J Surg Med. 2021;5(5):540-543.
DOI: 10.28982/josam.925624

Research article

Journal of Surgery and Medicine
e-ISSN=2602-2079

Ideal plate screw configuration in femoral shaft fractures: 3D finite element analysis

Ünal Saraç [1], Sercan Karadeniz [2], Alaettin Özer [3]

[1] Bayburt state hospital Orthopedics and Traumatology, Bayburt, Turkey
[2] Bulancak state hospital Orthopedics and Traumatology, Giresun, Turkey
[3] Yozgat Bozok University Faculty of Engineering, Department of Mechanical, Yozgat, Turkey

ORCID ID of the author(s)
ÜS: 0000-0002-3045-8747
SK: 0000-0003-2802-4816
AÖ: 0000-0002-3499-1215

Corresponding Author
Ünal Saraç
Bayburt Devlet Hastanesi Ortopedi ve Travmatoloji Servisi, Bayburt, Turkey
E-mail: unsaracal@gmail.com

Ethics Committee Approval
The study protocol does not need ethics approval since it describes mechanical work.
All procedures in this study involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments.

Conflict of Interest
No conflict of interest was declared by the authors.

Financial Disclosure
The authors declared that this study has received no financial support.

Published
2021 May 15

Abstract

Background/Aim: Plate screw fixation is an important method in femoral shaft fractures. Although there are many studies on plate screw fixation, the ideal plate screw configuration has not yet been determined. In our study, we investigated the optimal plate-screw configuration in femoral shaft fractures using the 3D finite element analysis method.

Methods: A fracture model was created by removing the segment from the femur model obtained from 3D computed tomography scanning. Five different fixation models were designed using a 4.5 mm diameter steel locked femoral shaft plate and different screw configurations. Screws with double cortex locks of 4.5 mm in width were used in different configurations. To evaluate the effect of screw diameter, a 5.5 mm diameter screw with a double cortex lock was used in one model. Static linear analyses of these prepared Finite Element models were performed using Ansys Workbench 2020 R2 Finite Elements software.

Results: The maximum stresses on the plate at the fracture sites were 156 MPa at 200 N, and 546 MPa at 700 N in model 1, 274 MPa at 200 N, and 784 MPa at 700 N in Model 2, 274 MPa at 200 N, and 959 MPa at 700 N in Model 3, 389 MPa at 200 N, and 1118 MPa at 700 N in Model 4, and 200 N is 274 MPa, and 961 MPa at 700 N in Model 5.

Conclusion: The stress on the plate in the fracture area increases in parallel with the increase in screw diameter, plate length and plate working distance. Filling all screw holes does not alter the stress on the plate at the fracture line level.

Keywords: Femoral fractures, Plate fixation, Screw configuration, Finite element study

How to cite: Saraç Ü, Karadeniz S, Özer A. Ideal plate screw configuration in femoral shaft fractures: 3D finite element analysis. J Surg Med. 2021;5(5):540-543.

Introduction

Femoral shaft fractures are one of the most common fractures treated by orthopedists [1]. Its incidence is 0.01% [2]. It often occurs because of high-energy traumas, and is associated with polytrauma, open fractures, and multiple fractures [3]. In young patients, it is frequently caused by traffic accidents, falling from a height, gunshot injuries, and in elderly osteoporotic patients due to falling from same heights [1, 2]. Skeletal traction, plate and screw, intramedullary nail and external fixator are used in the treatment of femoral shaft fractures [4-6]. Intramedullary nailing is the gold standard in treatment [2, 3]. Plate fixation is recommended for fractures where intramedullary fixation is not suitable [7, 8].

In the follow-ups performed after fixation with the plate, the plate was broken at a rate of approximately 3.5% - 13.3% [9, 10]. It has been stated that most of the causes of failure of internal fixation materials are related to material fatigue [11]. There are many studies about the plate screw configuration [12-14]. However, there is still no consensus on the optimal plate screw configuration.

In this study, we aimed to investigate the best plate screw configuration in femoral shaft fractures using 3D finite element analysis method and contribute to the literature.

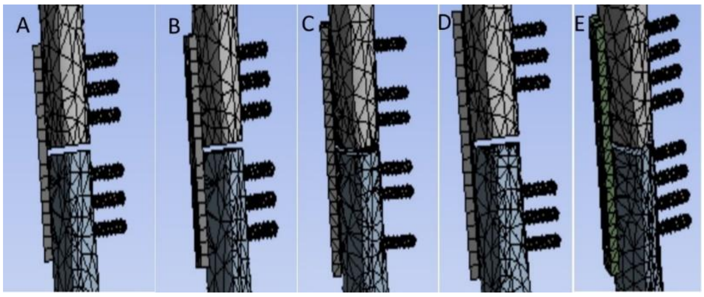
Materials and methods

Finite Element Method (FEM) is a mathematics-based calculation technique used in solving complex analytical structural problems. When creating a model resembling the human body, solid modeling programs such as Solid Works is utilized. This model is obtained from real CT scans using real computed tomography (CT) images. Modified solid models are produced in a problem-based solid modeling program, then transferred to a Finite Element Analysis software such as Ansys Workbench, a useful tool specifically for engineers [15].

In this study, 3-dimensional (3D) plates of different sizes, thicknesses and holes were created in Space Claim to be used in analysis. The femur model was obtained from 3D computed tomography scans used in previous studies in the literature [16,17]. In the 3D femur model, a fracture was created by removing the segment in the transverse plan from the femur diaphysis area. Plates were placed on the models and prepared for Finite Element Analysis under real loading conditions.

Five different fixation models were designed using a 4.5 mm diameter femoral shaft plate with steel lock and different screw configurations. Screws with double cortex locks of 4.5 mm in width were used in different configurations. To evaluate the effect of the screw diameter, a 5.5 mm diameter screw with double cortex lock was used in one model. In the first model, a 6-hole plate was used, and 3 screws of 4.5 mm diameter were placed the proximal and distal to the fracture. In the second model, a 6-hole plate and three screws with 5.5 mm diameter were placed proximal and distal to the fracture. In the third model, an 8-hole plate and 3 screws with locks placed with 4.5 mm between them were used. In the fourth model, an 8-hole plate and 3 screws were used. In this model, the working length was increased by leaving the screw holes closest to the fracture empty. In the fifth model, 8-hole plates and 4 screws were used (Figure 1).

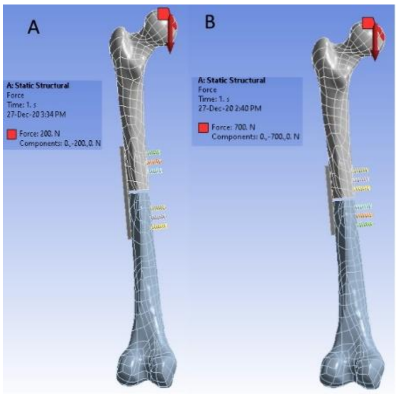
Figure 1: Schematic representation of the loads applied to the models. A: 200 N loading. B: 700 N loading



In this study, the following materials and properties were taken for the parts used in the model. Bone properties for femur: Modulus of Elasticity (E): 16.8 GPa, Poisson's Ratio (u): 0.47. Steel material was used for the plate, and the Modulus of Elasticity (E) was calculated as 200 GPa and Poisson's Ratio (u) as 0.3.

In the analyses, 200 N partial loading and 700 N full loading cases were used to test different loading cases, which were applied vertically to the proximal surface [12] (Figure 2).

Figure 2: Schematic representation of models. A:Model 1. B: Model 2. C: Model 3. D: Model 4. E. Model 5- MISSING PARTS



The connections between the plate, screws and femur were designed in the most realistic way, and the screws and femur connection were realized at the screw thread level. Thus, the distributions in the screw threads could also be obtained. In addition, the femur was fixed from the lowest part so that it could not displace in any direction. Static linear analyses were performed by importing these Finite Element models into Ansys Workbench 2020 R2 Finite Elements software.

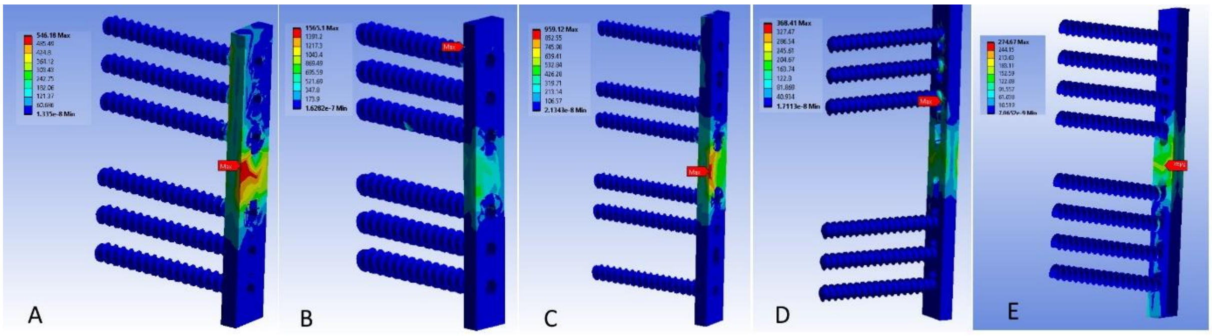
Results

As a result of the evaluation, we found that when the working length increased (the length between the two screws closest to the fracture), the load on the plate was higher in the fracture area. The maximum stress on the plate at the fracture site was 274 MPa at 200 N, and 961 MPa at 700 N in Model 5, and 389 MPa at 200 N, and 1118 MPa at 700 N in Model 4.

Comparing the filling of all screw holes in the 8-hole plate with spaced screws, we found that the stress on the plate was similar in both models. The maximum stress on the plate at 200 N was 274 MPa, and 959 MPa at 700 N in Model 3.

When the use of screws with a diameter of 5.5 and 4.5 mm was compared, it was observed that the stress on the plate at the fracture site was higher in the screws with 5.5 mm width.

Figure 3: Representation of finite element analysis. A:Model 1. B: Model 2. C: Model 3. D: Model 4. E. Model 5



We found that the stress on the plate at the fracture site increased with the plate length. The maximum stress on the plate at the fracture site was 156 MPa at 200 N, and 546 MPa at 700 N in Model 1, and 274 MPa at 200 N, and 784 MPa at 700 N in Model 2. (Figure 3) (Table 1).

Table 1: Stress distribution in models at different loads

	Model 1	Model 2	Model 3	Model 4	Model 5
200 N	156	274	274	389	274
700 N	546	784	959	1118	961

Discussion

Plate selection and screw configuration are important in solving implant failure and reducing complications in plate and screw osteosynthesis.

Plate working length is one of the most important mechanical parameters of plate systems and has a major impact on the mechanical environment and structural stability of the fracture site [18, 19]. Studies on plate systems with locks have revealed conflicting results. While some studies suggest increasing the length of the plate, there are opposing views in some others [20-25]. In our study, we found that increasing the working length increased the stress on the plate in the fracture site. Ellis T. et al. [25] found that increasing the working length in case of a gap in the fracture area correspondingly increased the stress on the plate, but if there was no gap in the fracture area, increasing the working length decreased the stress on the plate. In our study, we found a positive correlation between working length and stress on the plate.

Another important mechanical parameter in plate screw systems is plate length. Jianzhao Wang et al. [12] found that the increase in the length of the plate increased the stress on the plate but reduced the stress on the bone. In our study, we found that the increase in the length of the plate increased the stress load on the plate in the fracture area.

The location and configuration of the screws in the plate is another important parameter in plate and screw osteosynthesis. In a study they conducted, Wei Sheng et al. [13] found that the stress loads on the plate in nine different plate screw configurations of the same length were similar. They also found that the stress on the plate and femur increased significantly in the first and second screw holes near the fracture. In previous studies, it was stated that the use of screw holes near the fracture site had a great effect on the stress distribution in the plate fixation system [26, 27]. In our study, we observed that when we compared the filling of all screw holes and spaced screw placement in an 8-hole plate, the stress on the plate in the fracture line was similar in both groups.

Screw diameter also plays an important role in the mechanics of internal fixation [28, 29]. In their study comparing the screw diameters of 4 mm, 4.5 mm, 5 mm, Wei Sheng et al. [13] revealed that the highest stress on the plate was on the 4 mm screws. They showed that the most suitable screws were those with 5mm diameter. In our study, when the use of a 5.5 mm diameter screw was compared with the use of 4.5 mm, we found that the stress on the plate in the fracture line was higher in the model using 5.5 mm screws. This result was not in line with the study of Wei Sheng et al.

Limitations

Our study is a computer-aided biomechanical study, and biomechanical studies can be performed on cadavers related to the subject. Secondly, in our study, we examined plate screw fixation in two different lengths and five different configurations. Further studies on more models of different lengths and configurations could better demonstrate the biomechanical effects of plate and screw osteosynthesis. More comprehensive biomechanical studies are needed to determine the most appropriate screw plate configuration in plate-screw osteosynthesis.

Conclusion

As the plate's working length, screw diameter, and plate length are increased, the stress on the plate in the fracture area also increases. The reduction of the screws, provided that the screws were placed in the closest and furthest holes to the fracture, did not change the stress on the plate at the level of the fracture line.

References

1. Gösling T, Krettek C. Femoral shaft fractures. Der Unfallchirurg. 2019;122:59–75.
2. Weiss RJ, Montgomery SM, Al Dabbagh Z, Jansson KA. National data of 6409 Swedish inpatients with femoral shaft fractures: Stable incidence between 1998 and 2004. Injury. 2009;40:304–8.
3. Li AB, Zhang WJ, Guo WJ, Wang XH, Jin HM, Zhao YM. Reamed versus unreamed intramedullary nailing for the treatment of femoral fractures. Medicine. 2016;95:e4248
4. Scannell BP, Waldrop NE, Sasser HC, Sing RF, Bosse MJ. Skeletal traction versus external fixation in the initial temporization of femoral shaft fractures in severely injured patients. Journal of Trauma. 2010;68:633–40.
5. Zlowodzki M, Vogt D, Cole PA, Kregor PJ. Plating of Femoral Shaft Fractures: Open Reduction and Internal Fixation Versus Submuscular Fixation. Journal of Trauma. 2007; 63:1061–5.
6. Crist BD, Wolinsky PR. Reaming does not add significant time to intramedullary nailing of diaphyseal fractures of the tibia and femur. Journal of Trauma.2009;67:727–34.
7. Köseoğlu E, Durak K, Bilgen MS, Küçükalp A, Bayyurt S. Comparison of two biological internal fixation techniques in the treatment of adult femur shaft fractures (plate-screws and locked intramedullary nail). Turkısh Journal of Trauma.2011;17:159-65.
8. 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;33:1119–26.
9. Thapa S, Thapa SK, Dhakal S, Marasini R, Hamal B, Rai RK, et al. A comparative study of fracture shaft of femur in adults treated with broad dynamic compression plate versus intramedullary interlocking nail. J Coll Med Sci. 2016;12:66–9.
10. Adam P, Bonnomet F, Ehlinger M. Advantage and limitations of a minimally-invasive approach and early weight bearing in the treatment of tibial shaft fractures with locking plates. Orthop Traumatol Surg Res. 2012;98:564–9.
11. Birringer RP, Ganot GS, James BA. Failure Analysis of Internal Fixation Medical Devices: Overview and Case Studies. Journal of Failure Analysis and Prevention. 2016;16:849–57.

12. Wang J, Zhang X, Li S, Yin B, Liu G, Cheng X, et al. Plating System Design Determines Mechanical Environment in Long Bone Mid-shaft Fractures: A Finite Element Analysis. J Invest Surg. 2020;33:699–708
13. Sheng W, Ji A, Fang R, He G, Chen C. Finite Element-and Design of Experiment-Derived Optimization of Screw Configurations and a Locking Plate for Internal Fixation System. Comput Math Methods Med. 2019;21:5636528.
14. Cronier P, Pietu G, Dujardin C, Bigorre N, Ducellier F, Gerard R. The concept of locking plates. Orthop Traumatol Surg Res. 2010;96:17–36.
15. Öner K, Paksoy AE, Özer A. Fixation of femoral neck fractures with three cannulated screws: biomechanical changes at critical fracture angles. J Surg Med. 2020;4:660-3.
16. Öner K, Durusoy S, Özer A. Is the fracture morphology in the sagittal plane important in determining the ideal placement of the lag screw in intertrochanteric femoral fractures?: Ideal lag screw placement in intertrochanteric fractures in the sagittal plane. Injury. 2021;52:562-8.
17. Öner K, Durusoy S, Özer A. A new proximal femoral nail antirotation design:Is it effective in preventing varus collapse and cut-out? Jt Dis Relat Surg.2020;31:426-31.
18. Mardian S, Schaser KD, Duda GN, Heyland M. Working length of locking plates determines interfragmentary movement in distal femur fractures under physiological loading. Clin Biomech. 2015;30:391–6.
19. Hoffmeier KL, Hofmann GO, Mückley T. Choosing a proper working length can improve the lifespan of locked plates: A biomechanical study. Clin Biomech. 2011;26:405–9.
20. Niemeyer P, Südkamp NP. Principles and clinical application of the locking compression plate (LCP). Acta Chir Orthop Traumatol Cech. 2006;73:221-8.
21. Injury M. General principles for the clinical use of the LCP. Injury.2003:34:31-42.
22. Kanchanomai C, Muanjan P, Phiphobmongkol V. Stiffness and Endurance of a Locking Compression Plate Fixed on Fractured Femur. J Appl Biomec.2010;26:10–6.
23. Ellis T, Bourgeault CA, Kyle RF. Screw position affects dynamic compression plate strain in an in vitro fracture model. J Orthop Trauma. 2001;15:333-7.
24. Chao P, Conrad BP, Lewis DD, Horodyski MB, Pozzi A. Effect of plate working length on plate stiffness and cyclic fatigue life in a cadaveric femoral fracture gap model stabilized with a 12-hole 2.4 mm locking compression plate. BMC Vet Res. 2013;9:1-7.
25. Smith WR, Ziran BH, Anglen JO, Stahel PF. Locking plates: tips and tricks. J Bone Joint Surg Am. 2007;89:2298-307.
26. Cheal EJ, Hayes WC, White AA, Perren SM. Three-dimensional finite element analysis of a simplified compression plate fixation system. J Biomech Eng. 1984;106:295–301.
27. Chatzistergos P, Magnissalis E, Kourkoulis S. A parametric study of cylindrical pedicle screw design implications on the pullout performance using an experimentally validated finite-element model. Med Eng Phys. 2010;32:145-54.
28. Kohn D, Rose C. Primary Stability of Interference Screw Fixation: Influence of Screw Diameter and Insertion Torque. Am J Sports Med. 1994;22:334–8.

This paper has been checked for language accuracy by JOSAM editors.
The National Library of Medicine (NLM) citation style guide has been used in this paper.