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Original Article

Periprosthetic fracture fixation in Vancouver B1 femoral shaft fractures: A biomechanical study comparing two plate systems

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ABSTRACT

Introduction: Periprosthetic fractures of the femur are an increasing problem in today's trauma and orthopaedic surgery. Owing to the hip stem, implant anchorage is very difficult in the proximal femur. This study compares two plate systems regarding their biomechanical properties and the handling in periprosthetic fracture fixation of the proximal femur.
Materials and methods: Using eight pairs of fresh, frozen human proximal femora the Locking Compression Plate/ Locking Attachment Plate construct (LCP/LAP) (group I, DePuy Synthes) was compared to the new LOQTEQ® periprosthetic distal lateral femur plate (group II, AAP Implantate AG). After implantation of press fit femoral hip stems a Vancouver B1 fracture model was used. Biomechanical testing was performed by cyclic axial loading with a constant increment of 0.1 N/cycle starting from 750 N axial loading. Every 250 cycles an a.p. x-ray was done to evaluate failure.
Results: The Group II showed significant higher axial stiffness (+42%) compared with Group I. In addition, Group II withstood significantly more load-cycles until failure (20%). The mode of catastrophic failure was plate breakage in Group II, whereas, in Group I, all plates showed an early bending followed by plate breakage.
Discussion and conclusion: Both plate systems enable screw placement around hip stems. The hinge plate showed superior biomechanical results compared with the locking compression plate/locking attachment plate construct. Furthermore, the hinge plate offers variable hinges and variable angel locking making bicortical screw placement around hip stems more comfortable and safe.
The translational potential of this article: The results of this study can be directly transferred to patient care. With the innovative hinge plate, the surgeon has a biomechanically superior implant, which also offers improved options for screw placement compared to a standard locking plate.

Introduction

Worldwide and especially in Germany, the number of total hip arthroplasties (THAs) increases every year. In 2006 approximately 199,000 THAs were performed in Germany; in 2013, 210,000 of these operations were performed [1]. This corresponds to an increase of 5.5% in only seven years. In addition, life expectancy and activity level among the aged people are on the rise. Thus, the number of periprosthetic proximal femur fractures is growing [2–4].

Regarding fracture type, at least 30% of periprosthetic femoral fractures can be classified as Vancouver B1 with the fracture at the tip of the femoral stem and a stable femoral component. Thus, these fractures are subjected to open reduction and internal fixation using modern locking plates [5–7]. However, implant placement is difficult owing to the

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prosthesis stem, cement used for stem fixation, and the local bone loss. Therefore, the implant requirements differ substantially from a fractured femur without THA. Special implants and techniques have been developed in recent years to ensure periprosthetic implant anchorage. One of the first devices introduced was the locking attachment plate (LAP) (DePuy Synthes, Solothurn, Switzerland), which can be mounted on any locking hole of a 4.5 mm locking compression plate (LCP) (DePuy Synthes, Solothurn, Switzerland). The additional 3.5 mm locking screws run more or less transverse and thus can be placed around the femoral stem. A newly developed plate using a hinge mechanism for periprosthetic screw placement allows variable angularity and easy hinge adjustment. In addition, no screw hole is blocked by the hinge (AAP Implantate AG, Berlin, Germany).

The purpose of this study was to investigate the biomechanical characteristics of this newly developed plate and hinge construct in comparison to the standard LCP with LAP for the treatment of periprosthetic fractures in a Vancouver B1 fracture model. In addition, the screw placement in the hinge was compared with the LAP regarding intraoperative handling.

Materials and Methods

Specimens

For this study, eight pairs of fresh frozen human proximal femora were treated and tested in two matched pair groups. Before testing, quantitative computer tomography scans were performed, and the bone mineral density (BMD) was determined in the region of interest, represented by a 10 mm diameter sphere in the femoral head (cancellous bone). For the distal fracture part, 4th generation composite medium femora (Sawbones Europe, Malmö, Sweden) were used (Figure 1). Eight specimens were tested per group.

Implants

Zimmer cementless standard straight stems (Alloclassic® Zweymüller® Schaft SL, Zimmer GmbH, Switzerland) were implanted following the manufacturer's guidelines and using the appropriate material. X-ray images were taken to ensure appropriate fitting of the stem.

In Group I, the LAP in combination with a 13-hole 4.5/5.0 (length 316 mm) distal femur LCP (DePuy Synthes, Solothurn, Switzerland) was used. The LAP was attached in the third hole from proximal and was fixed using four bicortical 3.5-mm self-tapping screws. The LCP was fixed proximally with two monocortical periprosthetic 5 mm self-tapping screws (hole 1 and 4 from proximal). Distally, the LCP was fixed using three screws with nuts (Figure 1).

In Group II, a 13-hole (length 314 mm) periprosthetic distal femur plate (AAP Implantate AG, Berlin, Germany) was used. Two hinges were mounted between the 2nd and 3rd hole from proximal. For in situ fixation, a special clamp is available. The hinges were adjusted in situ to the bone surface to provide an optimal trajectory for the screw to encompass the stem. Then the hinges were fixed with the clamping screw. The construct was then fixed with four bicortical 3.5-mm head locking screws in the hinges using the multidirectional drill sleeve. In addition, two monocortical 5-mm locking screws were placed in the holes 1 and 4 from proximal. The distal locking of the plate was similar to that in Group one (Figure 2).

After instrumentation, two 1.5-mm Kirschner wires have been placed in the specimen (one in the distal part of the proximal fragment and one in the proximal part of the distal fragment) for cyclic x-ray evaluation.

Instrumentation was performed by two senior orthopaedic surgeons. After the instrumentation, feedback was gathered about the advantages and disadvantages of handling the two osteosyntheses. Both surgeons were interviewed separately.

Fracture model

In this study, a Vancouver B1 fracture was simulated by an osteotomy. After plate fixation and plain x-ray control, we performed an osteotomy located 5-mm distal to the tip of the stem tip with a horizontal cut proximally and a 45° cut distally (Figure 1).

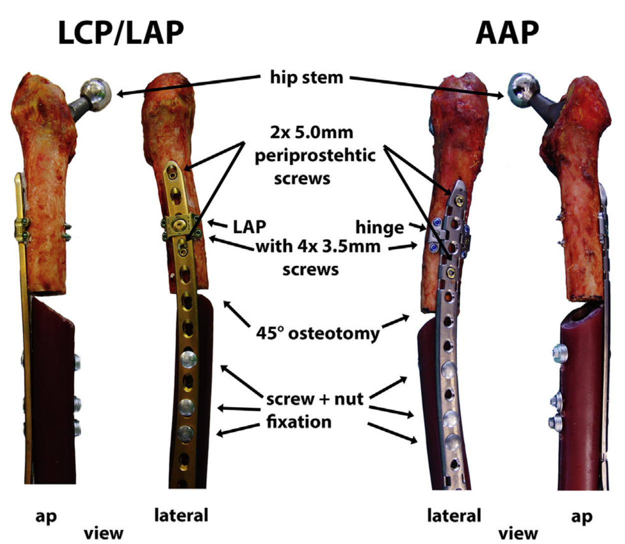

Figure 1. Implant configuration used for this study with the human bone proximally and the composite bone distally. The configuration for Group I shown left and for Group II shown right in anterior–posterior (AP) and lateral view. All specimens were fixed distally with screws and nuts. Proximally four 3.5-mm locking screws were used either with the LAP or the hinge. In addition, two 5.0-mm short locking screws were used in the first and fourth hole from proximal. The pictures also show the 45° osteotomy. LAP, locking attachment plate.

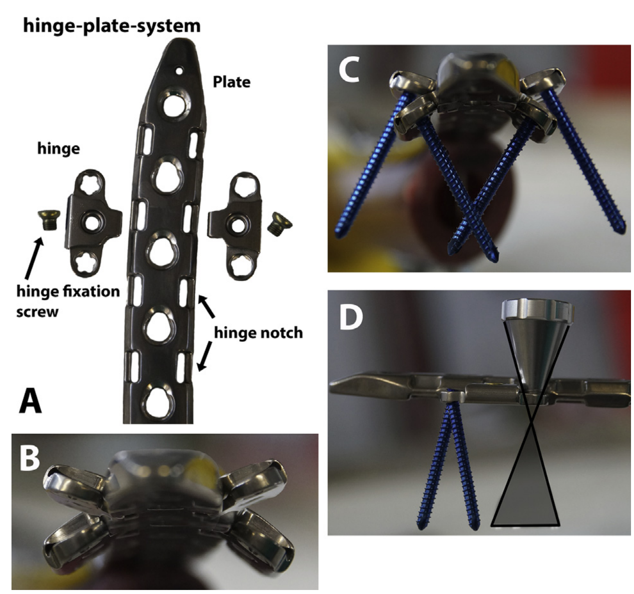

Figure 2. Implant system for periprosthetic fracture fixation using the hinge plate. (A) The components used in this study (plate, two hinges with hinge fixation screws). (B) Variability of the hinge, the hinge can be fixed in any position between these two extremes. Thus, the hinge allows an upward bending of about 20° and a downward bending of about 30°. (C) Possible screw angulation in medial/lateral direction using the hinge and the variable angle locking. (D) Variable angle locking upwards/downwards allows a screw angulations of about 20° in any direction.

Biomechanical testing

Testing was performed using an established set-up for fractures of the femur published earlier [8]. The specimens were placed inclined laterally at 7 ° under the machine actuator and were anatomically loaded with load applied over the femoral head of the prosthesis stem [9]. The head was placed vertically constrained in the machine actuator axis using a preshaped mould. The distal part of the femur was also placed in a custom-made mould (Technovit 4000, Heraeus, Hanau, Germany); in addition, a tilting table was used distally, allowing mediolateral pivoting (Figure 3). Testing was conducted using a servo hydraulic testing machine (Instron 8874, Pfungstadt, Germany). Cyclic axial loading was performed with a sinusoidal loading curve at a frequency of 1 Hz until failure. Loading started using a peak load of 750 N with an increment of 0.1 N/cycle. Base load was kept constant at 100 N.

Data acquisition and evaluation

Time, number of cycles, axial load and displacement were recorded using the machine transducers with a frequency of 64 Hz. The axial stiffness was calculated from the load–displacement curves of cycles 10 to 19. Therefore, minimal and maximal force, as well as displacement values have been used. For further evaluation, the mean value was used. Every 250 cycles, an x-ray in anterior–posterior view, including a reference sphere for scaling, was taken at the base load of 100 N. X-ray evaluation was performed using a custom-made software routine (Matlab 7.9 R2009b, Image processing Toolbox, The MathWorks GmbH, Ismaning, Germany). The number of cycles until 5° varus collapse compared with the initial x-ray was identified for all specimens and defined as number of cycles to failure [8]. Specimens were tested until catastrophic implant or construct failure.

After testing normal distribution of the data (Shapiro–Wilk test), the Wilcoxon signed-rank test was carried out to identify differences between study groups regarding axial stiffness and cycles to failure. The software package SPSS 24.0 (IBMN, IBM SPSS Statistics, Version 24.0, New York, US) was used for all statistical evaluations. The level of significance was set to alpha = 0.05.

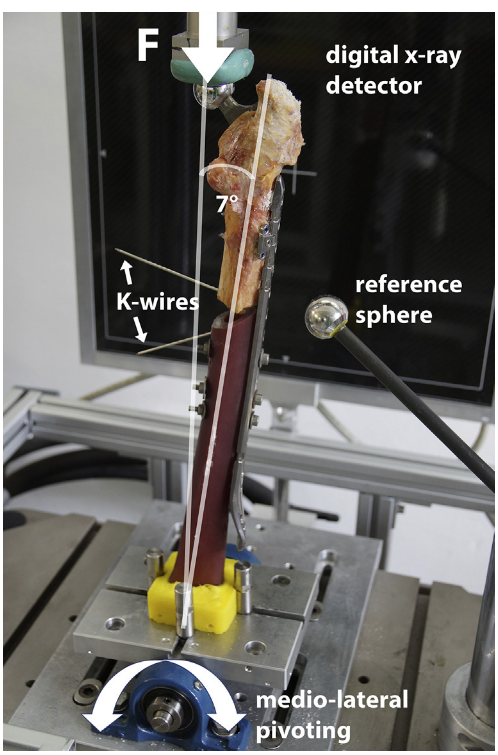

Figure 3. Test set-up with the specimen fixed on a tilting table distally. Proximally, the specimen is attached to the transducer with a custom-made mould, allowing free movement of the femoral head. The K-wires were used for x-ray evaluation (digital detector behind the specimen, x-ray unit in front of the specimen (not to see). K-wires, Kirschner wires.

Ethical approval

The human femora were obtained from a local anatomical institute. They were used in this examination under permission of the „Gesetz über das Leichen-, Bestattungs-und Friedhofswesen (Bestattungsgesetz) des Landes Schleswig-Holstein vom 04.02.2005, Abschnitt II, § 9 (Leichenöffnung, anatomisch)“. In this case, it is allowed to dissect the bodies of the donators (Körperspender/in) for scientific and/or educational purposes. An additional ethical approval is not necessary.

Results

Bone mineral density

The mean BMD was 184.2 mgHA/cm^3 [standard deviation (SD) ± 35.4] in Group I and 187.3 mgHA/cm^3 (SD ± 50.6) in Group II. There was no significant difference regarding BMD (p = 0.401). The human specimens represent osteopenic (50%) and normal (50%) bone densities following the categorisation of Choi et al. [10] for the spine. We found no correlation between the BMD and the stiffness or the cycles at failure.

Axial stiffness

The mean axial stiffness in Group II was 253.9 N/mm (SD ± 46.8) and 145.6 N/mm (SD ± 27.1) in the Group I (Figure 4). Group I showed only 58% of the stiffness of the Group II. This difference was statistically significant (p = 0.012).

Cycles to failure

Group II withstood statistically significant more cycles until failure (20%) compared with Group I (p = 0.025). The mean number of cycles to failure was 6969 cycles (SD ± 1455) in Group II and 5594 cycles (SD ± 1571) for Group I (Figure 5). This corresponds to a load at failure of 1447 N (SD ± 145) in Group II and 1309 N (SD ± 157) in Group I.

Catastrophic failure

The mode of catastrophic failure was plate breakage in Group II. In Group I, all plates showed an early bending followed by plate breakage, only one specimen showed bony failure.

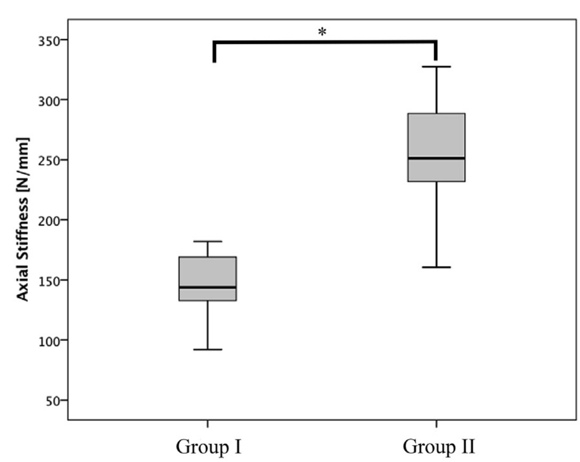

Figure 4. Box–Plot diagram of the axial stiffness in N/mm for both groups (* significant difference).

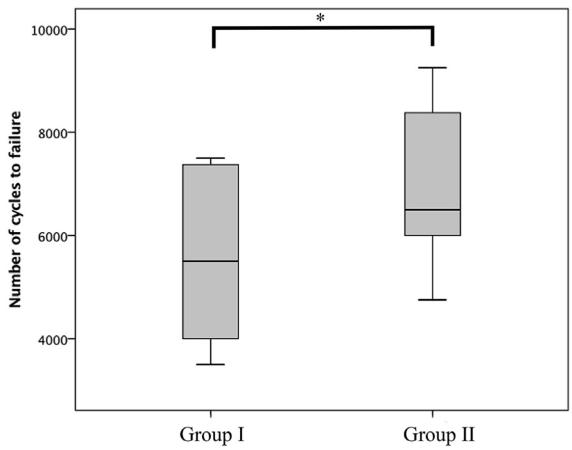

Figure 5. Box–Plot diagram of the number of cycles to failure of both groups (* significant difference).

Discussion

The treatment of periprosthetic fractures is an increasing problem in modern orthopaedic and trauma surgery. Especially, sufficient plate anchorage near a stable stem remains a challenge.

The present study compared a recently developed variable angle hinge plate for the stabilisation of periprosthetic femur fractures with the standard locking plate. In our biomechanical investigation, the new hinge plate showed superior behaviour regarding axial stiffness and number of cycles to failure compared with the standard group. More precisely, the hinge plates showed a 42% higher axial stiffness and resisted 20% more loading cycles until construct failure. The catastrophic failure mode was plate breakage in the hinge constructs and early plate bending followed by breakage in Group I.

The handling feedback showed that the modular structure of the hinge and the variable angle orientation of the hinge enables a safe in situ arrangement. Another difference is the variable angle fixation of the screw holes in the hinge. Both prevents in situ bending, which must be carried out to adapt the LAP. All these developments give the surgeon more flexibility during the operation for an optimal implant placement.

Fractures at the tip of the hip stem (Vancouver type B1) account for approximately one-third of periprosthetic proximal femur fractures [11]. These fractures occur owing to stress risers at the tip of the stem [12]. The LAP, which is attached to the LCP, (DePuy Synthes, Solothurn, Switzerland) was the first implant allowing bicortical screw placement around hip stems. Meanwhile, there are other implants available, addressing the challenge of screw placement around implants (e.g. noncontact-bridging plate, Zimmer Biomet, Freiburg, Germany). Several biomechanical studies showed the benefit of bicortical screw fixation compared with monocortical screws or stand-alone cerclages, in periprosthetic fracture fixation [13–18]. In contrast, Gordon et al. [19] showed a biomechanical benefit of a special cerclage construct in comparison with a locked plate in Vancouver type B1 fractures with a short stem. This is owing to the different working length of the both constructs, the plate was locked proximal and far distal only, whereas the cerclage construct consists of two stabilisers and four cerclage bands at the level of the spiral fracture. The controversial discussion of biomechanical results of periprosthetic femoral fracture fixation are addressed in a recent review by Wang et al. [20] In their analysis, they identified several issues that make direct comparison of the results impossible: different specimens used, varying fracture models, as well as nonstandardised test protocols. They stated that the development of an optimised treatment strategy would require a standardised test set-up and protocol [20].

Sufficient fracture fixation with a stable implant anchorage and thus establishing a biomechanical optimised environment represents the most crucial step to enhance healing of these fractures. Buttaro et al. [21] found hardware failure in six of fourteen patients treated with a lateral locking plate in Vancouver B1 periprosthetic fractures. To address these high-risk fractures, we used a defect fracture model to simulate an unstable situation without medial bone support as a worst-case scenario. It is known that these fractures are complex to treat and need enhanced stability, especially because obese patients are suffering from these injuries. In these cases, revision of the hip stem into a long stem construct [19] or a fixation using a double-plate construct should be considered in preoperative planning [22]. Our group was able to show that double plating is a reliable option in the treatment of complex periprosthetic fractures to enhance stability [23]. A recent investigation of Kammerlander et al. [24] shows that patients older than the age of 75 years treated for hip fracture are unable to maintain a partial weight-bearing. Sixty-nine percent of the patients exceeded the prescribed partial weight-bearing by more than twofold. Therefore, the goal of treating periprosthetic fractures must be immediate full load-bearing. The osteosynthesis must therefore carry 2 to 2.4 times the body weight when walking in the plains [9,25]. The implants investigated failed in our worst-case scenario with a progressive load increase at approx. 1400 N, which can be regarded as adequate. The difference in stiffness is more important, here the hinge plate has significant biomechanical advantages because it is more resistant to deformation owing to axial loading.

This study also has limitations; we used artificial femora simulating young and healthy bone conditions for the distal part. However, referring to the results of our previous study using human distal femora, we found no failures in this region [8]. Furthermore, it must be noted that the bone density was measured in the cancellous proximal portion and that the implant was anchored in the diaphyseal part. This could also be a reason in the lack of correlation between BMD and stiffness and cycles to failure. We included this information in the manuscript. Another limitation is the small sample size. This biomechanical study has also the limitation of applying pure axial loading without simulation of bending or torsional moments. Axial loading is the major physiologic loading condition; therefore, we decided to test under axial loading until failure.

Conclusion

The new developed hinge plate showed superior biomechanical results (axial stiffness and cycles to failure) compared with the standard LCP in combination with the LAP. In addition, the handling test showed a more comfortable implant fixation around the hip stem in periprosthetic fractures using the new variable angle hinge plate.

Funding

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Conflict of Interest

S.M. and C.K. are medical advisors for the aap Implants AG, Berlin. All other authors declare that they have no conflict of interest.

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