients who did not sustain the specific event being tested (ex. Patients who sustained a deep infection requiring subsequent I and D in comparison to those who did not sustain a post-operative deep infection).

For all analyses, significance was set at $P < 0.05$ levels. Student's *t*-tests were used to assess differences between continuous variables and Pearson chi-square tests were used to assess differences in categorical variables. Binary linear regression was performed with the dependent variables being specific events and unplanned outcomes, while the independent variables consisted of patient demographics and initial injury characteristics. Multivariate regression was performed with the dependent variables being SMFA categories (function, bothersome nature of injury, daily activities, emotional status and mobility) and independent variables being specific post-operative complications or unplanned outcomes (as described above) patient demographics and initial injury characteristics. All statistics were calculated using IBM SPSS version 23 (Armonk, NY: IBM Corp.).

Results

Patient demographics and initial injury characteristics

Overall, 321 patients were treated over an 11-year period from April 2006 to March 2016. Thirty-nine patients were treated with non-operative management. Seven patients did not follow up at our institution following operative management. Therefore, 275 patients, with 279 tibial plateau fractures, were at least 12-months post-operative management and were included in our analysis (Fig. 1). Long-term functional outcomes (mean = 18 months, range = 12–80 months) were available for 245 patients (89% of patients included in analysis).

The majority of the tibial plateau fractures in our database occurred due to a pedestrian being struck by a vehicle (30%) or due to a low velocity fall (22%). The mechanisms, by which the tibial plateau fractures in this study were sustained, are reported in Fig. 2. Demographics of the patients included in this study are demonstrated in Table 1. Tibial plateau fractures included in this

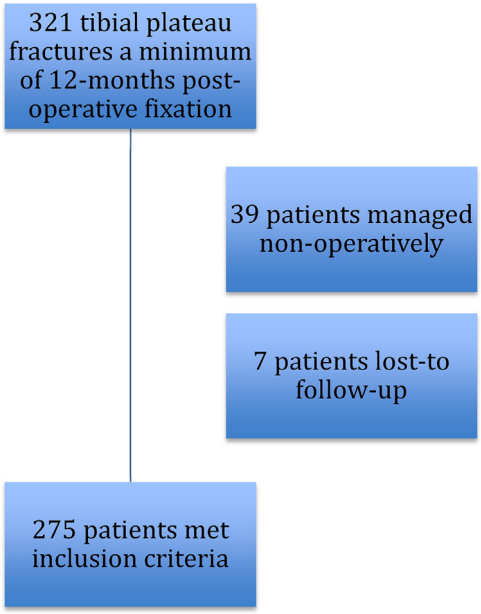

Fig. 1. Flow-chart demonstrating patients who met inclusion criteria for study and were therefore used in analysis.

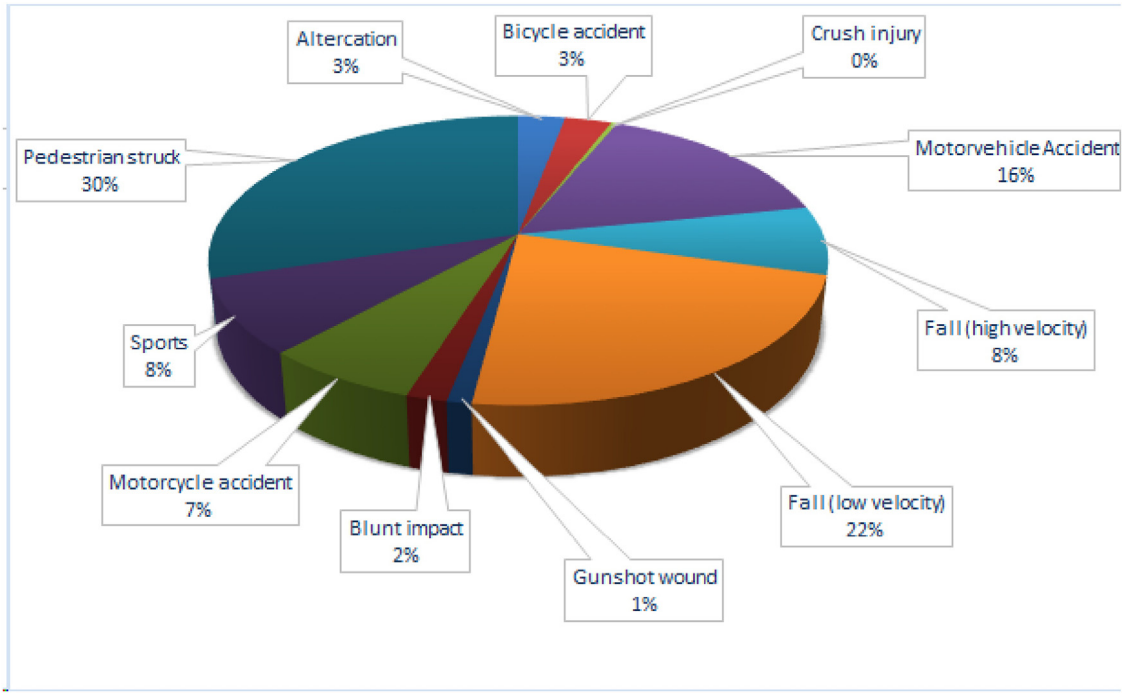

Fig. 2. Mechanisms by which the tibial plateau fractures took place. A majority of fractures were due to low velocity falls and pedestrians being struck.

Table 1
Demographics and patient related factors of individuals undergoing operative fixation of a tibial plateau fracture.

Demographic	
Age(in years)	Mean = 48.8 (SD = 14.63)
BMI(in Kg/M^2)	Mean = 26.1 (SD = 6.9)
Tobacco Use; % (n)	21.8 (60)
Alcohol Use (Social)	36.7% (101)
Gender	
Males	53.5% (147)
Females	46.5% (128)
Caucasian	41.1% (113)
African-American	27.2% (75)
Hispanic	13.1% (36)
Other race	18.5% (51)

analysis, in regards to their classification, were divided into a non-event and event group (Table 2).

Associated injuries

Thirteen patients (4.7%) experienced an event related to their initial injury (compartment syndrome, vascular injury, nerve injury). As far as events related to the initial fracture, six patients (2.2%) developed compartment syndrome, requiring surgical release. Four patients (1.5%) sustained a nerve injury due to the initial injury and three patients (1.1%) had an identifiable arterial injury at presentation.

Post-operative complications and unplanned outcomes

Forty-four patients (16%) sustained a post-operative complication or unplanned outcome. Sixteen patients (5.8%) sustained more than 1 post-operative event. Twenty-six post-operative complications occurred (9.5%), and twenty-six (9.5%) additional operations were performed due to a painful implant requiring removal, or arthrofibrosis requiring lysis of adhesions.

Ten patients (3.6%) sustained a deep infection requiring subsequent I and D. Six patients (2.2%) developed a superficial infection requiring oral antibiotics only. One patient (0.4%) presented with early implant failure requiring revision fixation. Two patients (0.7%) developed a fracture nonunion, requiring nonunion repair with bone grafting. Eight patients (2.9%) developed a venous thromboembolism, requiring anticoagulation. Seventeen patients (6.2%) went on to have a re-operation due to painful implant. Nine patients (3.3%) developed knee arthrofibrosis necessitating a lysis of adhesions procedure. The mean follow-up times, at which these complications and unplanned outcomes occurred are demonstrated in Table 3.

Predictors of post-operative events

Injury factors associated with the development of a complication or unplanned outcome, as described in our methods, were bicondylar tibial plateau fractures (Schatzker V, VI and AO/OTA 41-C1-3) ($P < 0.001$), injuries that fell under the Moore fracture-dislocation classification ($P = 0.005$), occurrence of an open fracture ($P = 0.022$), and development of compartment syndrome ($P = 0.001$). Further, patients were more likely to sustain a post-operative complication or unplanned outcome if they required dual plating ($P = 0.039$).

Subgroup analysis was performed in regards to specific post-operative complications and unplanned events. Nine males developed a deep infection in comparison to 1 female ($P = 0.018$). Three patients (23.1%) with open fractures, developed a deep infection. Four patients with diabetes mellitus (12.1%) developed a deep infection ($P = 0.005$). Seven patients with Moore fracture-dislocations (5.1%) sustained a VTE ($P = 0.026$). Seven patients with bicondylar fractures (7.1%) sustained a VTE ($P = 0.002$). Patients with a higher BMI were at greater risk for sustaining a VTE ($P = 0.001$). Three patients with diabetes mellitus

Table 2
Tibial plateau fractures included in analysis, classified by the Schatzker, Moore and AO/OTA Classifications.

	Operatively managed tibial plateau fractures (n = 279) N, %
Schatzker Classification	
Schatzker I	6, 2.2%
Schatzker II	139, 49.9%
Schatzker III	6, 2.2%
Schatzker IV	29, 10.4%
Schatzker V	24, 8.6%
Schatzker VI	75, 26.9%
AO/OTA Classification	
41-B1	20, 7.2%
41-B2	7, 2.5%
41-B3	153, 54.8%
41-C1	15, 5.4%
41-C2	30, 10.8%
41-C3	54, 19.4%
Moore fracture-dislocation Classification	
Moore I	10, 3.6%
Moore II	47, 16.8%
Moore III	8, 2.9%
Moore IV	12, 4.3%
Moore V	60, 21.5%

(9.1%) necessitated a lysis of adhesions procedure (P = 0.042). Six patients (6.1%) with bicondylar fractures necessitated a lysis of adhesions procedure in comparison to 3 patients (1.7%) with unicondylar fractures (P = 0.047). Ten patients with bicondylar fractures (10.1%) underwent a removal of hardware procedure in comparison to 7 patients (3.9%) of unicondylar fractures (P = 0.038). Thirteen patients (9.6%) of Moore fracture-dislocations necessitated a removal of hardware procedure (P = 0.018).

Development of a fracture nonunion was associated with open fractures (P = 0.002) and the post-operative complication of developing a deep-tissue infection ($P < 0.001$).

Logistic regression demonstrated independent predictors of sustaining a post-operative complication or unplanned outcome (Table 4).

Pain scores and range of motion (ROM)

Development of a post-operative complication or need for a reoperation was not associated with increased pain, as measured by the visual analog scale, at any time point.

Decreased knee ROM occurred at a higher rate among patients who sustained a post-operative complication or needed a reoperation at 3-month (P = 0.019), 6-month (P = 0.050), and long-term (P = 0.022) follow-up. Sub-analysis revealed decreased ROM in patients with arthrofibrosis prior to undergoing lysis of adhesions, at 3-month (P = 0.049), 6-month (P = 0.022), and long-term (P = 0.049) follow-up. There was no difference in knee ROM among these patients after undergoing lysis of adhesions for treatment of arthrofibrosis. Additionally, decreased ROM was noted at long-term follow-up, in patients who sustained a deep infection (P = 0.002).

Functional outcomes following post-operative events

At 3-month follow-up, no difference in functional outcomes existed between patients who sustained any post-operative complications.

At 6-month follow-up, functional outcomes were worse in the groups who developed complications or in patients before undergoing a re-operation, as demonstrated by a lower total SMFA (P = 0.044), bothersome nature of the injury (P = 0.048), daily activities (P = 0.025), and mobility (P = 0.018). Sub-analysis demonstrated that the individuals who developed a deep infection requiring I and D had worse outcomes in regards to performing daily activities (P = 0.049). Individuals who sustained a VTE had worse outcomes, as demonstrated by their total SMFA (P = 0.031), function (P = 0.031), bothersome nature of the injury (P = 0.044), and mobility (P = 0.010). Patients who developed arthrofibrosis and eventually required a LOA had worse overall function (P = 0.022) at 6-month follow-up.

Long-term functional outcomes were worse in the patients who developed a complication or experienced an unplanned outcome, in regards to their total SMFA (P = 0.031), function (P = 0.049), bothersome nature of the injury (P = 0.045), emotional status (P = 0.048), and mobility (P = 0.013). Sub-analysis demonstrated that the individuals who developed a deep infection requiring I and

Table 3
The mean follow-up times that a post-operative complication or unplanned outcome was documented.

Event	Mean Time of Event Occurrence
Venous Thromboembolism requiring anticoagulation	3 months
Superficial Infection requiring antibiotics	3.1 months
Deep Infection requiring I and D	3.3 months
Nonunion requiring repair	6 months
Arthrofibrosis requiring lysis of adhesions	9.8 months
Painful implant requiring removal	16.7 months

Table 4
Independent predictors of sustaining a post-operative complication or unplanned outcome following operative fixation of tibial plateau fractures. Logistic regression was performed with post-operative complications and unplanned outcomes being the dependent variable, while patient related factors and initial injury characteristics were independent variables. Odds ration (OR), 95% confidence interval (CI) and p-values are reported. Significance is set as a P-value < 0.05.

	Post-operative event	Deep infection	Superficial infection	VTE	Athrofibrosis requiring lysis of adhesions
Bicondylar tibial plateau fracture	OR = 2.650, 95% CI = 1.251–5.612, P = 0.011	N/A	N/A	N/A	OR = 6.968, CI = 1.190–40.804, P = 0.031
Compartment syndrome	OR = 0.066, CI = 0.010–0.431, P = 0.005	OR = 0.033, CI = 0.002–0.621, P = 0.023	N/A	N/A	OR = 0.060, CI = 0.004–0.096, P = 0.046
Open fracture	N/A	OR = 0.016, CI = 0.001–0.269, P = 0.004	N/A	N/A	N/A
Obese patients (BMI >30)	N/A	N/A	N/A	OR = 0.096, CI = 0.016–0.581, P = 0.011	N/A
Diabetes mellitus	N/A	N/A	OR = 0.101, CI = 0.10–1.004, P = 0.050	N/A	OR = 0.110, CI = 0.017–0.723, P = 0.022

D had worse functional outcomes in regards to total SMFA (P = 0.007), function (P = 0.013), bothersome nature of the injury (P = 0.005), daily activities (P = 0.006), emotional status (P = 0.027), and mobility (P = 0.039). Individuals who sustained a VTE had worse outcomes in regards to their functional status (P = 0.017), and emotional status (P = 0.023). Patients who underwent a subsequent procedure for painful removal of hardware had worse emotional status (P = 0.034) at long-term follow-up. Multivariate analysis demonstrated independent predictors of worse functional outcomes at long-term follow-up (Table 5).

Discussion

Open reduction and internal fixation is the standard of care for tibial plateau fractures that meet displacement criteria, are accompanied with an associated vascular injury requiring repair, are open fractures, or if compartment syndrome is present [2,4,5,6,16]. Operative management of tibial plateau fractures does not come without risks, and may be complicated by infections, thromboembolic events, fracture nonunion, and the need for further re-operation.

Associated injuries such as compartment syndrome, vascular injury, and nerve injury was present in 4.7% of our cohort and are not preventable. Post-operative complications and unplanned events occurred in 16% of the patients included in this study, including elective hardware removal. Ten patients (3.6%) sustained a deep infection requiring incision and drainage (I and D). Six patients (2.2%) developed a superficial infection requiring oral antibiotics only. One patient (0.4%) presented with early implant failure requiring revision fixation. Two patients (0.7%) developed a fracture nonunion, requiring nonunion repair with bone grafting. Eight patients (2.9%) developed a venous thromboembolism, requiring anticoagulation. Seventeen patients (6.2%) went on to have a re-operation due to painful implant. Nine patients (3.3%) developed knee arthrofibrosis necessitating a lysis of adhesions procedure. Our results are consistent with recent literature on adverse events following operatively managed tibial plateau fractures [2,20]. Following operative fixation of 519 tibial plateau fractures, Basques et al. reported that 7% of patients experienced a severe adverse event, 4% of patients sustained mild adverse events, and an additional 4% of patients sustained an infectious complication. However, the described study utilized the American College of Surgeons-National Surgical Quality Improvement Project (ACS-NSQIP) database, which is pooled administrative data that lacks the specificity and granularity of a prospective study where operative fixation of tibial plateau fractures was performed by one of three surgeons at a single academic institution. Additionally, the ACS-NSQIP database does not include specific operative details (such as staged management), pain scores, or functional outcomes.

The rate of post-operative complications in this study and recent literature is significantly lower than those reported in earlier years of tibial plateau literature. A study performed by Schatzker et al. in 1979, demonstrated a complication rate of 27% for operatively managed tibial plateau fractures [5]. One year after the Toronto Experience, Moore et al. reported a 19% complication rate following operatively managed tibial plateau fractures [7]. This may be due to an increased knowledge in the importance of soft tissue handling and utilization of staged management for severe tibial plateau fractures [2,9–16].

Table 5
Independent predictors of worse outcomes at long-term follow-up, following operative fixation of tibial plateau fractures. Multivariate regression was performed with SMFA and SMFA sub-groups being the dependent variable, while patient related factors, initial injury characteristics and post-operative complications or unplanned outcomes were independent variables. Beta (B), 95% confidence interval (CI) and p-values are reported. Significance is set as a P-value < 0.05.

	Function	Bothersome nature of injury	Daily activities	Emotional status	Mobility
VTE	B = 18.205, CI = 1.723–34.688, P = 0.031	N/A	N/A	B = 17.502, [CI] = 1.440–33.564, P = 0.033	N/A
Deep infection	N/A	B = 17.081, [CI] = 1.276–32.885, P = 0.034	N/A	N/A	N/A
Orthopaedic polytrauma	N/A	B = 7.732, [CI] = 2.048–13.415, P = 0.008	N/A	N/A	N/A
Increased age	N/A	N/A	B = 0.246, [CI] = 0.027–0.424, P = 0.028	N/A	B = 0.216, [CI] = 0.026–0.401, P = 0.026
Smoking	B = 9.505, [CI] = 2.414–16.596, P = 0.009	B = 8.736, [CI] = 2.120–15.352, P = 0.010	N/A	B = 10.583, [CI] = 3.673–17.493, P = 0.003	B = 7.780, [CI] = 0.826–14.933, P = 0.029
Non-Caucasian ethnicity	B = 8.799, [CI] = 3.033–14.566, P = 0.003	B = 7.516, [CI] = 2.135–12.866, P = 0.006	B = 10.141, [CI] = 3.567–16.716, P = 0.003	B = 7.324, [CI] = 1.755–12.993, P = 0.010	B = 11.585, [CI] = 5.850–17.321, P < 0.001

Events that occur early following the post-operative course include deep infections, superficial infections and VTE. Further into the post-operative course nonunion may occur, albeit rarely. Events that occur late into the post-operative course among these patients are re-operations to remove painful implants and lysis of adhesions to improve knee range of motion. This is further supported in a study of tibial plateau fractures from 2006. In a review conducted by Papagelopoulos et al., the authors discussed that early complications, such as VTE and infections, are typically due to a biological issue [2]. Therefore, it is important to provide long-term follow-up, as presented in our study, to assess the time-points in which complications occur.

This study provides insights to help predict which patients are at risk for developing events following operatively managed tibial plateau fractures. Severe injuries (bicondylar fractures, Moore fracture-dislocations, open fractures or development of compartment syndrome) are associated with an increased incidence of complications and re-operations.

The most common complication reported following this series of operatively managed tibial plateau fractures was infection, which has been noted in recent and historical reports [2,3,5,7,8,20,21–26]. The overall deep infection rate in this study was 3.6%, while a less severe superficial infection occurred in 2.2% of patients. In a recent report on adverse events following operatively managed tibial plateau fractures, Basques et al. reported an overall infection rate of 4.2%, which is comparable to the rate in our study. Rates presented in historical studies have infection rates ranging from 3% to 32% [2,3,5,7,20,27,28]. In a study performed by Roberts et al. in 1968, 50% of displaced tibial plateau fractures went on to develop a post-operative infection with subsequent loss of motion [27]. The authors treated these patient's with daily aspiration and closed irrigation of knee joint with saline and lineocin. In 1973, Bakalim et al. reported that 3% of patients sustained an infection [28]. In the study performed by Schatzker et al. in 1979, there was a 7.3% infection rate among operatively managed tibial plateau fractures [5]. Moore et al. noted a 7% infection rate in 1980 where antibiotics were only used in open fractures or following the development of an infection. Moore et al. additionally noted infection rates were doubled in patients whom were not administered prophylactic antibiotics [7].

Our results demonstrate that complications are more prevalent following high-energy and bicondylar tibial plateau fractures, and this is consistent with the current literature as well [2,5,7,8,12,21–26]. Deep infections occurred in 3% of bicondylar fractures operatively managed in this study. Additionally, superficial infections of this cohort occurred in 3% of bicondylar tibial plateau fractures. Barei et al. reported a 24% infection rate in a cohort of 51 patients sustaining bicondylar tibial plateau fractures treated with dual incisions and medial and lateral plating [29]. Ruffalo et al. reported an infection rate in 23% of these fractures [8].

In our study, we attribute our decreased infection rate among bicondylar fractures to utilizing a staged approach protocol [9]. Tsherne et al. discussed the need for soft tissue healing before definite fixation to allow for osteosynthesis [4]. The initial trauma leads to local edema and inflammation, which can cause venous compromise and hypoxia, and in turn contributes to additional soft tissue trauma [13]. Therefore, staged management for severe, high energy and bicondylar fractures, should be utilized with initial knee immobilization through external fixation, and once the tissues are healed, ORIF should be performed [9–16]. When utilizing staged management, Patterson and Cole reported no soft tissue complications or infections [15]. Egol et al. reported an infection rate of 5% when using this approach [9]. Stamer et al. reported a deep infection rate of 13% in bicondylar tibial plateau fractures managed with a staged protocol [14].

In addition to staged management, recent literature has discussed other less invasive techniques for management of tibial plateau fractures. These include tension wire fixation, lateral fixation with medial external fixation, and hybrid external fixation – all methods that require less soft tissue dissection than ORIF [8,9,21–26]. However, minimally invasive procedures for fixation of these fractures are often accompanied with difficult reduction of the articular surface, leading to unsatisfactory results [8,21–26]. Therefore, the pendulum has swung in favor of utilizing early temporizing knee spanning external fixation, followed by later staged management of these complex injuries [2,9–13].

The association of deep infections following open fractures was demonstrated in this study, and has previously been described [15,30–32]. Our results additionally demonstrate diabetes mellitus to be a risk factor for deep infections, which contrasts with a recent study looking at complications following high-energy bicondylar fractures [8]. Male patients in this cohort were also noted to have higher rates of deep infections.

While we cannot modify patient and injury factors, understanding predictors of post-operative infections allows surgeons to adopt aggressive strategies to try to mitigate these issues early. Papagelopoulos et al. discussed an aggressive treatment protocol for infections following tibial plateau fractures, which includes irrigation and debridement of devitalized bone and soft tissues with administration of 3–6 weeks of intravenous antibiotics [2]. If there is a severe fracture that involves intra-articular portions of the tibia, the knee joint should be evacuated and irrigated to prevent septic arthritis and cartilage destruction. The authors further recommend abscess packing with split skin grafting if applicable. If a sinus tract is present, irrigation and debridement performed, followed by use of suction drains. In regards to implants, if they are providing stability they should be retained, but if loose, the implant should be removed followed by pin traction or external fixation [2].

Fracture nonunion following operative-fixation of tibial plateau fractures occurred in 0.7% of the patients in this study, one following a unicondylar fracture and one in a bicondylar fracture. This is comparable to the nonunion rate in other studies, which examined large cohorts and their outcomes following tibial plateau fractures [33–35]. Behari et al. looked at extra-articular proximal tibial plateau fractures and reported a nonunion rate of 2% for plate/screw fixation, 3.5% if intramedullary nails were used, and 8% when external fixators were the only source of fixation [36]. Open fractures and deep infections were associated with nonunion development. Each of these associations with fracture nonunion are well known and reported for other fracture types as well [2,37,38].

Nonunions are more common following bicondylar fractures as opposed to unicondylar fractures, due to the good blood supply of cancellous bone located in the proximal tibial [35,39]. This complication most often follows Schatzker VI fractures and occurs at the metaphyseal-diaphyseal junction [2]. The anterior tibial artery in addition to the popliteal artery give the proximal tibia a substantial blood supply through four extraosseous branches to the lateral tibial metaphysis and the medial and lateral geniculate arteries, respectively [40]. Ruffalo et al. reported a high nonunion rate of 10% in bicondylar tibial plateau fractures [8]. In a study performed by Barei et al. the authors noted that nonunion of bicondylar tibial plateau fractures occurred in only 1.2% of their cohort [29].

General recommendations provided by Papagelopoulos et al. in their 2006 report suggest revision repair with bone grafting in aseptic nonunion. Infected nonunions should be treated with irrigation and debridement, placement of antibiotic beads, flaps when necessary, and external fixation to allow resolution of the infection [2].

Despite thromboprophylaxis for all, thromboembolic events occurred in 2.9% of patients in this study, which is the same percentage of thromboembolic events reported by Basques et al. in their large database study [20]. These rates are lower than those recorded historically [4,27,28]. Roberts et al. reported that 5% of patients suffered a VTE following operatively managed displaced tibial plateau fratures [27]. A few years later, in 1973, Bakalim et al. documented a 5% rate of VTE [28]. In 1993 Tscherne et al. reported a 6% rate of VTE in operatively managed tibial plateau fractures [4].

VTE occurred more frequently in obese patients, bicondylar tibial plateau fractures, and Moore fracture-dislocations. Thromboembolic events are complications that may lead to a pulmonary embolus contributing to mortality following orthopaedic trauma [30,41]. Studies have demonstrated pulmonary embolus rates following orthopaedic trauma to be as high as 27% [30,42,43]. Additionally, the risk for VTE is increased following lower extremity trauma due to decreased mobility [43]. Therefore, it is important to consider the predictors of developing a VTE following operative-management of tibial plateau fractures in order to adequately screen and provide appropriate thromboprophylaxis for these high-risk patients. Additional studies have demonstrated the use of Wells-criteria to be beneficial in predicting VTE in patients who sustained orthopaedic trauma [43]. More invasive methods for prevention of VTE, such as inferior vena cava filter placement and early anticoagulant therapy should be considered in high-risk patients [44].

Prior to validated surveys, reports on the outcomes following tibial plateau fractures were classified as acceptable or unacceptable according to Hohl and Luck [45]. Acceptable results included 90° of range of motion, the ability to fully extend the knee, endurance and strength sufficient for occupation and activities of daily living, normal gait, minimal discomfort following exertion, and knee stability. With the introduction of validated questionnaires such as the SMFA, we can more specifically assess what aspects of a patient's life are affected by their tibial plateau fracture. Due to the use of different scoring systems, it is difficult to compare functional outcomes between studies. In 1968, Roberts et al. reported unacceptable results in 42% of operatively managed fractures. Poor results occurred in 100% (2/2) of non-displaced fractures, 60% (3/5) of local compression fractures, and 31% (6/19) displaced fractures [27]. In 1973, Ramsussen et al. reported that 90% of operatively managed patients had good or excellent results [46].

Despite the reporting of complications following tibial plateau fractures, few reports if any have correlated these events with patient reported outcomes. Our study noted worse long-term functional results in patients who developed a post-operative complication or unplanned outcome following operative fixation of tibial plateau fractures through use of the validated SMFA survey. Patients of non-Caucasian ethnicity had worse long-term outcomes in each subcategory of the SMFA (function, bothersome nature of injury, ability to perform daily activities, emotional status, and mobility). Smoking negatively impacted numerous domains such as function, bothersome nature of the injury, emotional status, and mobility. Increased age was associated with more difficulty in performing daily activities following the fracture along with decreased mobility. Complications that were independent predictors of worse outcomes were deep infections (bothersome nature of injury) and VTE events (function, emotional status).

Differences in functional outcomes between event and non-event groups were not apparent at 3-month follow-up, yet began to affect patient outcomes at 6-months post-operative management. Patients who sustained a post-operative event similarly had decreased range of motion at 3-month, 6-month, and long-term follow-up.

No differences were noted in pain scores between groups sustaining a post-operative event and those whom did not. These data combined with earlier studies assessing complication rates should be taken into consideration when counseling patients who require operative fixation of tibial plateau fractures.

The reduction in complication rates in this report and recent literature, compared to historical controls is clearly multifactorial. Many improvements in various aspects of treatment have increased our knowledge and understanding of tibial plateau fracture management. These include: a better understanding of the natural history of untreated fractures, an improved anatomical understanding including the importance and function of the meniscus, improved imaging including CT and MRI, technologic advances in implants utilized for fixation, and surgical techniques and advancements including the introduction of minimally invasive techniques, staged management of high-energy tibial plateau fractures, and delicate soft tissue handling [2,5,7,8,21–26].

This study is limited by the inability to determine rates of late presenting complications such as osteoarthritis and need for total knee arthroplasty. Additional follow up is required to determine the rates and timeline of late presenting complications.

Conclusion

Orthopaedic trauma surgeons should be aware of the factors that lead to complications and unplanned events following operatively managed tibial plateau fractures, such as bicondylar tibial plateau fractures, Moore fracture-dislocations, open fractures, and fractures presenting with compartment syndrome. Specifically, patients were at increased risk for developing a deep infection if they had diabetes mellitus, open fractures, or were of male sex. Nonunion occurred following open fractures and deep infections. Patients who were obese were more likely to sustain a VTE. Bicondylar tibial plateau fractures were associated with VTE, painful implants requiring removal of the plate and screw construct, and arthrofibrosis necessitating return to the operating room for a lysis of adhesions procedure. Fractures that fell under the Moore fracture-dislocation classification predicted development of a VTE and painful implant's, which required removal.

Patients who developed a post-operative complication or unplanned outcome had decreased range of motion at 3-month, 6-month and long-term follow-up. Additionally, patients who sustained a post-operative event had worse functional outcomes at 6-month and long-term follow-up.

With the knowledge of injury characteristics as predictors for post-operative complications and unplanned events, orthopaedic traumatologists may be able counsel patients and provide early interventions aimed at improving these patients' long-term outcomes.

Conflict of interest statement

David Kugelman, Abdullah Qatu, Jack Haglin, Phillip Leucht Sanjit Konda, and Kenneth Egol have no conflicts of interests related to this study. Kenneth Egol, M.D. is a consultant for exactech.

Acknowledgement

No funding was received for this study.

References

[1] Egol KA, Koval KJ, Zuckerman JD. Handbook of fractures. Philadelphia, PA: Wolters Klewers Health; 2015. p. 525–33.

[2] Papagelopoulos PJ, Partsinevelos AA, Themistocleous GS, Mavrogenis AF, Korres DS, Soucacos PN. Complications after tibia plateau fracture surgery. Injury 2006;37(6):475–84.
[3] Young M, Barrack RL. Complications of internal fixation of tibial plateau fractures. Orthop Rev 1994;3(2):149–54.
[4] Tscherne H, Lobenhoffer P. Tibial plateau fractures: management and expected results. Clin Orthop Relat Res 1993;292:87–100.
[5] Schatzker J, Mcbroom R, Bruce D. The tibial plateau fracture: the Toronto experience 1968–1975. Clin Orthop Relat Res 1979;138:94–104.
[6] Lansinger O, Bergman B, Körner L, Andersson GB. Tibial condylar fractures: a twenty-year follow-up. J Bone Joint Surg Am 1986;68(1):13–9.
[7] Moore TM, Patzakis MJ, Harvey JP. Tibial plateau fractures: definition, demographics, treatment rationale, and long-term results of closed traction management or operative reduction. J Orthop Trauma 1987;1(2):97–119.
[8] Ruffolo MR, Gettys FK, Montijo HE, Seymour RB, Karunakar MA. Complications of high-energy bicondylar tibial plateau fractures treated with dual plating through 2 incisions. J Orthop Trauma 2015;29(2):85–90.
[9] Egol KA, Tejwani NC, Capla EL, Wolinsky PL, Koval KJ. Staged management of high-energy proximal tibia fractures (OTA types 41): the results of a prospective, standardized protocol. J Orthop Trauma 2005;19(7):448–55.
[10] Giannoudis PV. Surgical priorities in damage control in polytrauma. J Bone Joint Surg 2003;85B:478–83.
[11] Scalea TM, Boswell SA, Scott JD. External fixation as a bridge to intra-medullary nailing for patients with multiple injuries and with femur fractures: damage control orthopaedics. J Trauma 2000;48:613–23.
[12] Reichard AK, Seligson D, Alt V. External fixation of tibial plateau fractures: a retrospective evaluation and case report. Osteo Trauma Care 2004;12:33–6.
[13] Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: an update. EFORT Open Rev 2016;1(5):225–32.
[14] Stamer DT, Schenk R, Staggers B, Aurori K, Aurori B, Behrens FF. Bicondylar tibial plateau fractures treated with a hybrid ring external fixator: a preliminary study. J Orthop Trauma 1994;8:455–61.
[15] Patterson MJ, Cole JD. Two staged delayed open reduction and internal fixation of severe pilon fractures. J Orthop Trauma 1999;13:85–91.
[16] Yoon RS, Liporace FA, Egol KA. Definitive fixation of tibial plateau fractures. Orthop Clin North Am 2015;46(3):363–75.
[17] Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, et al. Fracture and dislocation classification compendium—2007: orthopaedic trauma association classification, database and outcomes committee. J Orthop Trauma 2007;21(Suppl. 10):S1–S163.
[18] Prat-Fabregat S, Camacho-Carrasco P. Treatment strategy for tibial plateau fractures: an update. EFORT Open Rev 2016;1(5):225–32.
[19] Jacobson KE, Chi FS. Evaluation and treatment of medial collateral ligament and medial-sided injuries of the knee. Sports Med Arthrosc 2006;14(2):58–66.
[20] Basques BA, Webb ML, Bohl DD, Golinvaux NS, Grauer JN. Adverse events, length of stay, and readmission after surgery for tibial plateau fractures. J Orthop Trauma 2015;29(3):e121–6.
[21] Gaudinez RF, Mallik AR, Szporn M. Hybrid external fixation of comminuted tibial plateau fractures. Clin Orthop 1996;63:203–10.
[22] Marsh JL, Smith ST, Do TT. External fixation and limited internal fixation for complex fractures of the tibial plateau. J Bone Joint Surg Am 1995;77:661–73.
[23] Ries MD, Meinhard BP. Medial external fixation with lateral plate internal fixation in metaphyseal tibia fractures: a report of eight cases associated with severe soft-tissue injury. Clin Orthop 1990;9:215–23.
[24] Stamer DT, Schenk R, Staggers B, Aurori K, Aurori B, Behrens FF. Bicondylar tibial plateau fractures treated with a hybrid ring external fixator: a preliminary study. J Orthop Trauma 1994;8:455–61.
[25] Watson JT. High-energy fractures of the tibial plateau. Orthop Clin North Am 1994;25:723–52.
[26] Dendrinos GK, Kontos S, Katsenis D, Dallas A. Treatment of high-energy tibial plateau fractures by the Ilizarov circular fixator. J Bone Joint Surg Br 1996;78:710–7.
[27] Roberts JM. Fractures of the Condyles of the Tibia: an anatomical and clinical end-result study of one hundred cases. J Bone Joint Surg 1968;50(8):1505–21.
[28] Bakalim G, Wilppula E. Fractures of tibial condyles. Acta Orthop Scand 1973;44(3):311–22.
[29] Barei DP, Nork SE, Mills WJ, Henley MB, Benirschke SK. Complications associated with internal fixation of high-energy bicondylar tibial plateau fractures utilizing a two-incision technique. J Orthop Trauma 2004;18(10):649–57.
[30] Morris BJ, Unger RZ, Archer KR, Mathis SL, Perdue AM, Obremskey WT. Risk factors of infection after ORIF of bicondylar tibial plateau fractures. J Orthop Trauma 2013;27:e196–200.
[31] Lin S, Mauffrey C, Hammerberg EM, Stahel PF, Hak DJ. Surgical site infection after open reduction and internal fixation of tibial plateau fractures. Eur J Orthop Surg Traumatol 2014;24:797–803.
[32] Dubina AG, Paryavi E, Manson TT, Allmon C, O'Toole RV. Surgical site infection in tibial plateau fractures with ipsilateral compartment syndrome. Injury 2017;48(2):495–500.
[33] Ebraheim NA, Sabry FF, Haman SP. Open reduction and internal fixation of 117 tibial plateau fractures. Orthopedics 2004;27:1281–7.
[34] Kumar A, Whittle AP. Treatment of complex (Schatzker type VI) fractures of the tibial plateau with circular wire external fixation: retrospective case review. J Orthop Trauma 2000;14:339–44.
[35] Manidakis N, Dosani A, Dimitriou R, Stengel D, Matthews S, Giannoudis P. Tibial plateau fractures: functional outcome and incidence of osteoarthritis in 125 cases. Int Orthop 2010;34(4):565–70.
[36] Bhandari M, Audige L, Ellis T, Hanson B. Review operative treatment of extra-articular proximal tibial fractures: evidence-based orthopaedic trauma working group. J Orthop Trauma 2003;17(8):591–5.
[37] Sen RK, Soni A, Saini UC, Singh D, Yuan T. Internal fixation and bone grafting for intraarticular nonunion of tibial plateau: a report of four cases. Chin J Traumatol 2011;14(6):371–5.
[38] Van Nielen DL, Smith CS, Helfet DL, Kloen P. Early revision surgery for tibial plateau non-union and mal-union. HSS J 2016;1–9.
[39] Chan DB, Jeffcoat DM, Lorich DG, Helfet DL. Nonunions around the knee joint. Int Orthop 2010;34(2):271–81.
[40] Borrelli Jr. J, Prickett W, Song E, Becker D, Ricci W. Extraosseous blood supply of the tibia and the effects of different plating techniques: a human cadaveric study. J Orthop Trauma 2002;16(10):691–5.
[41] Schiff RL, Kahn SR, Shrier I, Strulovitch C, Hammouda W, Cohen E, et al. Identifying orthopedic patients at high risk for venous thromboembolism despite thromboprophylaxis. Chest 2005;128(5):3364–71.
[42] Tornetta P, Bogdan Y. Pulmonary embolism in orthopaedic patients: diagnosis and management. J Am Acad Orthop Surg 2012;20(9):586–95.
[43] Abelseth G, Buckley RE, Pineo GE, Hull R, Rose MS. Incidence of deep-vein thrombosis in patients with fractures of the lower extremity distal to the hip. J Orthop Trauma 1996;10(4):230–5.
[44] Toker S, Hak DJ, Morgan SJ. Deep vein thrombosis prophylaxis in trauma patients. Thrombosis 2011.
[45] Hohl M, Luck JV. Fractures of the tibial condyle: a clinical and experimental study. J Bone Joint Surg 1956;38(5):1001–18.
[46] Rasmussen PS. Tibial condylar fractures. Impairment of knee joint stability as an indication for surgical treatment. J Bone Joint Surg 1973;973(55):1331–50.