Effect of additional fixation in tibial plateau impression fractures treated with balloon reduction and cement augmentation

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Background: Isolated tibial plateau impression fractures can be reduced through minimally invasive techniques using balloon inflation and cement augmentation. No evidence exists yet if an additional fixation at all and which method of fixation is necessary in the treatment of these fractures. The purpose of this study was to compare a locking plate and a screw raft for additional fixation after balloon reduction and cement augmentation in isolated tibial plateau impression fractures. Loss of reduction was subsequently analysed without additional fixation.

Methods: Lateral tibial plateau impression fractures were created in eight matched pairs of human cadaveric tibiae. Reduction was performed using a balloon inflation system, followed by cement augmentation. Additional fixation was performed with a lateral locking plate or a screw raft (four 3.5-mm screws). Specimens were cyclically loaded at 20–240 N, 20–360 N and 20–480 N. Subsequently, additional fixation was removed and the last cyclic interval (20–480 N) repeated. Loss of reduction was assessed by measuring subsidence of the subchondral bone.

Findings: Fractures treated with plate fixation exhibited less subsidence at higher loads compared with those treated with screw raft fixation (P < 0.05). Loss of reduction significantly increased after removal of the additional fixation.

Interpretation: This experimental study suggests that loss of reduction can be minimised by using locking plate fixation after balloon reduction and cement augmentation in the treatment of isolated tibial plateau impression fractures.

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1. Introduction

The number of geriatric fractures is continuously increasing. Lateral tibial impression fractures are usually seen in older patients who have reduced metaphyseal bone substance. With decreased bone quality, the tibial head fracture tends to be a pure impression of the articular surface, rather than a split-impression fracture. Without a split in the outer cortex, this impression fracture results in a Schatzker III type of fracture (Schatzker, 2005). The primary aim of surgical treatment in this patient population is anatomical restoration of the articular surface and stable fixation in order to allow weight-bearing as soon as possible. However, after surgical treatment of tibial plateau fractures, subsidence of the articular surface when the patient becomes mobile again, with consequent valgus malalignment of the limb, has frequently been reported in the literature (Russell et al., 2008).

Recently, several authors have described minimally invasive techniques using inflatable balloon systems for reduction of a depressed articular surface (Ahrens et al., 2012; Broome et al., 2012; Craiovan et al., 2014; Hahnhaussen et al., 2012; Mauffrey et al., 2014; Pizanis et al., 2012). Metaphyseal defects after reduction of the joint surface are augmented with bone substitutes to avoid secondary loss of reduction. Reduction can be additionally secured by screws passing across the cement cloud in the metaphyseal bone. Combination of balloon reduction followed by percutaneous screw insertion represents a full minimally invasive treatment of tibial impression fractures (Craiovan et al., 2014; Mauffrey et al., 2014). Previous biomechanical studies have reported a high degree of stability for tibial plateau impression fractures treated with cement augmentation and screw fixation without using a lateral plate (Doht et al., 2012; Yetkinler et al., 2001). Nevertheless, a locking plate is often used for additional fixation, in order to reduce the risk of screw-head cut-out at the lateral cortex and subsequent loss of reduction (Hahnhaussen et al., 2012; Pizanis et al., 2012). There is as yet no evidence on which method of fixation provides the greatest...
stability in the treatment of tibial plateau impression fractures after balloon reduction and cement augmentation, or even whether fixation is necessary at all.

The purpose of this study was to compare a locking plate and a screw raft for additional fixation after balloon reduction and cement augmentation in isolated tibial plateau impression fractures. Loss of reduction was also analysed after the additional fixation was removed. It was hypothesised that a screw raft is biomechanically equivalent to a lateral locking plate in tibial plateau impression fractures reduced by balloon inflation and cement augmentation. The second hypothesis was that removing additional fixation results in increased loss of reduction and cement cloud subsidence.

2. Methods

In the first part of the study, plate and screw raft fixation for tibial plateau impression fractures were tested using a cyclic protocol with stepwise-increasing load magnitudes. In the second part, the plate or screw raft fixation was removed and the specimens were tested with cement augmentation alone.

2.1. Specimen preparation

Eight matched pairs of human fresh-frozen tibiae were used for testing (mean age: 78 years, SD 10 years, six females). The bodies were donated by people who had given their informed consent for their use for scientific and educational purposes prior to death (McHanwell et al., 2008; Riederer et al., 2012). Local bone mineral density (BMD) was measured 10 mm below the lateral articular surface of the tibia using quantitative computed tomography (LightSpeed VCT, GE Healthcare, Milwaukee, Wisconsin, USA), showing a mean BMD of 90.0 mg HA/cm³ (SD 30.0). The specimens were stored at −20 °C and thawed overnight at 6 °C prior to preparation and biomechanical testing. At room temperature, skin and musculature were removed. The tibia was cut at the mid-diaphysis, 20 cm distal to the tibial plateau, and potted in a metal cup using polymethylmethacrylate (Technovit 3040, Heraeus Kulzer, Wehrheim, Germany), resulting in a free specimen length of 15 cm. The tibia was oriented with the long axis of the tibial shaft at a 5° angle to vertical in order to simulate a slight valgus orientation (Doht et al., 2012; Yetkinler et al., 2001).

2.2. Fracture creation

The fracture was created by impressing a cylindrical indenter (diameter 14 mm) into the lateral tibial plateau surface. Prior to impression, twelve holes (diameter 2 mm), arranged in a circle with a diameter of 14 mm, were drilled as predetermined breaking points (Doht et al., 2012; Yetkinler et al., 2001). The indenter was positioned in the centre of the arranged predetermined breaking points and impressed to a depth of 8 mm at 1 mm/s using a servohydraulic materials testing machine (Mini-Bionix II 858, MTS, Eden Prairie, Minnesota, USA).

2.3. Balloon reduction and cement augmentation

All of the procedures were performed by an orthopaedic trauma surgeon (R.M.). The impression fracture was reduced using a balloon inflation system (Kyphon; Medtronic, Sunnyvale, California, USA) inserted from the anteromedial aspect of the tibia. Under fluoroscopy, the balloon was positioned centrally under the impressed subchondral bone. Anatomical reduction was achieved by balloon expansion. The volume of contrast solution determined the minimum quantity of cement that was subsequently injected into the void (VertecemV+; Synthes Inc., West Chester, Pennsylvania, USA).

2.4. Fixation

The tibiae in each pair were randomly assigned to the two fixation techniques (Fig. 1), ensuring an equal number of left and right tibiae for each method. The lateral locking plate (3.5 mm; Synthes) was provisionally positioned to the lateral aspect of the tibia with the proximal screw holes parallel to the articular surface of the lateral condyle. In a cranio-caudal direction, the plate position was chosen in such a way that at least one proximal screw passed centrally through the cement cloud. The plate was fixed with K-wires.

In the group with plate fixation, locking screws (3.5 mm; Synthes) were inserted with four proximal, one kickstand and one diaphyseal locking head screws. In the group with screw raft fixation, holes for the raft were drilled using the four proximal holes in the locking plate. The plate was removed and four 3.5-mm cortical screws (Synthes) were inserted through the lateral tibia. The length of the proximal screws was chosen in order to avoid perforation of the medial cortex.

2.5. Biomechanical test set-up

The femoral component of a hemi-total knee arthroplasty (TKA) (Oxford; Biomet, Bridgend, United Kingdom) was rigidly attached to the actuator of the servohydraulic materials testing machine (Fig. 2). The embedded specimen was mounted on an X-Y-bearing table in order to ensure uniform loading across the reduced impression fracture. The cyclic loading protocol consisted of three loading intervals of overall 15,000 compression load cycles at 20–240 N, 20–360 N and 20–480 N (5000 load cycles per interval) applied at 2 Hz, representing a high range of physiological gait. These load magnitudes simulate a patient weighting 80 kg in the rehabilitation with 66%, 100% and 133% of weight-bearing during gait (McDonald et al., 2011). Load magnitudes were chosen on the basis of the following considerations: firstly, during gait, the net joint contact force for a single leg stance is reported as being three times body weight (Taylor et al., 2004). Secondly, load-sharing
between the medial and lateral compartment is 55–45% (Zhao et al., 2007). Thirdly, in comparison with the native femoral condyle, a hemi-TKA reduces the contact area to 30% (Zdero et al., 2001) and in order to apply a comparable contact pressure to the native femoral condyle the force for the hemi-TKA was reduced correspondingly.

To evaluate the stabilising effect of additional fixation on subsidence of the cement cloud in the cancellous bone, the additional fixation was removed after 15,000 cycles. The last cyclic interval (20–480 N) was applied for another 5000 load cycles. Radiographs (Siremobil 2000, Siemens Healthcare, Erlangen, Germany) were taken at a load of 20 N initially and at the end of each loading interval for radiographic documentation of the tibia plateau reduction and implant migration.

2.6. Data evaluation

Subsidence of the lateral plateau reduction was measured on radiographs using an image-processing program (icoview 3.5; ITH icoserve, Innsbruck, Austria). A line was drawn connecting the medial and lateral border of the tibial plateau. Perpendicularly, a line was drawn across the centre of the impression fracture. The distance between the line of the tibial plateau and the subchondral bone was measured along the perpendicular line across the fracture. Subsidence of the subchondral bone was defined as an increase in distance during each loading interval in relation to the initial radiograph before cyclic loading (Fig. 3). In addition, subsidence of the cement cloud and screws was documented.

2.7. Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics 22.0 (IBM Corporation, Armonk, New York, USA). Normality of distribution within each group was screened with Shapiro–Wilk test. Groups were compared using paired Student’s t-test. P values below 0.05 were considered significant.

3. Results

Isolated impression fractures were successfully created in all specimens. The mean cement volume injected was 2.7 ml (SD 1.0) for the group with a plate and 2.1 ml (SD 0.6) for the group with screw raft fixation (P = 0.178). After anatomical reduction, the distance of the subchondral plate to the proximal border of the cement cloud was 5.0 mm (SD 1.6) and 4.6 mm (SD 1.7), respectively (P = 0.687).

3.1. Plate versus screw raft

The group with plate fixation showed a mean subsidence of 0.6 mm (SD 0.4) and 0.8 mm (SD 0.5) during cyclic loading at 240 N and 360 N, respectively. The group with screw raft fixation showed a mean subsidence of 0.8 mm (SD 0.6) and 1.0 mm (SD 0.6) during cyclic loading at 240 N and 360 N, respectively. These differences were not significant (P = 0.174, P = 0.206). The group with plate fixation showed significantly less subsidence during cyclic loading at 480 N (mean 0.9 mm (SD 0.6)) compared with the group with screw raft fixation (mean 1.5 mm (SD 0.8)) (P = 0.039) (Fig. 4).

No implant breakages were observed in either group. The screws and cement cloud remained stable in all specimens with plate fixation.
In the group with screw raft fixation, after loading at 360 N and 480 N one specimen showed cement cloud subsidence without screw subsidence, and two specimens showed subsidence of the cement cloud with the attached screw.

3.2. Cement only

After plate removal, subsidence increased significantly to 1.3 mm (SD 0.7) during cyclic loading at 480 N, compared with subsidence with plate fixation during loading at 480 N (mean 0.9 mm (SD 0.6), \( P = 0.002 \)). After screw raft removal, subsidence significantly increased to 1.9 mm (SD 0.9), compared with subsidence with screw raft fixation during loading at 480 N (mean 1.5 mm (SD 0.8), \( P = 0.003 \)) (Fig. 5). The subsidence after removal of the addition fixation was not significantly different between the two groups (\( P = 0.111 \)).

In each of the two groups, subsidence of the cement cloud was observed in five out of eight specimens.

4. Discussion

The present biomechanical study investigated the effect of additional fixation after balloon reduction and cement augmentation of isolated tibial impression fractures. The first hypothesis in the study was not supported, as fractures treated with locking plate fixation showed greater resistance during cyclic loading and no subsidence of the cement cloud, compared with fractures treated with screw raft fixation. The second hypothesis was supported, as removal of additional fixation resulted in increased subsidence of the articular surface and cement cloud.

Reduction of tibial plateau impression fractures using balloon inflation systems followed by cement augmentation represents a minimally invasive technique that avoids iliac bone grafting and the associated harvest-side morbidity. In a cadaveric study with tibial plateau split-implant fractures, Heiney et al. (2014) showed that balloon reduction and cement augmentation resulted in more anatomical reduction and superior biomechanical properties in comparison with fracture reduction using conventional bone tamps and cancellous bone chips. This is in accordance with previous studies reporting greater resistance against cyclic loading and increased failure loads for tibial plateau fractures treated with cement augmentation instead of autograft bone grafts (McDonald et al., 2011; Trenholm et al., 2005). Two studies investigated isolated tibial plateau impression fractures treated with cement augmentation using a lateral cortical window approach. Yetkinler et al. (2001) compared fractures treated with cement augmentation alone or in combination with screw fixation. No significant differences were found in the subsidence of the articular surface during cyclic loading or in ultimate failure loads. Doht et al. (2012) investigated the effect of screws placed in a jail configuration (two anteroposterior and two lateromedially directed screws) after cement augmentation of tibial plateau impression fractures. No significant differences were noted in the subsidence of the articular surface during cyclic loading. Higher failure loads were reported for the fractures treated with cement augmentation and screw fixation compared with those treated with cement augmentation only. In the present study, additional fixation (plate and screw raft) showed a stabilising effect on cement cloud and reduction. This was clearly seen, as the rate of cement cloud subsidence increased after removal of the additional fixation.

Fractures treated with screw raft fixation or plate fixation showed comparable loss of reduction at load magnitudes simulating partial and full weight-bearing. However, in two cases fractures treated with screw raft fixation showed subsidence of the cement cloud, with the attached screw cutting through the lateral cortex. A lateral locking plate might therefore be indicated particularly in patients with compromised bone quality, a thin cortex, or severe fracture patterns, in order to minimise postoperative loss of reduction. In patients with a high risk of soft-tissue complications, screw raft fixation still represents an attractive technique that minimises surgical trauma and operating time.

Yetkinler et al. (2001) showed that subsidence can be reduced by extensive cement augmentation, removing all cancellous bone under the subchondral plate. When balloon inflation systems are used for tibial plateau reduction, the location of the cement cloud depends on the initial balloon position. Placing the balloon and cement too close to the subchondral plate might increase the risk of balloon penetration or cement leakage into the joint, resulting in cartilage damage (Mauffrey et al., 2014). Thus, the final cement cloud position might be more distal, with additional fixation material being placed in the cancellous bone under the subchondral plate without passing the cement cloud (Ahrens et al., 2012; Mauffrey et al., 2014; Pizanis et al., 2012). On the other hand, a more proximal location of the cement cloud might reduce postoperative subsidence of the articular surface, as the cancellous bone which can be compressed is minimised and supported by the large surface of the cement cloud. The effect of subchondral cement injection of the overlying cartilage has still been poorly investigated. Concerns were raised about cartilage damage caused by heat necrosis and disruption of the cartilage nutrition. Goetzen et al. (Riederer et al., 2012) recently showed that the injection of PMMA-based bone cement close to the joint line did not seem to damage the adjacent subchondral bone or cartilage in an in-vivo sheep model. The authors concluded that cement augmentation in the metaphyseal region appears to be a safe procedure without harming the subchondral plate and the adjacent cartilage. In the present study, the cement cloud was placed approximately 5 mm under the subchondral plate. The impact of the craniocaudal location of the cement cloud on postoperative loss of reduction needs to be investigated in future studies.

The present study has some limitations. A homogeneous impression fracture was created with a circular subchondral plate pushed into the tibial metaphysis. This resulted in a reproducible fracture and permits data comparison with previous studies, but the results may be only valid for this fracture pattern (Doht et al., 2012; Yetkinler et al., 2001). The clinical fracture pattern of isolated tibial plateau impression fractures, such as fragmentation of the subchondral plate, irregular shape and depth of the fracture were not simulated in this laboratory fracture type. Loads were applied directly to the reduced fracture using the femoral part of a hemi-knee TKA, and load distribution caused by the lateral meniscus was neglected. In addition, the biomechanical protocol did not include a load-to-failure test. A load-to-failure test would provide information about resistance to greater loads, in case of a catastrophic event such as a fall. However, the postoperative loss of reduction may be primarily caused by repetitive loading during mobilisation and can be adequately simulated in a cyclic loading protocol. After cyclic loading, the additional fixation was removed in order to test the cement cloud without additional fixation. However, when interpreting these results, it should be borne in mind that the specimens had already been tested for three cyclic load intervals beforehand.

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![Fig. 5. Subsidence of the subchondral bone with plate or screw raft fixation after cyclic loading at the highest load interval (20–480 N) and after removal of the additional fixation (20–480 N), presented as box plots with medians and interquartile ranges (25–75%). Statistically significant differences (\( P < 0.05 \)) are indicated with brackets and an asterisk (*).](image-url)
5. Conclusions

Fractures treated with plate fixation showed less subsidence at higher loads than those treated with screw raft fixation. After screw removal, loss of reduction significantly increased and higher rates of cement cloud subsidence were observed. The results of the present study suggest that postoperative loss of reduction can be minimised by using a locking plate fixation after balloon reduction and cement augmentation in the treatment of isolated tibial plateau impression fractures.

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