BIOMECHANICAL COMPARISON OF MEDIAL VERSUS LATERAL SIDED PLATING IN FEMORAL FRACTURES

ABSTRACT

Objective: The aim of the present study was to determine whether the side of application of the plate itself affects the mechanical stability of the fixation. The specific question addressed is whether or not a lateral or medial plate application is biomechanically better, for the treatment of distal diaphysis fractures of the femur. Methods: Stability and stiffness of medial sided plating relative to the conventional lateral sided plating in distal diaphysis of the femur were measured by analyzing axial loading forces leading to implant failure. Sixty synthetic femurs were tested in physiological bending, to calculate the yield and ultimate load to displacement following fixation of distal diaphysis fractures of the femur by either medial or lateral sided plating. Axial loading was applied to samples using a uniaxial testing machine. Results: There was more implant deformation in the lateral sided plating group – a difference with statistical significance. Conclusion: Medial sided plating was found to be as stiff as lateral plating. Medial plating may be a reasonable treatment option that can be used safely in selected cases. Level of Evidence I, Therapeutic Studies Investigating the Results of Treatment

Keywords: Femoral fractures. Bone plates. Stress, mechanical.

RESUMO

Objetivo: O objetivo deste estudo foi determinar se o lado de aplicação da placa em si afeta a estabilidade mecânica da fixação. A questão específica abordada é se a aplicação da placa lateral ou medial é melhor ou não em termos biomecânicos para o tratamento das fraturas da diáfise distal do fêmur. Métodos: A estabilidade e a rigidez da placa medial com relação à lateral, convencional na diáfise distal do fêmur, foram medidas pela análise das forças de carga axial que levam à falha do implante. Sessenta fêmures sintéticos foram testados em flexão fisiológica, para calcular a tolerância e a carga final para o deslocamento após a fixação das fraturas diafisárias distais do fêmur com placa medial ou lateral. A carga axial foi aplicada às amostras usando máquina de teste uniaxial. Resultados: Verificou-se maior deformação do implante no grupo de placa lateral – diferença com significância estatística. Conclusão: Constatou-se que a placa medial era tão rígida quanto a lateral. A placa medial pode ser uma opção de tratamento razoável e segura em casos selecionados. Nível de evidência I, Estudos terapêuticos - Investigação dos resultados do tratamento.

Descritores: Fraturas do fêmur. Placas ósseas. Estresse mecânico.
condyle, and 30 mm in diameter at the mid-diaphysis. The femur was divided into three parts, the proximal femur, diaphysis and distal femur. These parts were delineated as the proximal femur, ending at the distal part of the lesser trochanter, the middle – from this point to the distal metaphysis - and the distal femur, including the distal metaphysis and epiphysis. The diaphysis was further divided into proximal, mid-diaphysis and distal diaphysis. Fracture was created in 30 samples, at the junctional area between the diaphysis and distal metaphysis, 150 mm (36%) proximal from the distal joint surface. Fractures were also created in a further 30 samples, just inside the distal 1/3 portion of the diaphysis, 180 mm (43%) proximal from the distal joint surface. Thus, the models were categorized into four groups according to their osteotomy levels and fixation methods. Group 1 had an osteotomy 150 mm from the distal joint surface that was stabilized by medial sided plating (M-15, n=15); Group 2, 180 mm osteotomy level - medial sided plating (M-18, n=15); Group 3, 150 mm osteotomy level - lateral sided plating (L-15, n=15) and Group 4, had 180 mm osteotomy level - lateral side plating (L-18, n=15).

4.5 mm low-contoured broad locked dynamic compression plates with 8 holes were bent so that they fit the femoral curve during plate application. The plates were first provisionally applied to the lateral or medial surface of the femur, to dictate the screw position. Screw holes were prepared by drilling centrally through the oval holes of the plate. The plate was then placed either on the medial or lateral side, in neutral mode. After drilling the screw holes, 4.5 mm tapping was done to facilitate insertion of the screws. Eight cortices were screwed by 4.5 mm non-locking cortical screws on each side of the simulated fracture. Each model was then anatomically positioned on the uniaxial testing machine (Shimadzu Autograph AG-X, 2007, Kyoto, Japan) to accept load along their mechanical axes (Figure 1). To secure the distal femur, 8 pointed screws were inserted with a jig, into the femoral condyles. The femoral head was also stabilized by a bolt pin to the spherical connection adaptor (Figure 2). After calibrating the testing machine, which was repeated before each test, static tests were performed in compression mode of 10 kN load capacity (Shimadzu AG-X tensile test machine) according to the ASTM D695 testing standard, with a crosshead velocity of 5 mm/min. Fifteen synthetic femur specimens for each case were tested. The femurs were loaded progressively at a speed of 5 mm/min until the occurrence of a subsequent fracture. During the tests, load-displacement (deformation) curves (Figure 3) were recorded online using the Trapexium X software, and analyzed for the following structural bone properties: yield load (the force causing the first bone damage visible in the load displacement curve, the force at which the load displacement curve broke from linearity), ultimate load (the force causing bone fracture), displacement at yield (defined as the amount of bone deformation at the yield point), and displacement at fracture (deformation at the fracture point). According to the producer, the measurement error of the method was ±1% of the recorded value. Testing after each experimental period was performed on the same day, by the same operator. The level of the subsequent fracture was determined by the distance from the upper end of the greater trochanter to the fracture line on the lateral cortex. The first 60 mm from the upper end of the greater trochanter was defined as the proximal part of the femur. Thus, the following 258 mm femoral diaphysis was divided equally into proximal, mid and distal diaphyseal parts (Figure 4). Some models showed two fracture lines. According to the level and number of subsequent fracture, six groups of subsequent fractures were observed. Implant deformation was also evaluated for plastic deformation of the plate, by inspecting each model. The configuration of subsequent fracture was separated into four groups, based on the fracture line. A transverse fracture line originating from the
lateral cortex that had a reverse oblique pattern on the medial cortex was placed in Group A. Group B consisted of a transverse fractures originating from the lateral cortex that had an oblique pattern on the medial cortex; Group C consisted of transverse fractures originating from the medial cortex that had a reverse oblique pattern on the lateral cortex. Group D had a fracture line related to a screw entry point (Figure 5).

Statistical Methods
The normality of distribution of the parametric data was checked using the Kolmogorov-Smirnov test. The distribution was accepted as parametric if the results of the Kolmogorov-Smirnov test were not significant. The results for yield and ultimate load to displacement, and comparisons of the subsequent fracture levels between 15 and 18 cm osteotomy groups, were subjected to the t test. Multiple pairwise comparisons were performed by the Mann-Whitney U test. The number of subsequent fracture and implant deformations was analyzed by the Chi-Square test. Kruskal-Wallis one-way analysis of variance was used to measure statistical differences between modalities, and P values < 0.05 were considered significant.

RESULTS
Fifty-three synthetic composite femurs were available for the current study. Of the sixty models, two models with inexact osteotomy levels and five models with improper data acquisition during testing were excluded from the study.

Stability and Stiffness
In all the specimens, it was noted that there was a significant difference in yield displacement values between medial sided plating and the conventional lateral sided plating in the distal diaphysis of the femur specimens (Figure 6). The yield displacement values of M15, M18, L15 and 18 were 13.79 mm, 14.92 mm, 10.75 mm and 10.18 mm, respectively. The ultimate load values of M15, M18, L15 and 18 were 2826.59 N, 2556.61 N, 2456.41 N and 2326.1 N, respectively. The ultimate load values of the medial sided plating specimens at osteotomy levels 15 and 18 were higher than those of the lateral sided plating specimens (Table 1). Yield ($P_{15}=0.409$, $P_{18}=0.427$) and ultimate loads to displacement ($P_{15}=0.357$, $P_{18}=0.701$) values were not statistically significantly different between groups.

| Group | Number of specimen | Mean values | Standard deviation (+) | Standard deviation (+) |
|-------|--------------------|-------------|------------------------|------------------------|
| Yield load (N) | M15 | 2333.58 | 65 | 60 |
| | L15 | 1627.32 | 80 | 70 |
| | M18 | 1978.45 | 45 | 45 |
| | L18 | 1773.31 | 55 | 70 |
| Ultimate load (N) | M15 | 2826.59 | 85 | 90 |
| | L15 | 2456.41 | 70 | 75 |
| | M18 | 2556.61 | 80 | 65 |
| | L18 | 2326.1 | 60 | 55 |
| Displacement at fracture | M15 | 21.40 | 0.25 | 0.5 |
| | L15 | 24.80 | 0.3 | 0.6 |
| | M18 | 24.45 | 0.4 | 0.3 |
| | L18 | 60.2 | 0.9 | 0.85 |
Features of Subsequent Fracture

The samples demonstrated at least one subsequent fracture. Subsequent fractures mostly occurred at the proximal femoral region. A single subsequent fracture was seen in 41 samples (77.3%), while 12 samples (22.7%) showed two subsequent fractures. The second fracture was always at the first or eighth screw hole (91.7%). In the models with two subsequent fractures, the mean distance from the greater trochanter to the first fracture line was 164.6 mm, while the distance to the second fracture line was 289.5. Subsequent fractures seen in lateral sided plating (L15 and L-18) group demonstrated a predilection for the proximal femur. In the group of medial sided plating (M-15 and M-18), subsequent fractures mostly occurred in the mid-diaphyseal region (Table 2). There were no statistically significant differences in terms of the number and location of subsequent fractures.

For the subsequent fractures, a transverse fracture line originating from the lateral cortex that had a reverse oblique pattern on the medial cortex was the most frequent fracture configuration (58.5%). This was followed by a transverse fracture originating from lateral cortex with an oblique pattern on the medial cortex (13.2%); a transverse fracture originating from the medial cortex with a reverse oblique pattern on the lateral cortex (1.9%), and a fracture line at a screw hole (26.4%), respectively.

Implant Deformation

Of the 53 synthetic femurs, plastic deformation of the plate was seen in 21 samples (39.6%) after accomplishing axial loading. Surprisingly, these deformed implants, with the exception of one at the 18 cm osteotomy, all belonged to lateral sided plating group (Figure 7). The implant deformation rate was 71.4% in the L15 group, and 76.9% in the L18 group (Table 3). There was more implant deformation in lateral sided plating group, with statistical significance (P<0.0001).

Discussion

For fractures of the femoral diaphysis, from the lesser trochanter to 10 cm proximal to the knee joint, locked intramedullary nailing is the standard treatment modality. However, a plate osteosynthesis is particularly advantageous in certain situations. Patients with an excessively narrow intramedullary canal, polytrauma patients, and those with vascular injury associated with the femoral fractures constitute good indications for plate osteosynthesis. Orthopaedic surgeons tend to attach a lateral plate in almost all cases, due to the simplicity of the procedure, and better preservation of the muscles, nerves and vascularization. Medial sided femoral plating has been reported less frequently for the clinical management of lower limb deformities after correction osteotomies. Despite its occasional use, no clinical and mechanical information on this technique in the trauma setting has been reported. From a mechanical standpoint, our results showed no significant difference between lateral and medial sided plating by means of axial loading.

Superficial femoral vessels are injured with greater frequency than common femoral vessels in femoral fractures. In the setting of femoral fractures associated with vessel injury, the vessels should be explored via a posteromedial approach to the femur. A posterioromedial approach allows medial plating to the distal femur diaphyseal fracture. Therefore, fractures located in the distal diaphyseal region were used for the study.

The loading model described by Koch is used to investigate the biomechanical behavior of the femur models. Koch carried out a detailed analysis of a femur without muscles and soft tissues to show that the lateral side of the femur was in tension and the medial side was in compression. An analysis of Koch’s model by Fetto et al. revealed that the tensile load on the lateral side changed to a compressive load when the actions of the iliotibial band and vastus lateralis- gluteus complex were included. It was the contribution of Pauwels that introduced the tension band principle, which states that tensile forces on the convex side of a curved tube can be converted to compressive forces by applying an implant to the convex side of the tube. The tension band principle works when there is anatomic apposition of cortices on the opposite side of application of plate. It does not apply when there is comminution on the opposite cortex or in comminuted fractures. Ascenzi et al. had demonstrated the different collagen orientation within the femoral diaphysis as to the aspect of compression and tension. This principle was strongly propagated by AO. They offered the typical application of this principle by fixing a plate to the femur on the lateral side of the diaphysis. However, Cordey et al. speculated that the tension side of the femur, which is at the lateral aspect, particularly at the proximal part, turns around the anterior aspect distally. This means that when a plate is fixed to the lateral aspect of the distal femur, this plate may not be applied according to the tension

| Table 2. Subsequent fracture location. Lateral sided plating group has a predilection for the proximal femur. In the group of medial sided plating, subsequent fractures mostly occurred in the mid-diaphyseal region. |
| --- |
| Group | Sample size | Mean (mm) | Standard deviation | Fracture location |
| M15 | 13 | 211.69 | 111.70 | Mid-diaphyseal |
| L15 | 14 | 142.00 | 70.31 | Proximal diaphyseal |
| M18 | 13 | 169.69 | 70.35 | Mid-diaphyseal |
| L18 | 13 | 126.23 | 26.24 | Proximal diaphyseal |

| Table 3. Implant deformation according to the groups. All deformed implants, except for one belong to lateral sided plating group. |
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| Group | Sample size | Implant deformation | Implant deformation |
| M15 | 13 | 13 | 0 | 0% |
| L15 | 14 | 4 | 10 | 71.4% |
| M18 | 13 | 12 | 1 | 7.7% |
| L18 | 13 | 12 | 10 | 76.9% |

**Figure 7.** Implant deformation in the lateral sided plating group. B. Excellent plate contour in the medial sided plating group.
2. Krettek C, Schandelmaier P, Tscherne H. [Distal femoral fractures. Transarticular
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1. Winquist RA, Hansen ST Jr, Clawson DK. Closed intramedullary nailing of
human femur to remove these undesirable characteristics seen
in cadaveric specimens. Therefore, we used a thoroughly validated model
of the experiment was to represent bone quality by the synthetic
bone, and found that although the trends may be similar, screw
performance in the synthetic models was markedly different from
the medial plates were spared.
The variability of cadaveric specimens has always been a problem,
requiring enormous sample sizes to obtain satisfactorily significant
results. For this reason, synthetic femurs were chosen for this study.
Synthetic femurs have a standardized geometry, very small speci-
men to specimen variability, and material behavior approximating
that of bone.23 Schoenfeld et al. looked at the pullout strength and
load to failure properties of self-tapping cortical screws in synthetic
and cadaveric environments representing healthy and osteoporotic
bone, and found that although the trends may be similar, screw
performance in the synthetic models was markedly different from
that in cadavers.24 As distal diaphyseal femoral fractures are mostly
seen in young adults, due to high energy related traumas, part
of the experiment was to represent bone quality by the synthetic
composite femurs. Therefore, we used a thoroughly validated model
of human femur to remove these undesirable characteristics seen
in cadaveric specimens.

AUTHORS’ CONTRIBUTIONS: Each author made significant individual contributions to this manuscript. FA (0000-0003-4208-8162)* and BT (0000-0002-0184-8850)* were the main contributors in the drafting of the manuscript. FA and Mustafa Ozmen (0000-0001-6795-2856)* evaluated the data from the statistical analysis. FA, BT and TS (0000-0002-3276-5820)* performed the literature search and review of the manuscript, and contributed to the intellectual concept of the study. *ORCID (Open Researcher and Contributor ID).

REFERENCES
1. Winquist RA, Hansen ST Jr, Clawson DK. Closed intramedullary nailing of
femoral fractures. A report of five hundred and twenty cases. J Bone Joint Surg
Am. 1984;66(4):529-39.
2. Krettek C, Schandelmaier P, Tscherne H. [Distal femoral fractures. Transarticular
reconstruction, percutaneous plate osteosynthesis and retrograde nailing].
Unfallchirurg. 1996;99(1):2-10.
3. Kinast C, Bolhofner BR, Mast JW, Ganz R. Subtrochanteric fractures of the
femur. Results of treatment with the 95 degrees condylar blade-plate. Clin
Orthop Relat Res. 1989;(238):122-30.
4. Sink EL, Hedequist D, Morgan SJ, Hresko T. Results and technique of unstable
pediatric femoral fractures treated with submuscular bridge plating. J Pediatr
Orthop. 2006;26(2):177-81.
5. Kanlic EM, Anglen JO, Smith DG, Morgan SJ, Pesáñez RF. Advantages of Submuscular Bridge Plating for Complex Pediatric Femur Fractures. Clin Orthop Relat Res. 2004;426:44-51.

6. Apivatthakakul T, Chiewcharntanakit S. Minimally invasive plate osteosynthesis (MIPO) in the treatment of the femoral shaft fracture where intramedullary nailing is not indicated. Int Orthop. 2009;33(4):1119-26.

7. Sher MH. Principles in the management of arterial injuries associated with fracture/dislocations. Ann Surg. 1975;182(5):630-4.

8. Hommel GJ, Lobrano C, Ogden AL, Mukherjee DP, Anissian L, Marymont JV. A quantitative analysis of tension band plating of the femur diaphysis. Arch Orthop Trauma Surg. 2011;131(10):1325-30.

9. Cordey J, Borgeaud M, Frankie M, Harder Y, Martinet O. Loading model for the human femur taking the tension band effect of the ilio-tibial tract into account. Injury. 1999;30 Suppl 1:26-30.

10. ASTM D695-10. Standard Test Method for Compressive Properties of Rigid Plastics. ASTM. 2008;8:1-8.

11. Backstein D, Morag G, Hanna S, Safir O, Gross A. Long-term follow-up of distal femoral varus osteotomy of the knee. J Arthroplasty. 2007;22(4 Suppl 1):2-6.

12. Preston CF, Fulkerson EW, Meislin R, Di Cesare PE. Osteotomy about the knee: applications, techniques, and results. J Knee Surg. 2005;18(4):268-72.

13. Wang JW, Hsu CC. Distal femoral varus osteotomy for osteoarthritis of the knee. J Bone Joint Surg Am. 2005;87(1):127-33.

14. Aglietti P, Menchetti PP. Distal femoral varus osteotomy in the valgus osteoarthritic knee. Am J Knee Surg. 2000;13(2):89-95.

15. McDermott AG, Finkle JA, Farine I, Boynton DL, Macintosh DL, Gross A. Distal femoral varus osteotomy for valgus deformity of the knee. J Bone Joint Surg Am. 1988;70(1):110-6.

16. Asensio JA, Kuncir EJ, García-Núñez LM, Petrone P. Femoral vessel injuries: Analysis of factors predictive of outcomes. J Am Coll Surg. 2006;203(4):512-20.

17. Koch JC. The laws of bone architecture. Am J Anat. 1917;21(2):177.

18. Fetto J, Leali A, Moroz A. Evolution of the Koch model of the biomechanics of the hip: clinical perspective. J Orthop Sci. 2002;7(6):724-30.

19. Pauwels F. Die Bedeutung der Bauprinzipien des Stütz und Bewegungsapparates für die Beanspruchung der Röhrenknochen. Z Anat Entw Gesch. 1948;114:129-66.

20. Ascenzi A, Improta S, Portigliatti Barbos M, Carando S, Boydé A. Distribution of lamellae in human femoral shafts deformed by bending with inferences on mechanical properties. Bone. 1987;6(5):319-25.

21. Müller ME, Allgöwer M, Schneider R, Willenegger H. Manual of internal fixation. 2nd ed. Berlin: Springer, 1979.

22. Mooney V, Claudi B. Fractures of the shaft of the femur. In: Fractures. Rockwood, CA. Jr.; Green, DP., eds. Philadelphia, JB Lippincott; 1975. p.1093.

23. Papini M, Zdero R, Schenkel J, Zaizal P. The biomechanics of human femurs in axial and torsional loading: comparison of finite element analysis, human cadaveric femurs, and synthetic femurs. J Biomech Eng. 2007;129(1):12-9.

24. Schoenfeld AJ, Battula S, Sahai V, Vrabec GA, Corman S, Burton L, et al. Pullout strength and load to failure properties of self-tapping cortical screws in synthetic and cadaveric environments representative of healthy and osteoporotic bone. J Trauma. 2008;64(5):1302-7.