Biomechanical Evaluation of Interfragmentary Compression At Tibia Plateau Fractures In Vitro Using Different Fixation Techniques

A CONSORT-compliant article

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Abstract: Reliable osteosynthesis of intraarticular fractures depends on lasting interfragmentary compression. Its amount differs in the applied fixation method. The interfragmentary compression of cancellous and cortical lag screws and angle stable locking plates was quantified in an osteoporotic and non-osteoporotic synthetic human bone model.

A split fracture of the lateral tibia plateau (AO/OTA type 41-B1.1) was mimicked by an osteotomy in right adult synthetic human tibiae with hard or soft cancellous bone. Specimens were fixed with either two 6.5 mm cancellous, four 3.5 mm cortical lag screws, or 3.5 mm LCP proximal lateral tibia plate preliminary compressed by a reduction clamp (n = 5 per group). A pressure sensor film was used to register the interfragmentary compression. One-way analysis of variance (ANOVA) with Bonferroni post hoc correction was performed for statistical analysis ($p < 0.05$).

Interfragmentary compression under reduction clamp was 0.59 ± 0.12 MPa in the non-osteoporotic and 0.55 ± 0.14 MPa in the osteoporotic group. The locking plate itself maintained the compression in non-osteoporotic (0.53 ± 0.11 MPa) and osteoporotic bone (0.50 ± 0.14 MPa). Four 3.5 mm cortical lag screws provided a compression of 1.69 ± 0.65 MPa in non-osteoporotic bone, being not significantly different to the osteoporotic bone group (1.43 ± 0.47 MPa, $P = 1.0$). Two 6.5 mm cancellous lag screws showed a significantly higher compression in non-osteoporotic (2.1 ± 0.59 MPa) compared to osteoporotic (0.77 ± 0.21 MPa, $P < 0.01$) bone.

Angle stable locking plates maintained the compression preliminarily applied by a reduction clamp. Two 6.5 mm cancellous lag screws are especially suited for non-osteoporotic bone, whereas four 3.5 mm cortical screws exhibited comparable compression in both bone qualities.

Abbreviations: ANOVA = One-way Analysis of Variance, LCP = Locking Compression Plate, MPa = MegaPascal, TAN = Titanium Aluminum Niobium.

INTRODUCTION

Proximal tibia fractures comprise about 1.2% of all fractures.[1] One of the most common fracture pattern is a simple lateral split (AO/OTA type 41-B1.1, Schatzker type I).[2,3] This type of fracture usually occurs in two different groups: Young patients after high-energy trauma or elderly osteopenic patients after low-energy injuries. In the latter, a depression component is often associated.[4] The main trauma mechanism in this fracture type is pure abduction force or valgus combined with axial load.[5] Soft tissue injury, bone quality, patient's age, redisplacement, and posttraumatic arthritis are important factors influencing the outcome of proximal tibia fractures.[2,4,6–11] During the last decades, the treatment shifted from predominantly conservative with unsatisfactory results to a more operative one. Most authors advocate reduction and internal fixation in case of an articular step of 2 to 3 mm and above, an instability of more than 5 to 10° in full extension[2,12,13] and to prevent tibia plateau widening during fracture consolidation.

In these injuries, a functional aftercare including early joint motion[13–15] is well established. Internal fixation techniques are required to endure rehabilitation. Koval et al[16] and Parker et al[17] published biomechanical studies supporting the use of solely two 6.5 mm cancellous screws in lateral split fractures. Current fixation techniques of lateral tibia plateau fractures include 6.5 mm cancellous lag screws, 3.5 or 4.5 mm cortical lag screws, both with optional antiglide plate or L and T-shaped angle stable locking compression plates (LCP). Some of these methods can be performed either in an open or percutaneous fashion.[18,19] To achieve interfragmentary compression with the use of a locking plate, an additional lag screw has to be applied before plate fixation or the plate has to be fixed and compressed to the reduced fracture by a reduction clamp prior to locking screw insertion.

The aim of this study was to investigate the interfragmentary compression of 3 different fixation techniques for lateral tibia plateau split fracture fixation, using 3.5 mm cortical lag screws, 6.5 mm cancellous lag screws, and 3.5 mm LCP proximal lateral tibia plate preliminary compressed by a reduction clamp. The interfragmentary compression was measured in

2 surrogate bone models, simulating osteoporotic and non-osteoporotic bone quality.

MATERIAL AND METHODS

Specimens and Study Groups

Thirty right adult synthetic human tibiae with cortical and cancellous bone structure (Synbone, Malans, Switzerland) were used in this study. Each specimen provided hard or soft cancellous bone to mimic non-osteoporotic and osteoporotic bone quality, respectively. It has been shown in previous studies, that synthetic human tibiae are a valid substitute for human bones.[20,21] The surrogate tibiae were randomly assigned into 6 groups in total, consisting of 3 groups with non-osteoporotic bone quality and 3 groups with osteoporotic bone quality. Each group comprised 5 specimens (n = 5). Three different fixation techniques were investigated using implants made of TiAl6N7 (TAN) alloy (Synthes GmbH, Solothurn Switzerland): Two 6.5 mm cancellous screws (length 60 mm, thread length 16 mm); four 3.5 mm cortex screws (length 65 mm) and right lateral 3.5 mm LCP proximal tibia plate (4 holes, length 81 mm, Synthes, Solothurn Switzerland), fixed proximally with four 3.5 mm self-tapping locking screws (length 56 mm) (Figure 1). All 3 fixation techniques were investigated in surrogate non-osteoporotic and osteoporotic bone.

Instrumentation and Testing

An-osteotomy on the lateral tibia plateau was set, representing a simple split fracture of the lateral tibia plateau (AO/OTA type 41-B1.1, Schatzker type I). The osteotomy was oriented in the sagittal plane orthogonal to the tibia plateau plane, 17 mm medial from the lateral edge of the tibia plateau, created by a 1 mm saw blade.

The drill holes were set according to the distance of the plate head locking holes of the 3.5 mm LCP proximal tibia plate to provide a standardized and comparable orientation of the holes between the groups. The LCP proximal tibia plate was placed on the lateral aspect of the tibia head with the locking-head screw holes located in the subcortical area of the tibia plateau. The proximal edge of the plate was oriented in parallel to the joint line so that the locking holes were located 7.5 mm below the tibia plateau surface. The four holes for 3.5 mm cortical lag screw instrumentation were drilled in the same position as the locking holes in the plate head with a Ø2.5 mm drill bit, oriented in parallel to the dorsal edge of the tibia plateau. The lateral fragment was overdrilled with a Ø3.5 mm drill bit to set a gliding hole for lag screw application. Due to a limited space between the screw heads, application of washers was not possible for this fixation technique. The two 6.5 mm cancellous screws were set at the position of the most anterior and posterior hole of the locking plate head and oriented in parallel to the dorsal edge of the tibia plateau. The holes were predrilled with a Ø3.5 mm drill bit. Each screw was equipped with a washer (Synthes GmbH, Solothurn, Switzerland). Prior to screw tightening, a pressure sensor film (Model 5033, TekScan Inc., South Boston, MA), protected by two rubber pads of 1 mm thickness on each side, was introduced in the osteotomy gap from the articular side to determine the amount of interfragmentary compression at the osteotomy gap at the level of the tibia plateau (Figure 2).

For instrumentation of the LCP, two Kirschner wires were used to preliminarily fix the plate in the position mentioned above and Ø2.8 mm drill holes were set via a Ø2.8 mm drill guide in the 4 plate head locking holes according to the manufacturer's guidelines. After removal of the Kirschner wires, the sensor film and the rubber pads were installed as mentioned above. The plate was fixed to the reduced fracture by a clamp with the sensor film in place and the interfragmentary compression effected by the clamp was registered. After instrumentation of the 4 locking screws at the plate head, the clamp was removed and the compression force at the fracture site was measured again.

Data Acquisition and Analysis

Pressure was recorded along the articular osteotomy gap and mean pressure of each sample was calculated. Statistical analysis was performed using SPSS software package (SPSS 20.0.0; SPSS, Chicago, IL). Normal distribution of the data within each study group was indicated by the Shapiro–Wilk Test. Significant differences between the study groups regarding mean pressure at the fracture site were tested statistically with one-way Analysis of Variance (ANOVA) and Bonferroni post hoc test. Significance level was set at $P = 0.05$.

Since no human material and no patient-related data were used, ethical approval was not necessary.

FIGURE 1. Instrumented specimens: Two 6.5 mm cancellous lag screws with washers (left), four 3.5 mm cortical lag screws (middle) and 3.5 mm LCP proximal lateral tibia plate (right).
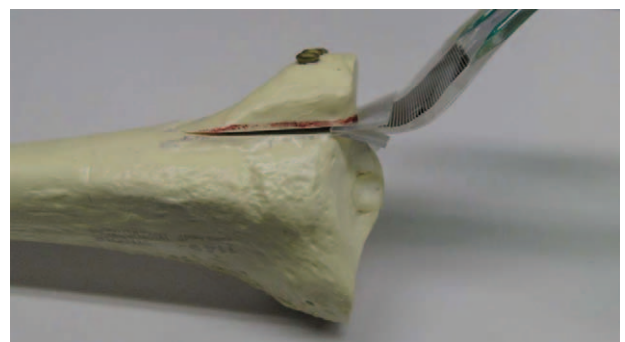
FIGURE 2. Test setup. Specimen instrumented with a pressure sensor film in the osteotomy gap and four 3.5 mm cortical lag screws. Two rubber pads of 1 mm thickness were applied at each side of the sensor for a better transmission of the pressure to the sensor film and smoothening of the pressure peaks due to minimal local mismatch at the osteotomy.
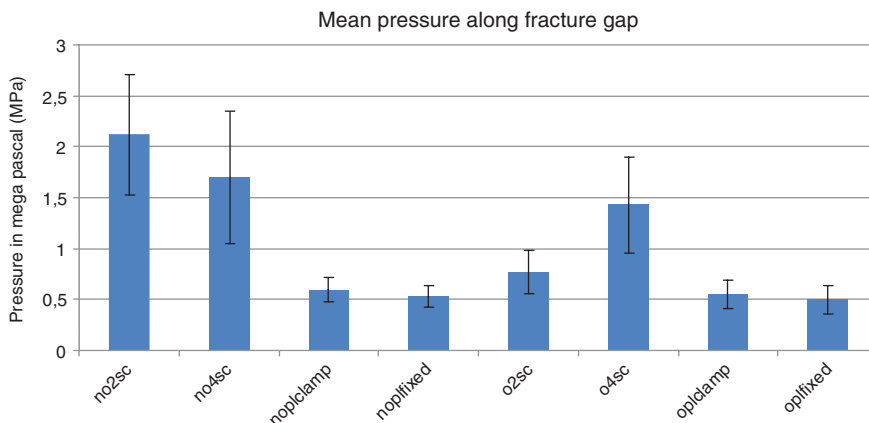
FIGURE 3. Mean interfragmentary compression of two 6.5 mm cancellous lag screws (2sc), four 3.5 mm cortical lag screws (4sc), and 3.5 mm LCP lateral proximal tibia locking plate (pl) investigated in non-osteoporotic (no) and osteoporotic (o) surrogate bone. The interfragmentary compression in the plate group was determined after preliminary fixation of the plate to the reduced fracture by a reduction clamp (clamp) and subsequent definite plate fixation and clamp removal (fixed). The columns and error bars indicate mean pressure (MPa) with standard deviation in each study group, consisting of 5 specimens (n = 5). Mean pressure values between the study groups fixed with two 6.5 mm cancellous screws in osteoporotic and non-osteoporotic bone were significantly different. Mean pressure values in all plate groups under clamping and after definite plate instrumentation and clamp removal were not significantly different. The mean pressure values between the groups with 4 cortical screw fixation in osteoporotic and non-osteoporotic bone were not significantly different.

RESULTS

Mean pressure values in each study group are shown in Figure 3. Both lag screw techniques, 2 cancellous screws (2.12 MPa SD ±0.59) and 4 cortical screws (1.69 MPa SD ± 0.65) exhibited a comparable interfragmentary compression in non-osteoporotic bone ($P = 1.00$). Interfragmentary compression in osteoporotic bone was not significantly different using 4 cortical lag screws 1.42 MPa (SD ± 0.46) or 2 cancellous screws 0.77 MPa (SD ± 0.21) ($P = 0.32$). Comparing the 4 cortical lag screw fixation in non-osteoporotic and osteoporotic bone, the amount of interfragmentary compression was similar in both groups ($P = 1.00$). Two cancellous screws exhibited a significantly higher compression in non-osteoporotic bone compared to osteoporotic bone ($P < 0.01$). A significantly lower interfragmentary compression was achieved when the plate was fixed by a reduction clamp in comparison to both lag screw techniques in non-osteoporotic bone ($P < 0.01$) and in comparison to 4 cortical lag screws in osteoporotic bone ($P = 0.03$). The locking plate, instrumented under compression was able to maintain the interfragmentary compression, applied during preliminary fixation by the reduction clamp in both, non-osteoporotic and osteoporotic bone. The mean pressure was 0.60 MPa (SD ± 0.11) under preliminary clamp fixation and 0.53 MPa (SD ± 0.10) after plate fixation ($P = 0.4$) in non-osteoporotic bone. In osteoporotic bone the mean pressure under preliminary clamp fixation was 0.55MPa (SD ± 0.14) and 0.50MPa (SD ± 0.14) after plate fixation ($P = 0.6$).

DISCUSSION

Lasting interfragmentary compression can be achieved by lag screw techniques and locking plates, preliminarily compressed by a reduction clamp. Interfragmentary compression with two 6.5 mm cancellous screws was in a comparable range to four 3.5 mm cortical screws. The choice between these 2 options would depend on the fracture pattern: For osteosynthesis of a simple split fracture of the lateral tibia plateau, two 6.5 mm cancellous screws would be sufficient. In split fractures with additional central depression fragment, four 3.5 mm cortical screws would be more appropriate as demonstrated by Karunakar et al,[22] who observed a significantly lower local depression stiffness in this fracture type, fixed with two 6.5 mm cancellous screws compared to four 3.5 mm cortical screws. An antiglide plate placed at the inferior edge of the fracture secures the fracture fragment from inferior dislocation.[22] The same effect can be achieved using a buttress plate.[22] Using an osteoporotic bone foam model with a split depression fracture, Patil et al[23] observed a significantly higher force required to produce a depression in the four 3.5 mm cortical screw construct than in the two 6.5 mm cancellous screw construct. In the non-osteoporotic bone foam model, difference in force required to produce a depression was not significant in-between the two constructs, indicating that the two cancellous screw technique would be better suited for non-osteoporotic bones. Comparing the two 6.5 mm cancellous screw fixation placed orthogonally to the fracture in a poster-olateral coronal shear fracture model of the tibia plateau to a laterally placed 3.5 mm LCP proximal tibia plate, a smaller displacement under axial load was observed in the plate group, although the plate was not ideally placed for this fracture type.[21] Best stability was obtained by a posteriorly placed buttress plate in this study.[21] Mueller et al[24] reported no significant difference between two dual plating constructs and a lateral fixed angle plate construct in terms of stiffness, maximum load to failure, and medial condylar displacement. Consistent with our results,

pullout force of subchondrally placed screws of 6.5 and 3.5 mm diameter, did not differ significantly in a human tibia model.[25]

Although locking plates function via the principle of angular stability, holding the tibia plateau comparable to a ceiling beam, preliminarily applied compression after proper reduction is advisable for sufficient fracture fixation. The lateral 3.5 mm proximal tibia locking plate construct maintained the compression preliminarily applied by the Weber clamp in non-osteoporotic and osteoporotic bone. Even though a lesser amount of compression was achieved by the Weber clamp compared to both screw constructs, persisting compression combined with good interdigitation of the fracture fragments would prevent loss of reduction.

This study has some limitations: It is a bench study. The ability of each construct to maintain the fracture reduction under physiologic motion of the knee joint was not evaluated. Construct stability after postoperative knee joint motion could not be judged on.

CONCLUSION

Two 6.5 mm cancellous screws should only be used in non-osteoporotic bone, since interfragmentary compression was significantly lower for these screws in osteoporotic bone. Four 3.5 mm cortical screws could be applied in both bone qualities, because interfragmentary compression was comparable in osteoporotic and non-osteoporotic bone.

The success of any internal fixation depends on the ability to maintain interfragmentary compression. Locked implants like the locking compression plate maintain the interfragmentary compression preliminarily applied by a reduction clamp.

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