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How is hip prosthesis and proximal femoral nail stability affected by lesser trochanter fractures: A comparative finite element analysis

Kalça protezi ve proksimal femoral çivi stabilitesi küçük trokanter kırıklarından nasıl etkilenir: Karşılaştırmalı sonlu eleman analizi

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ABSTRACT

Objectives: This study aims to evaluate the effects of lesser trochanter (LT) and iliopsoas tendon on implant stability by using finite element analysis (FEA).

Materials and methods: Effects of iliacus and psoas major muscles on hip joint was evaluated with inverse dynamics methods to calculate joint reaction and muscle forces. Intertrochanteric femur fracture was simulated according to AO (Arbeitsgemeinschaft für Osteosynthesefragen) 31A1 and 31A2 classifications in three-dimensional modelling software. Uncemented three-dimensional model of modular nail prosthesis combination was used in FEA. All analyses were performed with Ti6Al4V's 114 GPa elastic modulus value. Effects of LT on implant stability were evaluated with two different implant designs using the same femoral stems and four different femoral models, two of which with intact LT and two of which with fractured LT.

Results: Reaction forces of the hip joint decreased by 10% in the 0-40° hip flexion range. Maximum stress distribution for proximal femoral nail (PFN) model with fractured LT was 204.68 MPa at the distal locking screw on the interconnection point of PFN, while it was 335.35 MPa for the hip prosthesis with fractured LT. The direction of stress distribution for PFN model with fractured LT varied from medial to lateral and anterior to posterior. Maximum stress distribution for the hip prosthesis model with intact LT was 357.42 MPa, with direction of stress distribution from lateral to medial and posterior to anterior.

Conclusion: Hip prosthesis models with intact or fractured LT were similar in terms of stress distribution and deformation values, while there were differences between PFN models with intact or fractured LT. Thus, intact LT was significant in PFN implant stability. Further clinical and experimental analyses are necessary on this topic.

Keywords: Finite element analysis; hip prosthesis; lesser trochanter; proximal femoral fractures; proximal femoral nail.

ÖZ

Amaç: Bu çalışmada, küçük trokanter (KT) ve iliopsoas tendonunun implant stabilitesi üzerine etkileri sonlu element analizi (SEA) kullanarak değerlendirildi.

Gereç ve yöntemler: Eklem tepkisi ve kas kuvvetlerini hesaplamak için iliacus ve psoas majör kaslarının kalça eklemine etkileri ters dinamik metotları ile değerlendirildi. İntertrokanterik femur kırığı üç boyutlu modelleme yazılımı ile AO (Arbeitsgemeinschaft für Osteosynthesefragen) 31A1 ve 31A2 sınıflandırmasına göre simüle edildi. Sonlu element analizinde modüler çivi protez kombinasyonunun çimentosuz üç boyutlu modeli kullanıldı. Bütün analizler Ti6AI4V'nin 114 GPa elastik modulus değeri ile gerçekleştirildi. Küçük trokanterin implant stabilitesine etkisi aynı femoral stemi kullanan iki farklı implant tasarımıyla ve iki sağlam KT'li ve iki kırık KT'li dört farklı femoral model ile değerlendirildi.

Bulgular: Kalça ekleminin reaksiyon kuvvetleri 0-40° kalça fleksiyon aralığında %10 azaldı. Maksimum stres dağılımı kırık KT'li proksimal femoral çivi (PFÇ) modelinde PFÇ'nin ara bağlantı noktasındaki distal kilitleme vidasında 204.68 MPa iken, kırık KT'li kalça protezi için 335.35 MPa idi. Kırık KT'li PFÇ modeli için stres dağılımı yönü medialden laterale ve anteriordan posteriora değişti. Sağlam KT'li kalça protezi modelinde maksimum stres dağılımı 357.42 MPa olup stres dağılımı yönü lateralden mediale ve posteriordan anteriora idi.

Sonuç: Kırık veya sağlam KT'li kalça protezi modelleri stres dağılımı ve deformasyon değerleri açısından benzer iken sağlam veya kırık KT'li olmalı PFÇ modelleri arasında farklılıklar vardı. Buna bağlı olarak, PFÇ implant stabilitesi için KT önemli idi. Bu konu hakkında ileri klinik ve deneysel analizler gereklidir.

Anahtar sözcükler: Sonlu eleman analizi; kalça protezi; küçük trokanter; proksimal femoral kırıklar; proksimal femoral çivi.

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Proximal femoral fractures (PFFs) are commonly seen in post-menopausal elderly females.[1] The mortality rates in these patients may rise up to 10%.[2] Proximal femoral fractures are generally classified as intra- and extra-articular types. Intra-articular fractures contain femoral head and neck fractures, and extra-articular fractures are classified as pertrochanteric, intertrochanteric and subtrochanteric fractures. Hip fractures are generally classified as stable and unstable fracture patterns.[3] Generally, instability is described by the presence of a region of comminution of the medial cortex and posterolateral stability. The most commonly used classification is AO (Arbeitsgemeinschaft für Osteosynthesefragen)/ASIF (Association for the study of Internal Fixation) group, which basically divides the trochanteric fractures (type 31A) into three groups: A1 fractures (stable pertrochanteric fractures), A2 fractures (unstable pertrochanteric fractures with medial comminution including a fractured lesser trochanter [LT]) and A3 fractures (unstable intertrochanteric fractures with intact or fractured medial comminution). The instability of A2 and A3 fractures is created when one or both of the cortices is comminuted in a way that progressive (varus) displacement will follow unless intrinsic stability is provided by means of a stabilizing implant. The forces that tend to displace the fracture must be neutralized by the implant. Theoretically, these forces are best transmitted through an implant close to the center of axial loading, resulting in shorter lever arm and lower bending moment.[4] Implant choice is generally dependent on bone quality. Bone mineral density can be used as a good predictor for implant choice.[5] Hip fracture treatment modalities can be simply classified as internal fixation and hip arthroplasty. However, each treatment regimen has advantages and disadvantages. The advantages of internal fixation are the preservation of hip joint and relatively shorter surgeries whereas the disadvantages are lag screw cut out, non-unions, pseudarthrosis, avascular necrosis and coxarthrosis. Proximal femoral nail (PFN) is one of the most commonly used implants for hip fractures. Complications related with PFN application may occur per- or postoperatively. Inappropriate fracture reduction may yield a necessary hip arthroplasty. The effects of LT on implant and fracture stability are controversial. Ehrnthaller et al.[6] reported that LT plays a significant role on the stability of osteoporotic PFFs and posteromedial instability, which may cause various dislocations and fragment movements on fracture line. Do et al.[7] also reported a correlation between the size of the LT fragment and increasing instability and stress on implant; however, we were unable to find any data on the effects of LT on PFN and hip prosthesis stability in the literature.

Therefore, in this study, we aimed to evaluate the effects of LT on implant stability by using finite element analysis (FEA).

MATERIALS AND METHODS

Effects of psoas major and iliacus removal musculoskeletal modeling

This study was conducted at Afyon Kocatepe University Medicine Faculty and Alanya Alaaddin Keykubat University Hospital between January 2015 and January 2016. AnyBody Modeling System version 6.0 software (Anybody Technologies, Aalborg, Denmark) was employed for performing the musculoskeletal analysis.[8] System uses inverse dynamics methods to calculate joint reaction and muscle forces based on a third order polynomial muscle recruitment model. Simulations were completed in a two-step process where at the first step kinematics of the human motion was resolved and an inverse dynamics analysis was then performed to calculate force equilibrium conditions at each time step. Lower extremity model (a.k.a. LegTLEM-Twente Lower Extremity Model) used in the model was developed in Twente University, Netherlands, and validated with several supporting publications.[9] Model consists of 159 muscle fascicles representing 55 muscles and represents seven joint degrees of freedom for each leg. In this study, iliopsoas and psoas major muscles were deactivated (Figure 1). This study was approved by the Institutional Ethics Committee (Afyon Kocatepe University Local Ethics Committee No: 2015/11/300). In our study, we used femur computed tomography images of a healthy adult male selected from a hospital imaging archive with blind selection; for this reason, there was no need for patient informed consent forms. The procedures followed were in accordance with the ethical standards of the committee responsible for human experimentation and with the Helsinki Declaration of 1975, revised in 2000.

Reconstruction of three-dimensional models from computed tomography (CT)

In our study, we used CT images of an adult male femur randomly selected from hospital's archive. 512*512 pixel resolution images were obtained using using SOMATOM Sensation 40 CT (Siemens AG, Erlangen, Germany) and device adjustments were set to 120 kV and 187.5 m. Computed tomography images were processed with Mimics (Materialise, Leuven, Belgium) software. A total of 665 Digital Imaging and Communications in Medicine images of human femur had slice thickness of 1 mm and pixel size of 0.6 mm. Models were transformed into Non-Uniform Rational Basis Splines surface format with SOLIDWORKS 2015 software (Dassault Systèmes SolidWorks Corporation, Massachusetts, USA) using point cloud methods. Intertrochanteric femur fracture was simulated according to the AO classifications 31A1 and 31A2 in Three-Dimensional (3D) Modeling Software (Dassault Systèmes SolidWorks Corporation, Massachusetts, USA).

Implant design

Uncemented 3D model of Modular Nail Prosthesis Combination® (Neologic Sağlık Hizm. İzmir, Turkey) was modeled for FEA. In this modular design, PFN consisted of two parts: in case of femoral neck non-union or coxarthrosis development after the initial treatment, intramedullary nail can be converted into a hip prosthesis easily with only removing the proximal part of the PFN and replacing a connector which connects the proximal part of the hip implant to the nail. This modularity is assumed to decrease surgery time and allow easy application (Figure 2).

Fracture description

We used two groups of implants and four fracture models, two of which with intact LT and two of which with fractured LT. Proximal femoral nail and hip prosthesis modules were embedded in each group.

In the first group, we aimed to evaluate 31A1 fracture type (intact LT) by AO. These fractures are simple, two part pertrochanteric fractures in that the fracture line can start laterally anywhere on the greater trochanter and run towards the medial cortex.[10]

In the second group, the multifragmentary pertrochanteric type 31A2 fracture was evaluated. Here, the fracture line can start laterally anywhere on the greater trochanter and run towards the medial cortex which is fractured in two places. This results in the detachment of a third fragment which includes the LT.[10] A fracture line was drawn near the insertion point of iliopsoas tendon in these models to evaluate the LT effect.

Finite element analysis of the cephalomedullary nail

A human femur model was analyzed with FEA under predetermined loading conditions.[11] Material properties of all components were assigned as linear elastic isotropic. All materials of the PFN were prepared from Ti6Al4V with elastic modulus of 114 GPa. A value of 0.3 was assigned to all materials' Poisson's ratios. Modulus of elasticity of trabecular and cortical components of the femur was taken as 0.86 GPa and 16.8 GPa, respectively.[12] Our study simulated the stance phase of walking,

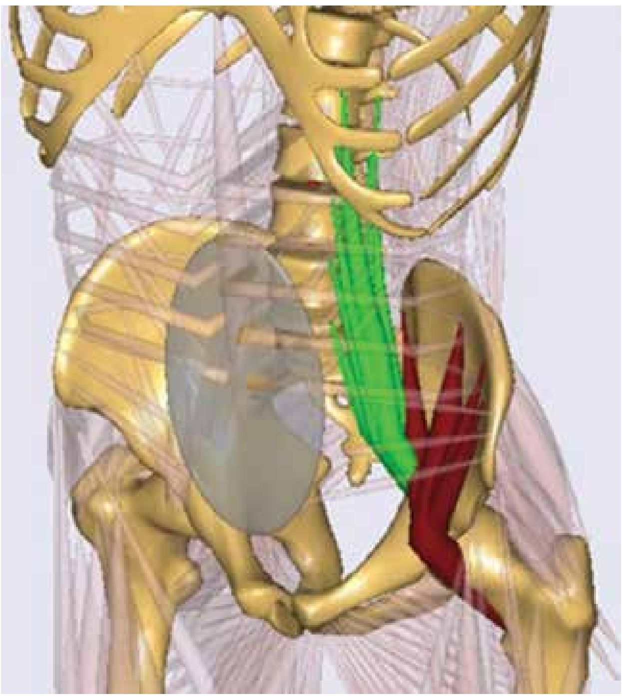

Figure 1. Illustrations of psoas and iliacus muscles in artificial human model.

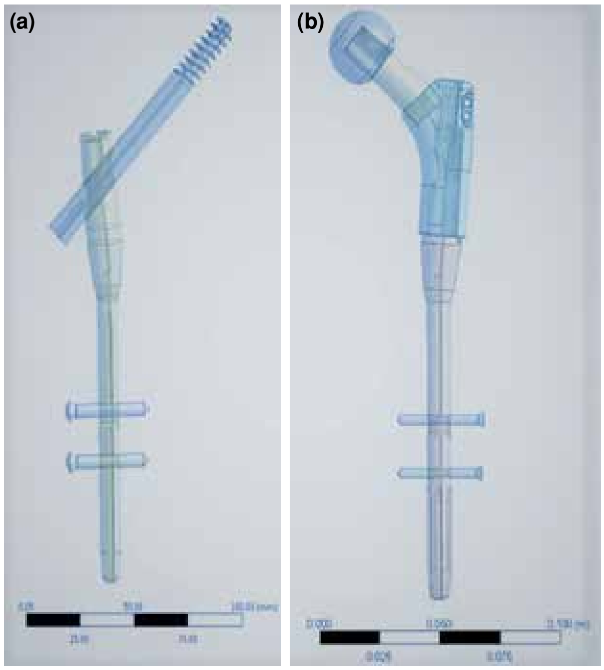

Figure 2. Three-dimensional images of newly developed modular nail prosthesis system. **(a)** Proximal femoral nail module, **(b)** hip prosthesis module.

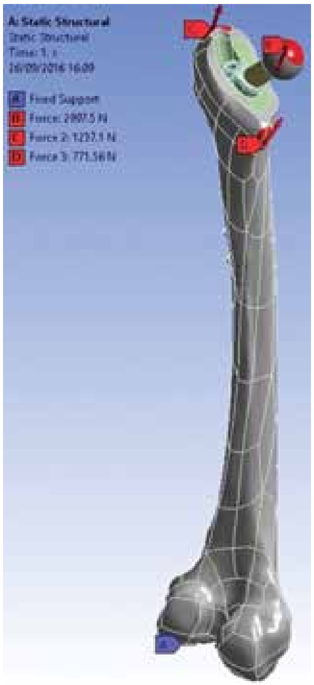

Figure 3. Prosthesis embedded femur model and load bearing conditions. Main force (applied to femoral head at 23° on frontal and 6° on sagittal planes) was taken to be 2997 N. Forces of abductor and iliopsoas muscles were taken as 1237 N (24° on frontal and 15° on sagittal planes) and 771 N (41° on frontal and 26° on sagittal planes).

which is the most commonly used position in virtual environment studies (Figure 2). Finite element models of PFN and bone system were composed of approximately 1,526,424 elements and 2,224,310 nodes. Three dimensional 10-node tetrahedral structural solid elements were used to model the whole system. The element size was 3 mm for the cortical bone, and the contact size between the PFN and the trabecular bone was 1 mm.[11] In this study, we evaluated four different femoral models, two of which were PFN and hip prosthesis embedded in femoral model with intact LT, the main force (applied to the femoral head at 23° on the frontal and 6° on the sagittal planes) was taken to be 2.997 N. Force of the abductor and the iliopsoas muscles were taken as 1237 N (24° on the frontal and 15° on the sagittal planes) and 771 N (41° on the frontal and 26° on the sagittal planes).[13] The other two were fractured LT models. In these models, force of the abductor and the iliopsoas muscles were taken as 1237 N (24° on the frontal and 15° on the sagittal planes) was not applied (Figure 3).

RESULTS

Musculoskeletal analysis during hip flexion movement from a one-legged stance posture was performed using inverse dynamics method. Subject's posture was set at 90° knee flexion and 0° hip flexion as starting condition. Motion was defined by specifying constant velocity hip flexion angle to reach 60° flexion in 2.0 seconds. An additional stability constraint was set to have center of mass of the subject in line with the center of the supporting right foot. Effect of removing left psoas major and iliacus was simulated by setting muscular strength values to zero. Hip joint reaction

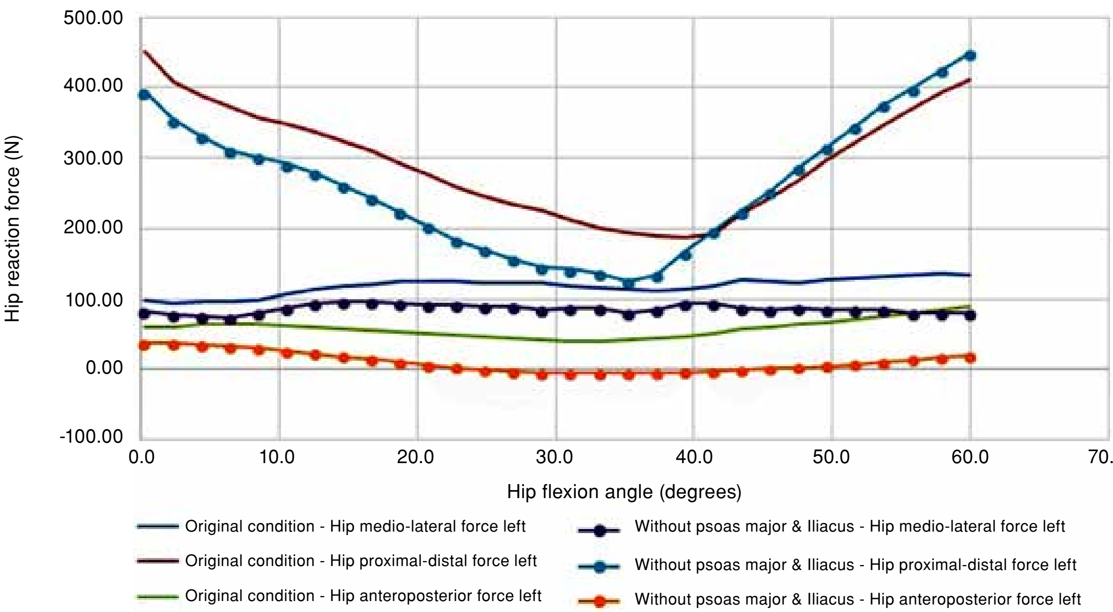

Figure 4. Effect of removing left psoas major and iliacus muscles was simulated by setting muscular strength. Hip joint reaction forces were observed to decrease about 10% during 0-40° hip flexion range.

TABLE I

A comparison of direction of stress distribution, maximum stress distribution and deformation values of proximal femoral nail and hip prosthesis embedded femoral model with intact/fractured lesser trochanter

	Proximal femoral nail with fractured LT	Proximal femoral nail with intact LT	Hip prosthesis with fractured LT	Hip prosthesis with intact LT
Direction of stress distribution	Medial → Lateral A → P	Lateral → Medial P → A	Medial → Lateral A → P	Lateral → Medial P → A
Max stress distribution point/value (MPa)	Interconnection point of PFN with distal locking screw/204.68 MPa	Interconnection point of PFN distal cortical bone/438.28	Interconnection point of prosthesis head with femoral stem/335.35	Interconnection point of prosthesis head with femoral stem/357.42
Deformation values (mm)	4.92	17.28	5.62	15.24

LT: Lesser trochanter; A: Anterior; P: Posterior; MPa: Megapascal; mm: millimeter; PFN: Proximal femoral nail.

force and rectus femoris muscle activation force were compared between original and modified models. Hip joint reaction forces decreased approximately 10% during the 0 to 40° hip flexion range. After, hip flexion angles of 40° hip joint reaction forces became equal for original and modified models. However, the hip joint flexion exceeded 40° during overground and treadmill walking.[14] The missing support of psoas major and iliacus was accompanied by rectus femoris as it generates 70 N (modified case) instead of 50 N (original case) at 60° hip flexion (Figure 4).

Whole system's maximum stress distribution, load bearing on fracture and implant surface, Von Mises stress distribution on proximal locking screw and deformation rates were compared with each other on four femur models (Table I).

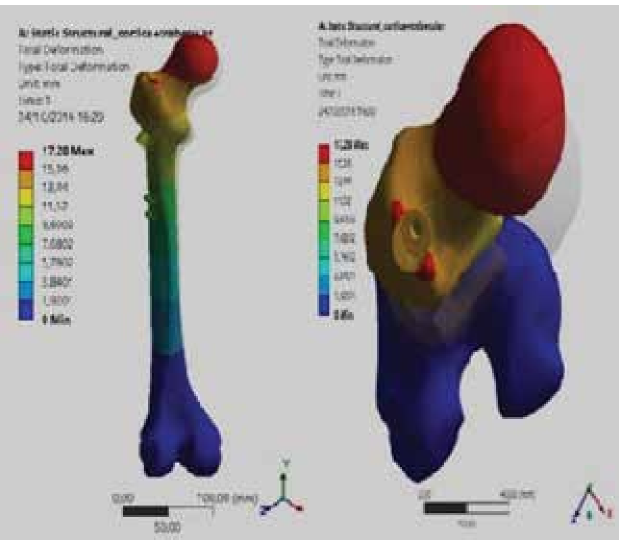

Figure 5. Deformation value was 17.28 mm in proximal femoral nail embedded femur model with intact lesser trochanter.

According to our finite element results, maximum stress distribution in PFN embedded model with intact LT was 438 mPa at the interconnection point of PFN distal and cortical bone. Direction of stress distribution moved from lateral to medial and posterior to anterior, respectively. Deformation value was 17.28 mm (Figure 5). Maximum stress distribution in fracture line was 41.84 mPa (Figure 6a).

Maximum stress distribution in PFN embedded model with fractured LT was 204.68 mPa at the interconnection point of PFN on the distal locking screw. Direction of stress distribution moved from medial to lateral and from anterior to posterior. Deformation value was 4.92 mm. Maximum stress distribution in fracture line was 40.263 mPa (Figure 6b).

Maximum stress distribution in prosthesis embedded model with fractured LT was 335.35 mPa at the interconnection point of prosthesis head with

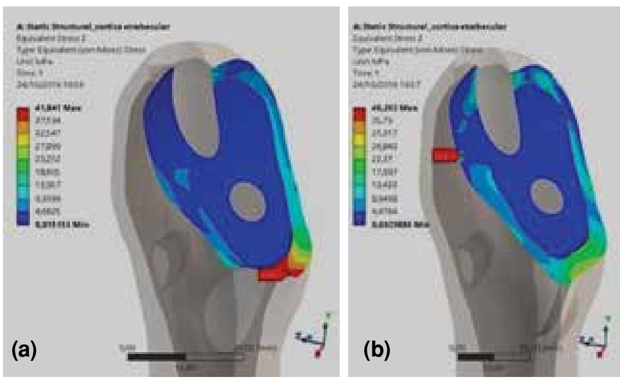

Figure 6. Maximum stress distribution in fracture line was 41.84 MPa in proximal femoral nail embedded femur model with fractured lesser trochanter **(a)** and 40.263 MPa in proximal femoral nail embedded femur model with intact lesser trochanter **(b)**.

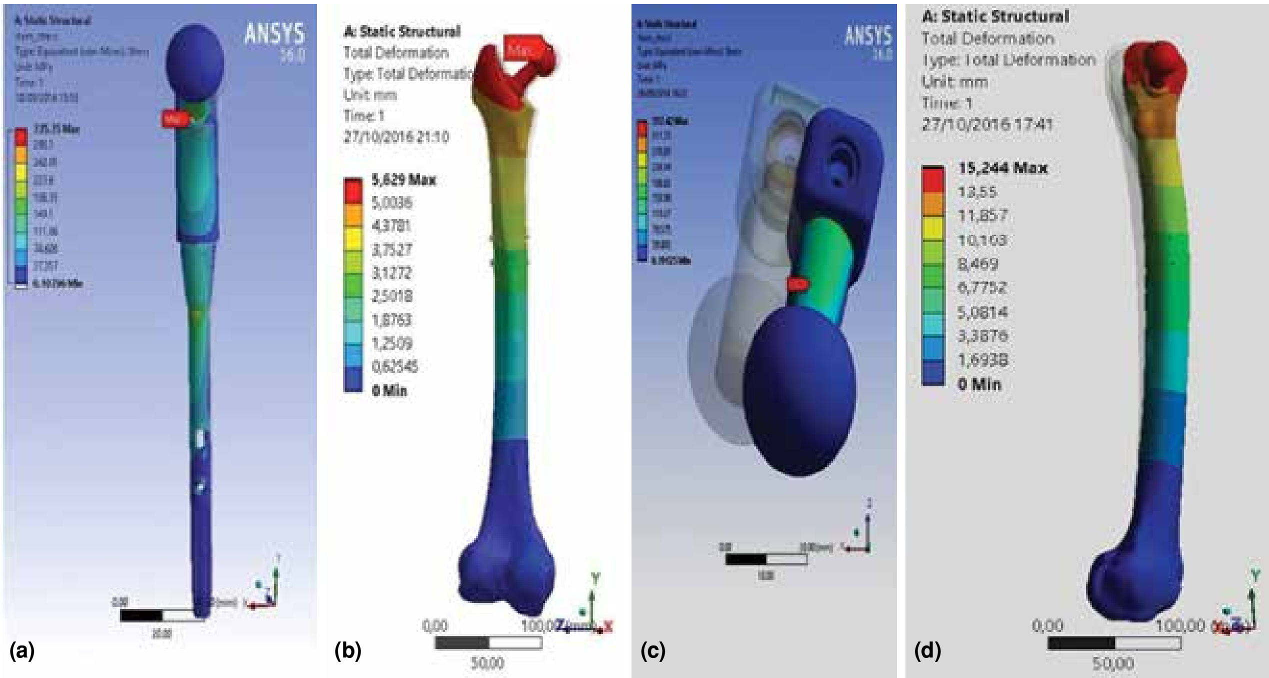

Figure 7. (a) Maximum stress distribution in prosthesis embedded model with fractured lesser trochanter was 335.35 MPa at interconnection point of prosthesis head with femoral stem. Direction of stress distribution moves from medial to lateral and anterior to posterior. **(b)** Deformation value was 5.62 mm. **(c)** Maximum stress distribution for prosthesis embedded model with intact lesser trochanter was 357.42 MPa on interconnection point of prosthesis head with femoral stem. Direction of stress distribution moves from lateral to medial and posterior to anterior. **(d)** Deformation value was 15.24 mm.

femoral stem. Direction of stress distribution moved from medial to lateral and anterior to posterior. Deformation value was 5.62 mm (Figure 7a, b).

Maximum stress distribution in prosthesis embedded model with intact LT was 357.42 mPa at the interconnection point of prosthesis head with femoral stem. Direction of stress distribution moved from lateral to medial and posterior to anterior. Deformation value was 15.24 mm (Figure 7c, d), (Table I).

DISCUSSION

In this study, we aimed to determine the effects of iliopsoas tendon and LT on implant stability. Absence of iliopsoas tendon reduced hip reaction forces approximately 10% in 0-40° hip flexion range. Also, we found that rectus femoris muscle compensated for hip reaction forces. As a result, strengthening exercises for rectus femoris muscle should be advised. Indeed, Aprato et al.[15] reported that LT fracture may result in decreased hip flexion strength and LT displacement is directly correlated with flexion strength.

In our literature review, we were unable to find any FEA comparing hip prosthesis and PFN embedded femur models. We used a newly designed implant that can be used much the same way as stem used in either in PFN or hip prosthesis on the same femoral model. In PFN embedded model, absence of the LT changed the direction of stress distribution from anteromedial to posterolateral. In hip prosthesis model, the absence of LT changed the direction of stress distribution from posterolateral to anteromedial. Comparison of the deformation values for both implants with fractured LT did not reveal any significant effect of LT on the hip prosthesis. During our literature research, we were unable to detect any valuable data about the role of LT on implant stability.

Ehrnthaller et al.[6] reported that LT plays a significant role on the stability of osteoporotic PFFs. This study used 21 fresh frozen osteoporotic femora of 12 females and compared three different fixation models and role of LT on stability. Do et al.[7] showed that the volumetric ratio of LT/greater trochanter can be used to predict stability of intertrochanteric femoral fracture.

Due to unstable hip fracture, primary stability of the fixation may not allow full weight bearing and secondary operations due to implant failure may occur.

For this reason, calcar replacement hemiarthroplasty is usually advocated due to possible failure in such patients.[16]

Bao et al.[17] suggested that retaining of LT and reconstruction of calcar femorale are important for improving periprosthetic biomechanics and reducing local complications. According to our results, deformation values of hip prosthesis were affected more than two and a half times if iliopsoas tendon was avulsed. Lesser trochanter fracture revision should be further analyzed for improving the stability of hip prosthesis.

In this study, the greatest limitation is the FEA/experimental study design. Thus, our findings should be improved with biomechanical and clinical studies. Our values were conducted in static conditions, while values may vary in dynamic conditions. According to ISO 7206-4,[18] stems of total hip prosthesis are loaded at 2.99 kN and 1.2 kN for primary and revision prostheses, respectively. The reason is that anatomical loading conditions are such according to the related standard and this value was accepted as reference for the current study. Our study provided numerical results that are comparative on same bone and implant.

In conclusion, the stress distribution and deformation values on hip joint are not significantly different from each other with intact or fractured LT modelling for hip prosthesis implant designs. In contrast, the stress distribution values for PFN implant designs with intact or fractured LT were significantly different. In this study, we have shown that LT does not have any important role on hip prosthesis stability, while LT does play an important role on PFN implant stability. On the other side, it is known that reduction and fixation of the LT protect medial stability and avoid long-term implant failure. Additionally, when clinically considered, prosthetic fixation is open reduction and LT fixation can be performed anatomically. Proximal femoral nail fixation is closed reduction and anatomical fixation of LT may not be possible. Strengthening the iliopsoas tendon may affect stability when LT cannot be fixated. However, since this is a FEA study, there is need for further experimental and clinical work on this subject.

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Declaration of conflicting interests

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REFERENCES

1. Schipper IB, van der Werken C. Unstable trochanteric frac- tures and intramedullary treatment. The influence of fracture patterns on complications and outcome. Eur J Trauma 2004;30:29-34.
2. Konya MN, Korkusuz F, Maralcan G, Demir T, Aslan A. The use of a proximal femoral nail as a hip prosthesis: A biomechanical analysis of a newly designed implant. Proc Inst Mech Eng H 2018;232:200-6.
3. Esen E, Dur H, Ataoğlu MB, Ayanoğlu T, Turanlı S. Evaluation of proximal femoral nail-antirotation and cemented, bipolar hemiarthroplasty with calcar replacement in treatment of intertrochanteric femoral fractures in terms of mortality and morbidity ratios. Eklem Hastalik Cerrahisi 2017;28:35-40.
4. Sofu H, Üçpunar H, Çamurcu Y, Duman S, Konya MN, Gürsu S. Predictive factors for early hospital readmission and 1-year mortality in elder patients following surgical treatment of a hip fracture. Ulus Travma Acil Cerrahi Derg 2017;23:245-50.
5. Altay MA, Ertürk C, Işıkan UE. Bipolar hemiarthroplasty for the treatment of femoral neck fractures and the effect of surgical approach on functional results. [Article in Turkish] Eklem Hastalik Cerrahisi 2010;21:136-41.
6. Ehrnthaller C, Olivier AC, Gebhard F, Dürselen L. The role of lesser trochanter fragment in unstable pertrochanteric A2 proximal femur fractures - is refixation of the lesser trochanter worth the effort? Clin Biomech (Bristol, Avon) 2017;42:31-37.
7. Do JH, Kim YS, Lee SJ, Jo ML, Han SK. Influence of fragment volume on stability of 3-part intertrochanteric fracture of the femur: a biomechanical study. Eur J Orthop Surg Traumatol 2013;23:371-7.
8. Damsgaard M, Rasmussen J, Christensen ST, Surma E, de Zee M. Analysis of musculoskeletal systems in the AnyBody modeling system. Simul Model Pract Theory 2006;14:1100-11.
9. Klein Horsman MD, Koopman HF, van der Helm FC, Prosé LP, Veeger HE. Morphological muscle and joint parameters for musculoskeletal modelling of the lower extremity. Clin Biomech (Bristol, Avon) 2007;22:239-47.
10. Azboy I, Demirtaş A, Gem M, Cakır IA, Tutak Y. A comparison of proximal femoral locking plate versus 95-degree angled blade plate in the treatment of reverse intertrochanteric fractures. Eklem Hastalik Cerrahisi 2014;25:15-20.
11. Konya MN, Verim Ö. Numerical Optimization of the Position in Femoral Head of Proximal Locking Screws of Proximal Femoral Nail System; Biomechanical Study. Balkan Med J 2017;34:425-31.
12. 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;45:2045-50.

13. Oken OF, Soydan Z, Yildirim AO, Gulcek M, Ozlu K, Ucaner A. Performance of modified anatomic plates is comparable to proximal femoral nail, dynamic hip screw and anatomic plates: finite element and biomechanical testing. Injury 2011;42:1077-83.
14. Staszkiewicz R, Chwała W, Forczek W, Laska J. Influence of surface on kinematic gait parameters and lower extremity joints mobility. Acta Bioeng Biomech 2012;14:75-82.
15. Aprato A, Lo Baido R, Crosio A, Matteotti R, Grosso E, Massè A. Does lesser trochanter implication affect hip flexion strength in proximal femur fracture? Eur J Trauma Emerg Surg 2015;41:523-9.
16. Kim SY, Kim YG, Hwang JK. Cementless calcar-replacement hemiarthroplasty compared with intramedullary fixation of unstable intertrochanteric fractures. A prospective, randomized study. J Bone Joint Surg [Am] 2005;87:2186-92.
17. Bao NR, Zhao JN, Zhou LW, Zeng XF, Guo T. Complications of bipolar hemiarthroplasty for the treatment of unstable intertrochanteric fractures in the elderly. Zhongguo Gu Shang 2010;23:329-31. [Abstract]
18. ISO 7206-4:2010, Implants for surgery - Partial and total hip joint prostheses - Part 4: Determination of endurance properties and performance of stemmed femoral components. Available from: https://www.iso.org/standard/42769.html.