Effective combination of bone substitute and screws in the jail technique: a biomechanical study of tibial depression fractures

Stefanie Doht · Teresa Lehnert · Sönke Frey ·
Kai Fehske · Hendrik Jansen · Torsten Blunk ·
Rainer Heribert Meffert

Received: 28 April 2012 / Accepted: 10 June 2012 / Published online: 13 July 2012
© Springer-Verlag 2012

Abstract

Purpose The aim of this study was to investigate a new drillable calcium phosphate cement (Norian drillable Synthes GmbH) as a bone substitute either alone or in combination with screws in the jail technique (Petersen et al. *Unfallchirurg* Mar 109(3):219–234, 2006; Petersen et al. *Unfallchirurg* Mar 109(3):235–244, 2006) with regard to the primary stability in lateral tibial depression fractures.

Methods Lateral depression fractures of the tibial plateau were created in a biomechanical fracture model. After reduction they were stabilised with bone substitute (group one), bone substitute with additional four screws in the jail technique (group two) or four screws only (group three). Displacement under cyclic loading, stiffness and maximum load in load-to-failure tests were determined.

Results The groups with the bone substitute showed a lower displacement of the depressed articular fragment under cyclical loading and a higher stiffness. The maximum load was higher for the groups with screws.

Conclusions Only the combination of bone substitute and screws prevented secondary loss of reduction and, at the same time, provided enough stability under maximum load.

Introduction

Due to the demographic change, the proportion of geriatric trauma patients is steadily increasing. In particular fractures of the lower extremity confront the surgeon with problems; despite a low bone quality due to osteoporosis, the osteosynthesis must provide very high stability. Fractures of the tibial plateau account for 10 % of all fractures in the elderly [1, 2]. Depression fractures, especially of the lateral tibial plateau, are often seen in this patient group associated with the metaphyseal loss of bone substance. After reduction of the depressed fracture fragment a metaphyseal defect remains. In patients with osteoporosis, iliac crest bone graft is unsatisfactory and artificial bone substitutes must be used to fill the defect. In addition, the fractures are stabilised with screws.

Previous biomechanical studies have proved the stability of calcium phosphate cement compared to autologous bone graft. The bone substitute provided an equivalent or even better stability of a large defect than conventional bone graft [3]. Furthermore after fracture healing over 18 months in an in-vivo study, a reduction of the secondary subsidence of the tibial plateau was shown for the calcium phosphate cement compared to autologous bone graft [4].

New drillable calcium phosphate cement is now available and allows placement of screws after filling the metaphyseal defect. Therefore, the aim of this study was to provide a biomechanical analysis of the new drillable bone substitute, alone and in combination with screws in the jail technique with regard to the primary stability in lateral tibial depression fractures. Under cyclical loading and in load-to-failure tests, respectively, the influence of bone substitute, screws,

S. Doht (✉) · T. Lehnert · S. Frey · K. Fehske · H. Jansen ·
T. Blunk · R. H. Meffert
Department of Trauma, Hand, Plastic and Reconstructive Surgery,
University Clinics of Wuerzburg,
Oberduerrbacher Straße 6,
97080 Wuerzburg, Germany
e-mail: doht_s@klinik.uni-wuerzburg.de

or their combination on displacement, stiffness, and maximum load were determined in order to provide information for a rational operative treatment.

Materials and methods

Specimen

Human cadaver bones from donors with a mean age of 85 were used. They were harvested from fresh-frozen cadavers and the bone mineral density was determined by quantitative computer tomography (pQCT; Stratec Inc., XCT2000, Pforzheim, Germany) [5–7]. All specimens clearly showed a loss of the metaphyseal spongiosa as in osteoporotic bones. Additionally, conventional X-rays were taken to ensure normal bone geometry. For the biomechanical tests, the tibiae were separated from the fibula and all soft tissues. Then they were cut at middiaphysis to a length of 20 cm measured from the tibial plateau. The diaphysis of the bones was embedded in bone cement (Palacos, Heraeus Kulzer) in five degree valgus angulation in a custom-made device [3].

Biomechanical test set-up

The embedded tibiae were fixed in the material testing machine and axial forces were simulated by a cylindrical indenter (Fig. 1) [8]. In a pretesting series, cyclic loading was applied for up to 10,000 cycles in order to determine the test set-up. A total of 3,000 cycles proved to be sufficient to demonstrate distinct differences between the experimental groups and were therefore applied in the following main test series. The forces were set within a range that is typical for a postoperative partial weight bearing model and that was also applied in other biomechanical studies on tibial plateau fractures [3].

For testing, the specimens were first loaded with 125 N and unloaded to 20 N for ten settling cycles. Then, 3,000 cycles were applied from 20 N to 250 N and in the end a load-to-failure test was performed. The displacement of the depressed articular fragment during cyclic loading was measured and in the load-to-failure tests, the stiffness and maximum load were determined.

Fracture generation

Reproducible tibial depression fractures were created in a fracture model. On the lateral tibial plateau, five predetermined breaking points were set by drilling five holes arranged in a 12 mm diameter circle. Then, an axial force was applied with an indenter at 500 mm/min. The depth of the depressed plateau fragment was fixed at 15 mm (measured from the tibial plateau). Thus, lateral tibial depression fractures were induced reproducibly and the fracture structure was examined for abnormalities with conventional X-rays (Fig. 2).

Experimental groups

The tibial depression fracture was reduced indirectly using a guiding K-wire and cannulated ram until the articular plane of the lateral tibial plateau was restored anatomically. Three different stabilisation techniques were compared. In the first group, a bone substitute, i.e., calcium phosphate cement (Norian Drillable, Fa. Synthes) was inserted to support the elevated depression fragment. A specific characteristic of this calcium phosphate cement is that it can be drilled after insertion. A combination of bone substitute and additionally four crossing screws in the jail technique [9, 10] was used in the second group. The screws were inserted after ten minutes of hardening of the bone cement. The third group represented an unfilled defect, only fixed by four crossing

Fig. 1 Biomechanical test set-up and pre-drilling for reproducible depression fragments. **A** For biomechanical testing, the tibial bones were embedded at the diaphysis. Axial forces were simulated by force application on the lateral tibial plateau by an indenter. **B** and **C** By drilling five holes with a diameter of 1.9 mm in a circle of 12 mm, a highly reproducible depression fragment was created

Fig. 2 The lateral tibial plateau fractures with an articular depression fragment were examined for any additional fracture gaps macroscopically (*upper*) and radiologically (*lower*). In the X-rays, the depressed fragment with the articular corticalis localized within the metaphysis can be clearly observed

screws without bone substitute (Fig. 3). The reduction and stabilisation of all tibial depression fractures were done by

the same trained orthopaedic trauma surgeon. For hardening of the calcium phosphate cement, all specimens of all

Fig. 3 Groups of tibial plateau fracture stabilisation. **A** In group one, the tibial depression fracture was stabilised after reduction only by filling up the defect with bone substitute (drillable calcium phosphate cement). **B** In group two, for stabilisation, the defect was filled with

bone substitute and additionally four screws in the jail technique were inserted. **C** In group three, only four screws in the jail technique were used to stabilise the lateral tibial plateau fractures

groups were put in an incubator for 24 hours at a temperature of 37 °C. Seven specimens were investigated in groups one and two, and five specimens in group three.

Statistical analysis

All results underwent statistical analysis for normal distribution with the Kolmogorow-Smirnow test. Additionally, the Gauss distribution was controlled for each group. Data was evaluated statistically by analysis of variance (ANOVA).

Results

Cyclical loading

During cyclical loading, the displacement of the depression fragment was measured. Groups one and two, i.e., both with bone substitute, exhibited a distinctly lower displacement than group three without calcium phosphate cement (Fig. 4A). The difference was even more evident when the ten cycles used for settling were taken into account (Fig. 4B).

Fig. 4 Displacement of the depression fragment under cyclic loading with ten settling cycles (125 N) and 3,000 measuring cycles (250 N) for the three groups. Statistical significance is indicated by *. For the groups with bone substitute (drillable calcium phosphate cement), the displacement was lower than for the group without bone substitute. **A** Displacement after the 3,000 measuring cycles only. **B** Displacement after the ten settling cycles and 3,000 measuring cycles

Load-to-failure tests

In the load-to-failure tests, the maximum load was higher for the two groups with screws (groups two and three) compared to the group with bone substitute only (Fig. 5A). The two groups with bone substitute had a higher stiffness compared to the group stabilised with screws only (Fig. 5B).

Discussion

In the operative treatment of tibial plateau depression fractures, specifically in elderly patients with osteoporotic bones, the problem of a secondary loss of reduction of the depressed fragment is often observed [11]. Because of the metaphyseal loss of bone substance a metaphyseal defect remains after reduction of the articular fragment. Whereas in younger patients iliac crest bone is often used, in patients with osteoporosis this is unsatisfactory due to fatty degeneration and, thus, artificial bone substitutes are commonly applied instead [12].

Newly available drillable calcium phosphate bone cement widens the possibilities of bone substitutes resisting axial loading and could therefore possibly improve operative stabilisation of tibial plateau fractures. It is the first bone

Fig. 5 At the end of the biomechanical tests, load-to-failure tests were performed. Statistical significance is indicated by *. Maximum load (**A**) and stiffness (**B**) of the three groups are shown

substitute which can be drilled for screw placement after application resulting in a more complete filling of the defect, as the injection is not impaired by the screws.

Biomechanical investigations can be performed in order to differentiate between the effects of the two components, i.e., bone substitute and screws, on the displacement under cyclic loading, stiffness, and maximum load in load-to-failure tests. At the same time, such investigations may provide recommendations for operative treatment. For biomechanical testing human cadaver bones are often used. Similar to previous reports [8, 13, 14], in this study osteoporotic bones from old human donors were chosen. Bone quality was confirmed by measurement of the bone mineral density. In the first part of the biomechanical test set-up, cyclical loading was applied in order to simulate knee movements on partial weight bearing commonly used postoperatively. Clearly, application of bone substitute (with or without screws) led to lower displacement under cyclical loading, as compared to the treatment with screws only. In full agreement with our data, a study investigating the same fracture type found no significant displacement when applying a bone substitute with or without screws. However, the importance of the bone substitute could not be elucidated as a treatment with screws only was not performed [3].

Often, elderly patients cannot manage a partial weight bearing resulting in a maximum load of the lower extremity. Thus, after cyclical loading load-to-failure tests were performed. Here, for the groups with bone substitute, a higher stiffness was found. Basically this means that in the phase of the elastic deformation, for the groups with bone substitute the deformation under loads was lower than for the group with screws only. This result corresponds to the lower displacement under cyclical loading of these groups (with bone substitute). In contrast, under extreme loading, the application of screws (with or without bone substitute) proved to be crucial, leading to distinctly higher maximum loads than the treatment with bone substitute only. Interestingly, in the previous study using the same fracture type, no difference was observed with regard to maximum load when applying a bone substitute with or without screws [3]. A possible reason for the beneficial effect of screws in our study may be the use of four screws in the jail technique, as compared to two screws only in the previous study [3]. Future investigations may include the evaluation of the effects of different numbers and positioning of the screws applied.

In conclusion drillable calcium phosphate cement as bone substitute reduces the displacement of the depression fracture fragment under conditions simulating partial weight bearing, and screws in the technique increase the maximum load tolerated. Thus, in the operative treatment of tibial

depression fractures for primary stability a combination of bone substitute and screws appears favourable.

Acknowledgement The authors would like to thank Dr. Maria Moritz and Prof. Dr. Peter Schneider for supporting the measurement of the bone mineral density. Furthermore, they would like to thank Jürgen Schmid from Synthes GmbH for providing the drillable calcium phosphate cement, Norian drillable. The authors would also like to thank Gabi Walter from Heraeus Medical GmbH for supplying the bone cement, Palacos.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Wiss, DA (2006) Master techniques in orthopaedic surgery fractures. Lippincott Williams & Wilking
2. Kösters C, Schliemann B, Raschke MJ (2011) Tibial head fractures in the elderly. *Unfallchirurg* 114(3):251–260
3. Yetkinler DN, McClellan RT, Reindel ES, Carter D, Poser RD (2001) Biomechanical comparison of conventional open reduction and internal fixation versus calcium phosphate cement fixation of a central depressed tibial plateau fracture. *J Orthop Trauma* 15(3):197–206
4. Welch RD, Zhang H, Bronson DG (2003) Experimental tibial plateau fractures augmented with calcium phosphate cement or autologous bone graft. *J Bone Joint Surg Am* 85-A(2):222–231
5. Zahn RK, Frey S, Jakubietz RG, Jakubietz MG, Doht S, Schneider P, Waschke J, Meffert RH (2012) A contoured locking plate for distal fibular fractures in osteoporotic bone: A biomechanical cadaver study. *Injury* 43(6):718–725
6. Braun MJ, Meta MD, Schneider P, Reiners C (1998) Clinical evaluation of a high-resolution new peripheral quantitative computerized tomography (pQCT) scanner for the bone densitometry at the lower limbs. *Phys Med Biol* 43(8):2279–2294
7. Guglielmi G, Schneider P, Lang TF, Giannatempo GM, Cammisa M, Genant HK (1997) Quantitative computed tomography at the axial and peripheral skeleton. *Eur Radiol* 7(Suppl 2):S32–S42
8. Karunakar MA, Egol KA, Peindl R, Harrow ME, Bosse MJ, Kellam JF (2002) Split depression tibial plateau fractures: a biomechanical study. *J Orthop Trauma* 16(3):172–177
9. Petersen W, Zantop T, Raschke M (2006) Fracture of the tibial head. *Unfallchirurg* Mar 109(3):219–234
10. Petersen W, Zantop T, Raschke M (2006) Tibial head fracture open reposition and osteosynthesis-arthroscopic reposition and osteosynthesis (ARIF). *Unfallchirurg* Mar 109(3):235–244
11. Wirth CJ, Mutschler W, Bischoff HP, Püschmann H, Neu J (2010) *Komplikationen in Orthopaedie und Unfallchirurgie*. Thieme Verlag
12. Raschke M, Stange R (2009) *Alterstraumatologie*, 1st ed. Urban & Fischer
13. McDonald E, Chu T, Tufaga M, Marmor M, Singh R, Yetkinler D, Matityahu A, Buckley JM, McClellan RT (2011) Tibial plateau fracture repairs augmented with calcium phosphate cement have higher in situ fatigue strength than those with autograft. *J Orthop Trauma* 25(2):90–95
14. Ratcliff JR, Werner FW, Green JK, Harley BJ (2007) Medial buttress versus lateral locked plating in a cadaver medial tibial plateau fracture model. *J Orthop Trauma* 21(7):444–448