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Research Article

Finite Element Analysis of Unicondylar Knee Arthroplasty Combined with Proximal Fibular Osteotomy

Proksimal Fibular Osteotomisi ile Kombine Tek Kompartmanlı Diz Artroplastisinin Sonlu Eleman Analizi ile İncelenmesi

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Abstract: Besides conservative methods, various surgical treatment modalities including high tibial osteotomy (HTO), unicondylar knee arthroplasty (UKA) and total knee arthroplasty (TKA) have been applied for the treatment of medial gonarthrosis. Combined application of UKA and PFO may enable longer implant survival by reducing the load over the implant and subsequent implant wear. We aimed to investigate on a finite element (FE) model, whether integrating a fibulectomy would reduce the contact stresses on the UKA implant. Finite Elements model developed to evaluate changes in the biomechanical environment resulting from UKA implantation and fibula osteotomy for use in the study. Menisci, bone and implants modeled as linear elastic isotropic material. We developed a 3D knee joint model with UKA implant and performed PFO on this model. A vertical load of 800N was applied anatomically to the femoral head. Stress on the tibial component was assessed before and after fibulectomy was performed. The contact stress was evaluated for UKA the mean stress (10,2 MPa ± 6,8) and for UKA + Fibulectomy (9,44 MPa ± 6,5). Combined application of PFO and UKA reduced contact stresses over the implant on a Finite Element Model. The findings of our observe additionally offer which might also additionally enhance the affected patient satisfaction, medical effects and implant survivorship of UKA.

Keywords: unicondylar knee arthroplasty, proximal fibular osteotomy, finite element analysis

Özet: Konservatif yöntemlerin yanı sıra, medial gonartroz tedavisi için yüksek tibial osteotomi (HTO), unikondiler diz artroplastisi (UKA) ve total diz artroplastisi (TKA) gibi çeşitli cerrahi tedavi yöntemleri uygulanmaktadır. UKA ve PFO'nun birlikte uygulanması, implant üzerindeki yükü ve ardından implant aşınmasını azaltarak daha uzun implant ömrü sağlayabilir. UKA implantı üzerinde fibulektominin uygulanması implant üzerindeki temas stresini azaltıp azaltmayacağını sonlu elemanlar (FE) modeli üzerinde araştırmayı amaçladık. Çalışmada kullanılmak üzere UKA implantasyonu ve fibula osteotomisinden kaynaklanan biyomekanik ortamdaki değişiklikleri değerlendirmek için Sonlu Elemanlar modeli geliştirildi. Menisküs, kemik ve implantlar lineer elastik izotropik malzeme olarak modellendi. UKA implantı ile 3B diz eklemi modeli oluşturulup bu model üzerinde PFO uygulanmıştır. Anatomik olarak femur başına 800N luk dikey yük uygulandı. Fibulektomi yapılmadan önce ve sonra tibial komponent üzerindeki stres değerleri değerlendirildi. Temas stresi, UKA için ortalama (10,2 MPa ± 6,8) ve UKA + Fibulektomi için (9,44 MPa ± 6,5) olarak raporlandı.
PFO ve UKA'nın birlikte uygulanması, Sonlu Elemanlar Modelinde implant üzerindeki temas gerilimlerini azaltmıştır. Gözlemlerimizin bulguları ayrıca UKA'nın etkilenen hasta memnuniyetini, tıbbi etkileri ve implant ömrünü artırabilecek ek bir öneri sunmaktadır.

Anahtar Kelimeler: unikondiler diz artroplastisi, proksimal fibular osteotomi, sonlu eleman analizi

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1.Introduction

Knee osteoarthritis affects %12.1 of population older than 60 years old. (1) The medial compartment is 10 times more prone to develop arthritis than the lateral side of the knee. (2) Symptoms of the patients with gonarthrosis also arises more from the medial compartment. Both anatomical and mechanical factors have been accused for this pathology. (3,4) The normal mechanical axis of the lower limb (the line which is drawn through the center of the femoral head and to the center point of the ankle joint) passes medial to the center point of the knee joint, thus leading to direct %60-80 of the body weight to the medial compartment. Also, narrow meniscal surface area and thinner cartilage on the medial side contributes to the development of arthrosis. (5)

Besides conservative methods, various surgical treatment modalities including high tibial osteotomy (HTO), unicondylar knee arthroplasty (UKA) and total knee arthroplasty (TKA) have been applied for the treatment of medial gonarthrosis. Proximal fibular osteotomy (PFO) is a simple and relatively new approach which is gaining popularity recently. PFO basically consists of removing a 10 mm piece of fibula, 6 to 9 cm below the fibular head. PFO was described incidentally in the early 2000s, based on "follow-up observations of prisoners with medial arthritis of the knee who had relief in symptoms, after proximal fibular fractures frequently encountered in riots" (6). PFO is believed to weaken the lateral fibular support leading to a correction of the varus deformity, with the assumption that the medial part of the knee has only one cortical wall whereas the lateral side of the knee is supported by three cortices, one of tibia and two of fibula.(7) Accordingly, PFO applications may reduce the contact forces between medial femoral condyle and medial tibial plateau. Recently satisfying clinical results of PFO have been reported in the literature. (8-10)

UKA has gained popularity due to its advantages over TKA, which can be counted as faster recovery time, shorter length of hospital stay, smaller incisions and minimal bone resection.(11-13) However, concerns about the long term outcomes of UKA applications still remain. Although intraoperative and postoperative complication rates of UKA are reported to be lower than TKA, yet revision rates appear significantly higher in the literature.(14) Besides aseptic loosening, dislocation of bearing, infection, contralateral osteoarthritis and tibial plateau fracture; polyethylene wear and breakage is among the major revision reasons of UKA.(15,16) The favorable outcomes of PFO resulting from a neutral lower limb alignment, soft tissue rebalance and reduction of the load on medial compartment may overcome these important revision causes. Our hypothesis for this study was combined application of UKA and PFO may enable longer implant survival by reducing the load over the implant and subsequent implant wear. For this purpose, we developed a 3D knee joint model with UKA implant and performed PFO on this model. We aimed to investigate on a finite element (FE) model, whether integrating a fibulectomy would reduce the contact stresses on the UKA implant.

2.Materials and Methods

Knee Model Design

Femur, Tibia and Fibula bone samples forming the knee joint were obtained from open access CAD modeling website. Three-dimensional (3D) reconstruction and editing of the knee joint model were performed in Meshmixer (Autodesk Inc., San Rafael, CA, USA). The initial graphics exchange specification files exported from Meshmixer were processed into Solidworks (Dassault Systems Simulia Corp., Providence, RI, USA) to form solid models.

The menisci model was created using the Solidworks software semi-automatically according to the geometrical surface of the distal femur and proximal tibia. Based on Oxford unicondylar knee replacement (Biomet UK Ltd., Swindon, UK) manufacturer catalog, femoral and tibial compartments CAD supported drawings were performed. All solids were imported to analysis software (ANSYS 2020 R1, ANSYS Inc., Houston, TX, USA).

Finite Element Analysis

Finite Elements model was developed to evaluate changes in the biomechanical environment resulting from UKA implantation and fibula osteotomy for use in the study. Menisci, bone and implants were all modeled as linear elastic isotropic material, as previously described(17).

The prosthesis sizing was modeled with Solidworks software, taking into account the dimensions of the knee anatomy, with reference to the Oxford Partial Knee Prosthesis manufacturer guide (Fig.1). Solid models of Oxford UKA (Biomet UK Ltd., Swindon, UK) were offered by the manufacturer and implanted into the intact knee model(Fig.2). Bones were trimmed and implanted virtually with the prostheses according to the standard surgical procedure for creating the UKA FE model in Ansys Workbench 2020 R1.

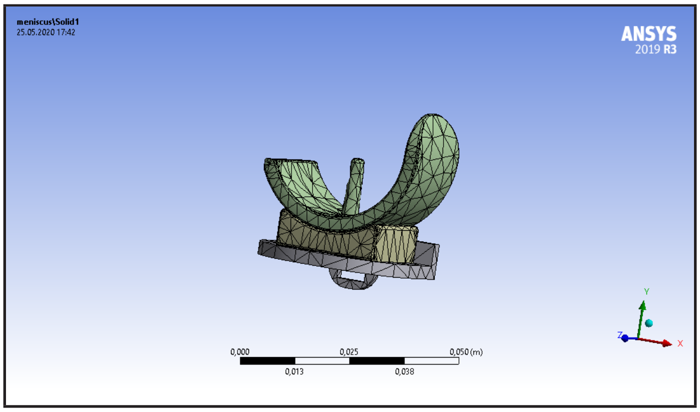

Figure 1: Oxford Partial Knee Prosthesis Design

Based on the results of the mesh convergence analysis, 2 mm element edge lengths were used for all components. The bone was represented with a single isotropic elastic modulus of 17,000 MPa. A uniform Poisson's ratio of 0.3 was assigned for all bone elements. The elastic modulus for the menisci 80 MPa Poisson's ratio 0.3 was assigned for menisci (18). Oxford Partial Knee Prosthesis and the elastic module as the tibial component isotropic material were determined as 195.000 MPa and the Poisson ratio as 0.3. The tibial insert was given as UHMWPE with a 165 mPa possin ratio of 0.4. During simulation, the distal fibula and tibia were constrained in all degrees of freedom. For model simplification and to focus on the joint stress under a maximum physiologic load condition during gait, a single-leg stance was assessed. A vertical load 800 N, was applied to the proximal femur. The stress over the tibial component was evaluated before and after performing a fibulectomy.

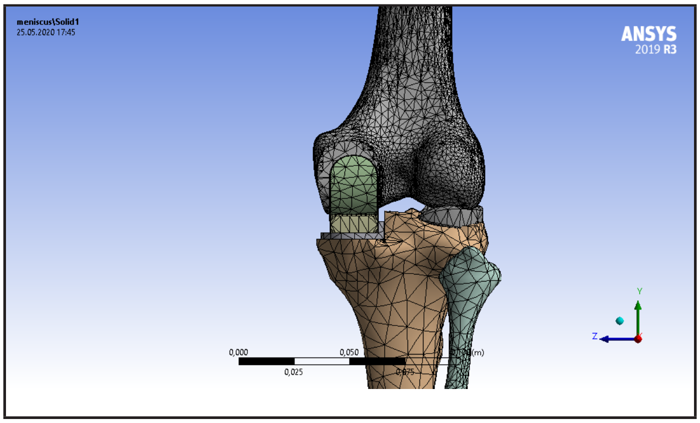

Figure 2: Oxford UKA implanted knee model

3.Results

The change in stress contour of the tibial component was evaluated at 4 points (medial-lateral, anterior-posterior) in intact fibula (A) and fibulectomy (B) groups (Fig. 3). The tibial insert stress values for the analyzed knee models are given in Table 1. The values of contact stress over the tibial insert slightly reduced after proximal fibular osteotomy compared to the other group. It was observed that some part of the load was transferred to the lateral region after fibulectomy.

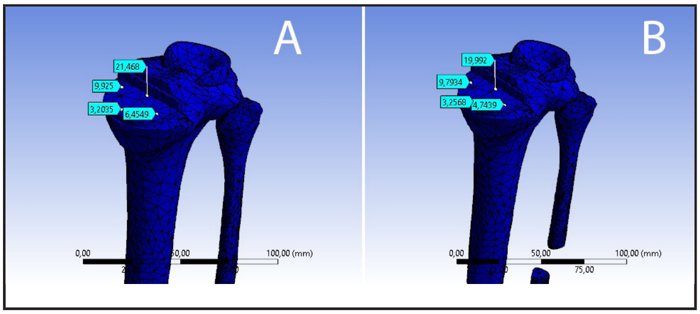

Figure 3: A) UKA implanted Intact Model B) UKA implanted + Fibulectomy

The contact stress was evaluated femoral head at 800 N with for UKA the mean stress (10,2 MPa ± 6,8) and for UKA + Fibulectomy (9,44 MPa ± 6,5).

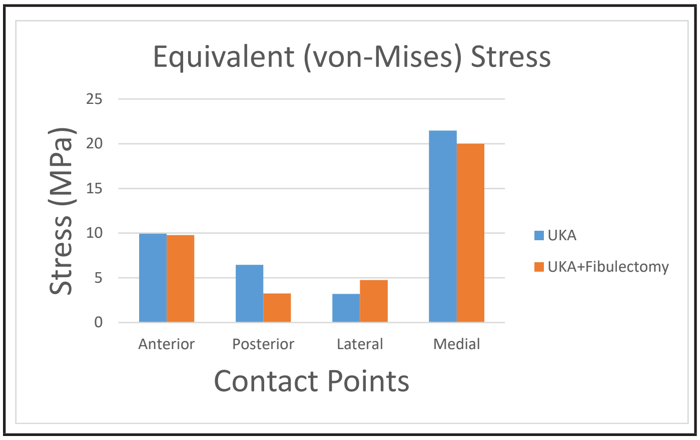

Table 1: Tibial insert contact stress values

4.Discussion

Our study proved our hypothesis suggesting that implementing of fibulectomy to UKA reduces contact stresses over the prosthesis. Results obtained from our finite element model revealed a favorable decrease of stress over the implants on medial knee joint. To the best of our knowledge this is the first study to evaluate the stress on UKA implants after PFO.

UKA provides faster pain relief and return to daily activities with less morbidities and complications compared to TKA. (11-13) However, implant survival and revision rates still remain a topic of debate. In their systematic review Kim et al. reported a revision rate of 4.6% (146 of 3138 knees) (15). Risk of revision is significantly higher for obese and morbid obese patients compared to non-obese patients(19). Varus malalignment is also considered an important risk factor for poor results after UKA. One of the initial strict selection criteria proposed by Kozinn and Scott was that medial UKA should only be performed in patients with a preoperative varus deformity of 15° or less.(20) Postoperative varus alignment was associated with increased compartment forces by overloading medially, which can ultimately lead to UKA failure from polyethylene wear or aseptic loosening.(20,21) Both varus malalignment and obesity are accused of increasing the load on the medial compartment of the knee leading to these unsatisfactory results.

On the other hand, it is shown that PFO reduces contact stresses on the medial side of the knee. Nie et al has demonstrated that PFO provides plausible biomechanical evidence for the improvement in clinical symptoms.(23) Pan et al. also presented decreased VonMises stress values on the medial knee joint after partial fibulectomy on a FE model and recommended PFO for the treatment of medial gonarthrosis with varus deformity. (24) Yazdi et al. tested the same effect on cadaver knees in their biomechanical study and they reported a decrease in the medial joint compartment. (25) All the above mentioned studies have evaluated native knee joints, whereas we developed a model utilizing UKA prosthesis. Our study also revealed a similar decrease of contact stresses over the implants placed on the medial compartment of the knee.

The only clinical application of simultaneous PFO and UKA in the literature was the case report of our patient. (26) The clinical follow-up of a 68 year old female patient who underwent bilateral UKA for medial gonarthrosis revealed a slightly better pain and functional outcomes in terms of VAS and AKS scores on the right knee which received UKA+PFO than the left knee. In light of this peculiar case, the potential benefits of the combination of PFO and UKA was considered as the reduction of loads over the implants on the medial compartment based on the widening of the joint space and varus deformity correction. Our FE analysis also supported the clinical observations obtained from this single case experience.

5. Conclusion

Combined application of PFO and UKA reduced contact stresses over the implant on a FE model. The findings of our study may provide an important basis to interpret in clinical practice by implementation of PFO to UKA which may improve the patient satisfaction, clinical outcomes and implant survivorship of UKA.

Combined utility of PFO and UKA decreased touch stresses over the implant on a FE model. The findings of our observe might also additionally offer an essential foundation to interpret in medical exercise with the aid of using implementation of PFO to UKA which might also additionally enhance the affected person satisfaction, medical effects and implant survivorship of UKA.

Conflict of Interest

The authors declare that they have no competing interests.

References

1. Dillon CF, Rasch EK, Gu Q, Hirsch R. Prevalence of knee osteoarthritis in the United States: arthritis data from the Third National Health and Nutrition Examination Survey 1991-94. J Rheumatol. 2006;33:2271-9.

2. Felson DT, Lawrence RC, Dieppe PA, Hirsch R, Helmick CG, Jordan JM, Kington RS, Lane NE, Nevitt MC, Zhang Y, Sowers M, McAlindon T, Spector TD, Poole AR, Yanovski SZ, Ateshian G, Sharma L, Buckwalter JA, Brandt KD, Fries JF. Osteoarthritis: new insights. Part 1: the disease and its risk factors. Ann Intern Med. 2000;17;133:635-46.

3. Dearborn J, Eakin C, Skinner H: Medial compartment arthrosis of the knee. Am J Orthop. 1996, 25:18-26.

4. Bartel DL: Unicompartmental arthritis: biomechanics and treatment alternatives . Instr Course Lect. 1992, 41:73.

5. Wu L, Hahne HJ, Hassenpflug T: A long-term follow-up study of high tibial osteotomy for medial compartment osteoarthrosis. Chin J Traumatol. 2004,;7:348-53.

6. Prakash L: PFO - Proximal Fibular Osteotomy in Medial Compartment Arthritis of the Knee with Varus Deformity. EC Orthopaedics, 2019.

7. Yang ZY, Chen W, Li CX, et al.Medial compartment decompression by fibular osteotomy to treat medial compartment knee osteoarthritis: a pilot study. Orthopedics. 2015;38:1110-14.

8. Liu B, Chen W, Zhang Q, Yan X, Zhang F, Dong T, Yang G, Zhang Y. Proximal fibular osteotomy to treat medial compartment knee osteoarthritis: Preoperational factors for short-term prognosis. PLoS One. 2018;13:e0197980.

9. Zou G, Lan W, Zeng Y, Xie J, Chen S, Qiu Y. Early clinical effect of proximal fibular osteotomy on knee osteoarthritis. Biomedical Research (2017) Volume 28, Issue 21

10. Vaish A, Kathiriya YK, Vaishya R. A critical review of proximal fibular osteotomy for knee osteoarthritis. Archives of Bone and Joint Surgery. 2019;7:453.

11. Drager J, Hart A, Abou Khalil J, Zukor DJ, Bergeron SG, Antoniou J. Shorter hospital stay and lower 30-day readmission after unicondylar knee arthroplasty compared to total knee arthroplasty. The Journal of arthroplasty. 2016;31:356-61.

12. Pandit H, Jenkins C, Barker K, et al. The Oxford medial unicompartmental knee replacement using a minimally-invasive approach. J Bone Joint Surg (Br). 2006;88:54–60.

13. Demirkiran ND, Ozmanevra R. Neutrophil to lymphocyte ratio of patients who underwent bilateral versus unilateral unicompartmental knee arthroplasty. Medicine.2020;9:227-30.

14. Chawla H, van der List JP, Christ AB, Sobrero MR,Zuiderbaan HA, Pearle AD. Annual revision rates of partial versus total knee arthroplasty: a comparative meta-analysis. The Knee. 2017;24:179-90.

15. Kim SJ, Postigo R, Koo S, Kim JH. Causes of revision following Oxford phase 3 unicompartmental knee arthroplasty. Knee Surgery, Sports Traumatology, Arthroscopy.2014 ;22:1895-901.

16. Dyrhovden GS, Lygre SH, Badawy M, Gøthesen Ø, Furnes O. Have the causes of revision for total and unicompartmental knee arthroplasties changed during the past two decades?. Clinical Orthopaedics and Related Research®.2017;475:1874-86.

17. Kwon OR, Kang KT, Son J, Kwon SK, Jo SB, Suh DS, Choi YJ, Kim HJ, Koh YG J Biomechanical comparison of fixed- and mobile-bearing for unicomparmental knee arthroplasty using finite element analysis Orthop Res. 2014; 32:338-45

18. Hopkins AR, New AM, Rodriguez-y-Baena F, Taylor M. Finite element analysis of unicompartmental knee arthroplasty. Med Eng Phys. 2010;32:14-21.

19. Kandil A, Werner BC, Gwathmey WF, Browne JA. Obesity, morbid obesity and their related medical comorbidities are associated with increased complications and revision rates after unicompartmental knee arthroplasty. The Journal of arthroplasty. 2015;30:456-60.

20. Kozinn SC, Scott RI. Unicondylar knee arthroplasty. JBJS. 1989;71:145-50.

21. Collier MB, Eickmann TH, Sukezaki F, McAuley JP, Engh GA. Patient, implant, and alignment factors associated with revision of medial compartment unicondylar arthroplasty. The Journal of arthroplasty. 2006;21:108-15.

22. Gulati A, Pandit H, Jenkins C, Chau R, Dodd CA, Murray DW. The effect of leg alignment on the outcome of unicompartmental knee replacement. The Journal of bone and joint surgery. British volume. 2009;91:469-74.

23. Nie Y, Ma J, Huang Z, Xu B, Tang S, Shen B, Kraus VB, Pei F. Upper partial fibulectomy improves knee biomechanics and function and decreases knee pain of osteoarthritis: a pilot and biomechanical study. Journal of biomechanics. 2018;11;71:22-9.

24. Pan D, TianYe L, Peng Y, JingLi X, HongZhu L, HeRan Z, QingWen Z, LeiLei C, ZhenQiu C, QiuShi W, Wei H. Effects of proximal fibular osteotomy on stress changes in mild knee osteoarthritis with varus deformity: a finite element analysis. Journal of Orthopaedic Surgery and Research. 2020 ;15:1-0.

25. Yazdi H, Mallakzadeh M, Mohtajeb M, Farshidfar SS, Baghery A, Givehchian B. The effect of partial fibulectomy on contact pressure of the knee: a cadaveric study. European Journal of Orthopaedic Surgery & Traumatology.2014;24:1285-9.

26. Demirkıran ND. Simultaneous Application of Proximal Fibular Osteotomy and Unicondylar Knee Arthroplasty. Cureus. 2019;11:e4763