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Fixation of femoral neck fractures with three cannulated screws: biomechanical changes at critical fracture angles

Femur boyun kırıklarında üç kanüllü vida ile tespit: kritik kırık açılarında biyomekanik değişiklikler

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Abstract
Aim: Increased fracture angle in the coronal plane results in more instability and complications in femoral neck fractures. Our aim in this study was to analyze biomechanical changes at critical fracture angles (30 degrees, 50 degrees, and 70 degrees) as described in Pauwels classification.
Methods: A femur model was obtained by 3D computerized tomography (CT) scanning. The angle of femoral neck fracture in the coronal plane observed on the CT image was created on the model at 30, 50 and 70-degree angles. Three cannulated screws were placed in the inverted triangle position. Screws were named “anterior-superior” (A), “posterior -superior” (B), and “inferior” (C). The obtained three different models were transferred to the ANSYS Workbench program. Von Mises stress distribution on the screws and distal fracture surfaces were recorded.
Results: In the 30-degree fracture model, the maximum stress was 18.062 MPa on the "A" screw. It was 22.13 MPa on screw "B" and 16.21 MPa on screw "C". In the 50-degree fracture model, the maximum stress values were 68.04 MPa, 89.52 MPa and 48.94 MPa in screws "A", "B", and "C", respectively. In the 70-degree fracture model, the maximum stress values were 120.02 MPa, 138.32 MPa and 98.37 MPa in screws "A", "B", and "C", respectively. The stress values on the distal fracture surfaces were 13.54 MPa, 43.80 MPa, and 50.07 MPa in the 30, 50, and 70-degree models, respectively.
Conclusion: Increasing fracture angle from 30 to 50 degrees in femoral neck fractures significantly increases the stress on the distal fracture surface and implants. However, this increase is minimal at angles higher than 50 degrees.
Keywords: Femoral neck fractures, Pauwels classification, Cannulated screw fixation, Finite element study

Öz
Amaç: Femur boyun kırıklarında koronal planda kırık açısının artması instabiliteyi ve komplikasyonları arttırmaktadır. Bu çalışmadaki amacımız Pauwels sınıflamasında belirlenmiş olan kritik açılardaki (30 derece, 50 derece, 70 derece) biyomekanik değişiklikleri analiz etmektir.
Yöntemler: 3D bilgisayarlı tomografi taramasından elde edilen femur modelinde koronal plandaki kırık açısına göre 30, 50 ve 70 derece femur boyun kırığı oluşturuldu. Inverted triangle pozisyonunda 3 adet kanüllü vida yerleştirildi. Vidalar anterior-superior (A), posterior –süperior (B) ve inferior (C) olarak isimlendirildi. Üç model Ansys Workbench programına aktarılarak vidalardaki ve distal kırık yüzeyindeki von mises stres dağılımları kaydedildi.
Bulgular: Maximum stres 30 derece kırık modelinde A vidasında 18,06 mpa idi. B vidasında ise 22,13 MPa, C vidasında 16,21 MPa olarak bulundu. 50 derece kırık modeline baktığımızda max stres değerleri A vidasında 68,04 MPa iken B vidasında 89,52 MPa, C vidasında ise 48,94 MPa olarak bulundu. 70 derece kırık modelinde A vidasında maximum stres 120,02 MPa, B vidasında 138,32 MPa idi. C vidasında ise 98,37 MPa olarak bulundu. Distal kırık yüzeyindeki stres değerleri ise 30, 50, 70 derece modellerde sırası ile 13,54 MPa, 43,80 MPa ve 50,07 MPa idi.
Sonuç: Femur boyun kırıklarında kırık açısının 30 dereceden 50 dereceye yükseltilmesi distal kırık yüzeyi ve implantlar üzerindeki gerilimi önemli ölçüde artırmaktadır. Ancak bu artış 50 derecenin üzerindeki açılarda minimumdur.
Anahtar kelimeler: Femur boyun kırığı, Pauwels sınıflaması, Kanüllü vida ile fiksasyon, Sonlu elemanlar analizi

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Introduction

Femoral neck fractures are common injuries [1]. Anatomically, they occur in the area between the intertrochanteric region and the femoral head [2]. While they occur due to high-energy traumas in young patients, the mechanism is mostly a low-energy trauma in the elderly [3,4].

Anatomical reduction and stable fixation in femoral neck fractures are critical factors to achieve success. Fixation with cannulated screws is a frequently used treatment method [5]. The most common complications of femoral neck fractures are avascular necrosis (AVN) and nonunion. The occurrence of these complications requires reoperations at a rate of 20% [6].

Pauwels classification is a frequently used system to classify femoral neck fractures. Based on the angle of the fracture line in the coronal plane, angles of up to 30 degrees are classified as type 1, angles between 30 degrees-50 degrees are classified as type 2, and angles higher than 50 degrees are classified as type 3 [7]. Several studies report that high fracture angles in the coronal plane increase the likelihood of failure after fixation with cannulated screws, thereby, resulting in increased rates of postoperative complications [8,9].

Despite many studies investigating this subject matter in the literature, more studies are needed to understand biomechanical changes and complications that may occur in association with different fracture configurations [10].

Our aim in this study is to contribute to the treatment of femoral neck fractures by examining the stress changes on the implants and distal fracture surface at different fracture angles.

Materials and methods

Finite Element Method (FEM) is a mathematical based computational technique used in solving complicated analytically structural problems. In this way, one creates a model similar to the real body with solid modeling programs such as Solid Works. This model is obtained by using real computerized tomography (CT) images from real CT scans. Modified solid models are generated in a solid modeling program based on the problem, then sent to a Finite Element Analysis software such as Ansys Workbench, which is a useful tool for especially engineers to solve various engineering problems.

The femur model used in our study was obtained from a three-dimensional (3D) computerized tomography (CT) scan. Fracture angles of 30 (30^o), 50 (50^o), and 70 degrees (70^o) were created on the obtained femur model based on the fracture angles in the coronal plane. Three cannulated screws were placed in the inverted triangle position (Figure 1).

Screws were named as anterior-superior (A), posterior-superior (B), and inferior (C) (Figure 2). The obtained three different models were transferred to the ANSYS Workbench program and von Misess stress distribution on the screws and distal fracture surfaces were recorded.

All models were applied a force of 1650N at a 15-degree (15^o) angle with the femoral shaft axis. The force applied was limited along the femoral shaft (Figure 3).

High-resolution 3D elements of 1mm are used for the construction of the mesh. The Elasticity Modules were taken as 16.8G Pa and 206 GPa for the femur and screws, respectively. The Poisson ratio was selected to be 0.3 for both the femur and the screws. The Linear Elastic Isotropic Model was used for material deformation in the analyses [11].

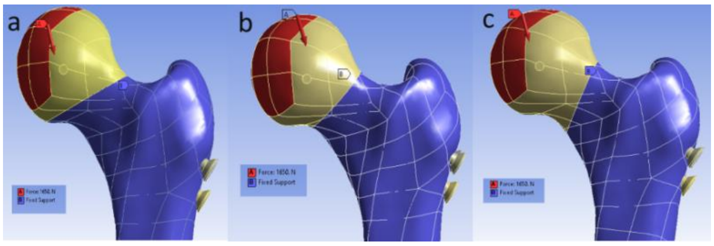

Figure 1: Shows the fracture angle models of 30^o, 50^o, and 70^o

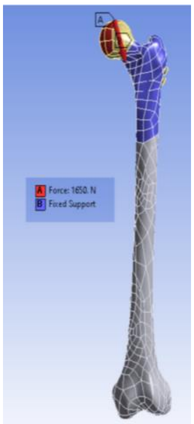

Figure 2: Screw placements: anterior-superior (A), posterior –superior (B), and inferior (C)

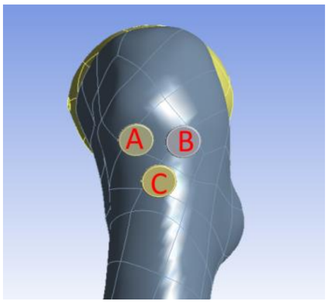

Figure 3: Schematic representation of the loads applied to the models. A 1650N load at an angle of 15 ^{o}

Results

The examination of the von Mises stress distribution on the screws revealed that maximum values occurred at the points where the screws crossed the fracture line and superiorly. In the 30-degree fracture model, the maximum stress was 18.062 MPa on the "A" screw. It was 22.13 MPa on screw "B" and 16.21 MPa on screw "C". In the 50-degree fracture model, the maximum stress values were 68.04 MPa, 89.52 MPa and 48.94 MPa in screws "A", "B", and "C", respectively. In the 70-degree fracture model, the maximum stress values were 120.02 MPa, 138.32 MPa and 98.37 MPa in screws "A", "B", and "C", respectively (Table 1) (Figure 4).

The maximum stress values on the distal fracture surfaces, obtained in the inferior cortex, were 13.54 MPa, 43.80 MPa, and 50.07 MPa in the 30, 50, and 70-degree models, respectively. (Table 2) (Figure 5).

Table 1: Maximum stress values on screws in fracture models

	Max stress (MPa) on screw locations		
Angle	A(screw)	B(screw)	C(screw)
30^o	18.06 MPa	22.13 MPa	16.21 MPa
50^o	68.04 MPa	89.52 MPa	48.94 MPa
70^o	120.02 MPa	138.32 MPa	98.37 MPa

Table 2: Maximum stress values on distal fracture surfaces in fracture models

Angle	Distal fracture surface stresses (MPa)
30º	13.54 MPa
50º	43.80 MPa
70º	50.07 MPa

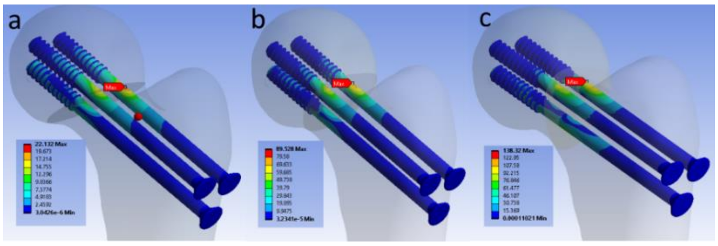

Figure 4: Von Mises stress distribution on screws by the fracture angles

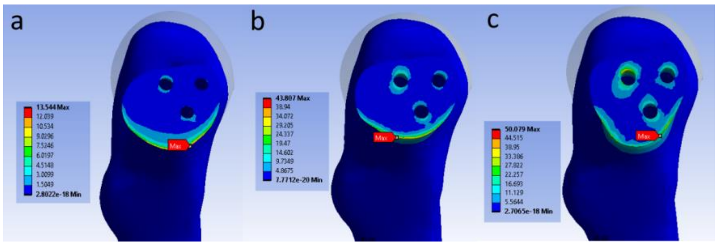

Figure 5: The stress distribution on distal fracture surfaces by fracture angles

Discussion

Despite the availability of several studies regarding the effects of fracture configuration and the type of implants on the success of stabilization in femoral neck fractures, no consensus has been achieved on this subject matter [12-17]. Jiantao et al. [18] investigated the optimal placement of cannulated screws in the treatment of femoral neck fractures. In their study, they stated that the most stable model was the inverted triangle model. In our study, we examined biomechanical changes by fracture angles in cannulated screw fixation performed by applying an inverted triangle model.

Hoshono et al. [3] and Collinge et al. [19] reported that a high fracture angle may lead to instability and implant and treatment failures. In our study, we observed that as the fracture angle increases, so does the stress intensity on both the implant and the distal fracture surface. In this sense, we suggest that high angles of fractures may impair stability, increase complications, and lead to treatment failures. When we analyzed the data we obtained on the distal fracture surface in detail, we observed that increasing the angle of the fracture from 30º to 50º raised the maximum stress value on the distal fracture surface approximately by fourfold. However, an increase in the angle from 50 º to 70º is associated only with a 16% increase. These findings demonstrate that the critical level of a biomechanical change is more notable with fracture angles ranging from 30º to 50º and that angles of more than 50º are not associated with significant differences across models. When these data are interpreted clinically, it is obvious that increasing the angle of fracture results in increased instability. In the Pauwels classification, fracture angles of more than 50º are classified as Type 3 and these angles are associated with high instability and complication rates [3,8,20,21]. However, our study results show that notable differences occur across fracture angles ranging from 30º to 50º, whereas biomechanical differences occur less at angles of more than 50 º. When the loads on the screws are examined, it is observed that a shift in the angle from 30º to 50º increases the load on all screws approximately by 4-fold but an increase from 50º to 70º results in an increase by approximately 2-fold. Furthermore, the load on the screws increases with the increasing load on the distal fracture surface. After examining the overall results of the study, we can argue that Pauwels type 2 fractures are at least as much unstable as type 3 fractures. Pauwels classification is important from a biomechanical aspect; however, we suggest that critical angle values for instability be reviewed and the classification be revised accordingly.

In a study on young patients with displaced femoral neck fractures, Hoshino et al. [19] reported lower complication rates with the use of fixed-angle devices used in anatomical reduction compared to fixation with screws. The authors reported that they did not know the reason for this finding, warranting further studies. Studies comparing various implant systems report that many implants provide sufficient stability despite some differences across implant types [5,7,11,22]. In our study, we obtained the stress values on inferior cortices of distal fracture surfaces. In cases with no inferior cortical contact, that is, when an anatomical reduction cannot be performed, the stress generated in the proximal fracture fragment will not be transferred to the distal fracture surface and the calcar region, impacting on the implant directly. Consequently, implant and treatment failures result. From this point of view, we argue that achieving a proper anatomical reduction is important for stability and success rather than the type of the implant in the treatment of femoral neck fractures.

In our study, we measured the highest stress value on the superior-posterior (B) screw compared to A and C screws. We think that the cause of high stress levels may be the 15º anteversion angle in the femoral neck. More comprehensive biomechanical studies are needed on this subject matter.

Limitations

A limitation of our study is its biomechanical computer-based design, warranting further clinical studies and studies on cadavers to support the results. Secondly, in our study, we examined the biomechanical effects of different angles but only on 3 models. Further studies to be conducted on more models with different angles may demonstrate biomechanical changes more appropriately. The results we obtained in this study should be supported by more comprehensive clinical and biomechanical studies.

Conclusion

In femoral neck fractures, a higher fracture angle in the coronal plane is associated with increased stress values on the distal fracture surface and cannulated screws. While the changes are more notable with increasing fracture angles from 30 º to 50º, they become minimal with angles of more than 50º.

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References

1. Grosso MJ, Danoff JR, Murtaugh TS, Trofa DP, Sawires AN, Macaulay WB. Hemiarthroplasty for Displaced Femoral Neck Fractures in the Elderly Has a Low Conversion Rate. J Arthroplasty. 2017 Jan;32(1):150-4. doi: 10.1016/j.arth.2016.06.048.
2. Panteli M, Rodham P, Giannoudis PV. Biomechanical rationale for implant choices in femoral neck fracture fixation in the non-elderly. Injury. 2015 Mar;46(3):445-52. doi: 10.1016/j.injury.2014.12.031.
3. Collinge CA, Mir H, Reddix R. Fracture morphology of high shear angle "vertical" femoral neck fractures in young adult patients. J Orthop Trauma. 2014 May;28(5):270-5. doi: 10.1097/BOT.0000000000000014.
4. Pauyo T, Drager J, Albers A, Harvey EJ. Management of femoral neck fractures in the young patient: A critical analysis review. World J Orthop. 2014 Jul 18;5(3):204-17. doi: 10.5312/wjo.v5.i3.204.

5. Li J, Wang M, Li L, Zhang H, Hao M, Li C, Han L, Zhou J, Wang K. Finite element analysis of different configurations of fully threaded cannulated screw in the treatment of unstable femoral neck fractures. J Orthop Surg Res. 2018 Oct 29;13(1):272. doi: 10.1186/s13018-018-0970-3.
6. Slobogean GP, Sprague SA, Scott T, McKee M, Bhandari M. Management of young femoral neck fractures: is there a consensus? Injury. 2015 Mar;46(3):435-40. doi: 10.1016/j.injury.2014.11.028.
7. Tianye L, Peng Y, Jingli X, QiuShi W, GuangQuan Z, Wei H, Qingwen Z. Finite element analysis of different internal fixation methods for the treatment of Pauwels type III femoral neck fracture. Biomed Pharmacother. 2019 Apr;112:108658. doi: 10.1016/j.biopha.2019.108658.
8. Cha YH, Yoo JI, Hwang SY, Kim KJ, Kim HY, Choy WS, Hwang SC. Biomechanical Evaluation of Internal Fixation of Pauwels Type III Femoral Neck Fractures: A Systematic Review of Various Fixation Methods. Clin Orthop Surg. 2019 Mar;11(1):1-14. doi: 10.4055/cios.2019.11.1.1.
9. Biz C, Tagliapietra J, Zonta F, Belluzzi E, Bragazzi NL, Ruggieri P. Predictors of early failure of the cannulated screw system in patients, 65 years and older, with non-displaced femoral neck fractures. Aging Clin Exp Res. 2020 Mar;32(3):505-513. doi: 10.1007/s40520-019-01394-1.
10. Shen M, Wang C, Chen H, Rui YF, Zhao S. An update on the Pauwels classification. J Orthop Surg Res. 2016 Dec 12;11(1):161. doi: 10.1186/s13018-016-0498-3.
11. Mei J, Liu S, Jia G, Cui X, Jiang C, Ou Y. Finite element analysis of the effect of cannulated screw placement and drilling frequency on femoral neck fracture fixation. Injury. 2014 Dec;45(12):2045-50. doi: 10.1016/j.injury.2014.07.014.
12. Li J, Wang M, Zhou J, Han L, Zhang H, Li C, Li L, Hao M. Optimum Configuration of Cannulated Compression Screws for the Fixation of Unstable Femoral Neck Fractures: Finite Element Analysis Evaluation. Biomed Res Int. 2018 Dec 9;2018:1271762. doi: 10.1155/2018/1271762.
13. Noda M, Saegusa Y, Takahashi M, Tezuka D, Adachi K, Naoi K. Biomechanical Study Using the Finite Element Method of Internal Fixation in Pauwels Type III Vertical Femoral Neck Fractures. Arch Trauma Res. 2015 Aug 26;4(3):e23167. doi: 10.5812/atr.23167.
14. Zhang YL, Zhang W, Zhang CQ. A new angle and its relationship with early fixation failure of femoral neck fractures treated with three cannulated compression screws. Orthop Traumatol Surg Res. 2017 Apr;103(2):229-234. doi: 10.1016/j.otsr.2016.11.019.
15. Noda M, Nakamura Y, Adachi K, Saegusa Y, Takahashi M. Dynamic finite element analysis of implants for femoral neck fractures simulating walking. J Orthop Surg (Hong Kong). 2018 May-Aug;26(2):2309499018777899. doi: 10.1177/2309499018777899.
16. Zhou L, Lin J, Huang A, Gan W, Zhai X, Sun K, Huang S, Li Z. Modified cannulated screw fixation in the treatment of Pauwels type III femoral neck fractures: A biomechanical study. Clin Biomech (Bristol, Avon). 2020 Apr;74:103-110. doi: 10.1016/j.clinbiomech.2020.02.016.
17. Zhang B, Liu J, Zhu Y, Zhang W. A new configuration of cannulated screw fixation in the treatment of vertical femoral neck fractures. Int Orthop. 2018 Aug;42(8):1949-1955. doi: 10.1007/s00264-018-3798-x.
18. Li J, Wang M, Zhou J, Han L, Zhang H, Li C, Li L, Hao M. Optimum Configuration of Cannulated Compression Screws for the Fixation of Unstable Femoral Neck Fractures: Finite Element Analysis Evaluation. Biomed Res Int. 2018 Dec 9;2018:1271762. doi: 10.1155/2018/1271762.
19. Hoshino CM, Christian MW, O'Toole RV, Manson TT. Fixation of displaced femoral neck fractures in young adults: Fixed-angle devices or Pauwel screws? Injury. 2016 Aug;47(8):1676-84. doi: 10.1016/j.injury.2016.03.014.
20. Cordeiro M, Caskey S, Frank C, Martin S, Srivastava A, Atkinson T. Hybrid triad provides fracture plane stability in a computational model of a Pauwels Type III hip fracture. Comput Methods Biomech Biomed Engin. 2020 Jul;23(9):476-483. doi: 10.1080/10255842.2020.1738404.
21. Kemker B, Magone K, Owen J, Atkinson P, Martin S, Atkinson T. A sliding hip screw augmented with 2 screws is biomechanically similar to an inverted triad of cannulated screws in repair of a Pauwels type-III fracture. Injury. 2017 Aug;48(8):1743-1748. doi: 10.1016/j.injury.2017.05.013.
22. Samsami S, Augat P, Rouhi G. Stability of femoral neck fracture fixation: A finite element analysis. Proc Inst Mech Eng H. 2019 Sep;233(9):892-900. doi: 10.1177/0954411919856138.

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