Original Article / Özgün Araştırma

Meandros Med Dent J
doi:10.4274/meandros.galenos.2023.65390
Meandros Med Dent J 2023;24(3):237-241



# Mechanical Effects of Different Femoral Stem Diameters of Distal Tumor Prosthesis on Femoral Cortex

## Distal Tümör Protezlerinde Farklı Femoral Stem Çaplarının Femoral Korteks Üzerindeki Mekanik Etkileri

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## Abstract

**Objective:** Distal femur tumor prostheses are often used in tumor surgery. One of the critical complications of these prostheses is the insufficiency of stems. The stems are used on several orthopedic implants to provide stability and strength to the bone-implant connection. This study aimed to determine the mechanical effects of the stem diameter on tumor prostheses.

**Materials and Methods:** Finite element analysis was performed on three distal femur tumor prosthesis designs implanted in the femur with different stem diameters (12, 14 and 15 mm) with the same stem length of 140 mm. A statically axial compression load of 800 N was applied to the femur, and stress values on the stems and femoral cortexes were calculated and compared.

**Results:** The stress measurements on the femur shaft were 49.289, 48.987 MPa and 45.424 MPa for stem diameters of 12, 13 and 15 mm, respectively, and on the distal portion of the femur were 61.205, 59.39 MPa and 52.526 MPa. For each diameter, the proximal stems had 301.24 MPa, 273.84 MPa, and 228.19 MPa stress values, whereas the distal stems had 365.49 MPa, 305.91 MPa and 275.41 MPa for diameters of 12, 14, and 15 mm.

**Conclusion:** Finite element model analysis indicated that when the stem diameter increases, the maximum stresses on the femoral cortex and stem decrease.

**Keywords:** Finite element analysis, stem diameter, tumor prosthesis

## Öz

**Amaç:** Distal femur tümör protezleri tümör cerrahisinde sıklıkla kullanılmaktadır. Bu protezlerin kritik komplikasyonlarından biri de stemlerin yetersizliğidir. Protezin stem (sap) kısımları, kemik-implant bağlantısına stabilite ve güç sağlamak için çeşitli ortopedik implantlarda kullanılır. Bu çalışma, stem çapının tümör protezleri üzerindeki mekanik etkilerini belirlemeyi amaçlamaktadır.

**Gereç ve Yöntemler:** Farklı gövde çaplarına (12, 14 ve 15 mm) ve aynı gövde uzunluğu 140 mm'ye sahip femura implante edilmiş üç distal femur tümör protezi tasarımına sonlu elemanlar analizi gerçekleştirildi. 800N statik eksenel kompresyon yükü femura uygulandı ve stemler ile femoral korteksler üzerindeki stres değerleri hesaplandı ve karşılaştırıldı. Femura 800N statik eksenel yük uygulanarak stemler ve femoral korteksler üzerindeki stress değerleri hesaplandı ve karşılaştırıldı.

**Bulgular:** Femur şaftındaki stres ölçüm değerleri, 12 mm, 13 mm ve 15 mm gövde çapları için sırasıyla 49.289 MPa, 48.987 MPa ve 45.424 MPa ve femurun distal kısmında 61.205 MPa, 59.39 MPa ve 52.526 MPa'dır. Her bir çap için stemlerin proksimali 301.24 MPa, 273.84 MPa ve 228.19 MPa stres değerlerine sahipken, stemlerin distalleri 12, 14 ve 15 mm çaplar için 365.49 MPa, 305.91 MPa ve 275.41 MPa stres değerlerine sahiptir.

**Sonuç:** Sonlu elemanlar analizi, stem çapı arttıkça femoral korteks ve stem üzerindeki maksimum stres değerlerinin azaldığını göstermiştir.

**Anahtar Kelimeler:** Sonlu elemanlar analizi, stem çapı, tümör protezi

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**Received/Geliş Tarihi:** 29.05.2023
**Accepted/Kabul Tarihi:** 11.08.2023

## Introduction

Extremity-saving surgery to treat bone and muscle tumors has frequently become applicable through advanced surgery techniques last 20 years (1). Tumor prostheses are used on revision knee and lower extremity saving surgery, unstable knees due to the damage of ligaments and tumor resections (1-3).

Endoprosthesis reconstruction has recently become a more common alternative to allograft or autograft in limb salvage procedures (4,5). The limb salvage operation usually necessitates extensive dissection in a poor medical condition host (5,6). In addition to the increased stress caused by the endoprosthesis, limited soft tissue support and constraint following the limb salvage procedure usually result in increased complications, particularly in long-term survivors (7,8).

Stems are used on several types of orthopedic implants to provide stability and strength to the bone-implant connection (9,10). The load transfer between the implant and the cortical bone is essential for implants with intramedullary stems (11-13). Implant-to-bone load transfer is affected by the implant's geometry and design in the resected bone surface area that typically separates the extramedullary and intramedullary portions of the implant (14,15).

Finite element analysis (FEA) is now the most used technique for analyzing physical phenomena in structural, solid and fluid mechanics, biomedicine, biomechanics, and orthopedics (9,16). FEA conducts analyses in two dimensions and three dimensions, linear and non-linear, static and dynamic ranges, and stress and strain fields on bones and prostheses to determine whether bones or parts of the skeleton are healthy or diseased. The models created and used for FEA should be sufficiently refined to accurately represent the geometry and mechanical behavior of the bone structure they simulate (17-19).

In this study, we aimed to determine the stress values on the femur and the stem at different stem diameters using FEA and to figure out the optimum stem diameter for the tumor prosthesis.

## Materials and Methods

A FEA was undertaken on a simplified 3D model of a tumor prosthesis with cylindrical glossy surfaces. A composite human femur's computed tomography scan created a solid femur model having 45 mm head diameter, 4 mm cortex thickness and 390 mm length from the proximal tip. And the 3D model of a distal femur hinged type tumor prosthesis was created with a modeling package of Autodesk Inventor Professional (Autodesk, San Rafael, California) and NX (Siemens Digital Industries Software, Plano, TX) software programs. The prosthesis is modeled with different stem diameters (12-14 and 15 mm) and all with a length of 140 mm. FEA was conducted to determine the bone and stem stress patterns with ANSYS Workbench software (ANSYS, Inc. Canonsburg, PA). The prosthesis was modeled using isotropic material properties for stainless steel 316 L. And the bone elements were assigned transverse isotropic cortical bone properties;

Cortical Bone: E:18,2 GPa - poison rate: 0.33

Stainless Steel: E: 193 GPa - poison rate: 0.31

The prosthesis was virtually implanted in the femur and the model was fully constrained against movement toward the distal end of the prosthesis (Figure 1). An axial load of 800N was statically applied to the head of the femur with 20° angles (oblique load) to its long axis to simulate the anatomic conditions. Stress distributions on the stem and femoral cortex resulted from static finite element analyses and were compared in all cases.

The current research does not require ethical approval as it involves no tissue and/or human material.

### Statistical Analysis

FEA is made in 3D models, so the properties of the sample entered in the computer do not change. In our study, only one prosthesis model is used, and material properties are the same, so statistical analysis is not performed.

## Results

Long-term results show advanced prosthesis loosening due to stress, as shown in theoretical biomechanical investigations (20,21). The risk of aseptic loosening rises and the surrounding bone is stress-shielded. It's

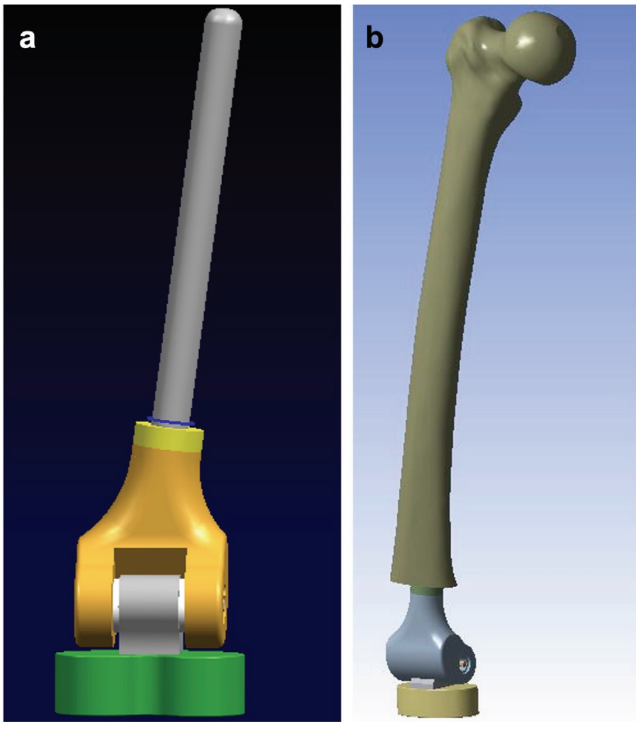


**Figure 1. (a)** 3D model of a prosthesis and **(b)** tumor prosthesis on bone

interesting to note that studies rarely attribute aseptic loosening to prosthetic design. Surprisingly, studies hardly ever link prosthetic design to aseptic loosening. The aseptic loosening processes for large tumor prostheses are probably similar to those in conventional total joint arthroplasty. They are connected to bone adaptation following changes in stress patterns. The different force orientations can subject the prosthesis to torsional, compression, shearing, and tension stress. Our FEA results indicated that the stress measurements on the femur shaft are 49.289 MPa, 48.987 MPa and 45.424 MPa for the stem diameters of 12 mm, 13 mm, and 15 mm respectively and on the distal portion of the femur is 61.205 MPa, 59.39 MPa and 52.526 MPa. For each diameter, the proximal stems have 301.24 MPa, 273.84 MPA and 228.19 MPa stress values while the distal stems having 365.49 MPa, 305.91 MPa and 275.41 MPa for the diameters of 12, 14 and 15 mm (Figure 2). And also the maximum Von-Mises stress values and locations can be seen on Figure 3.

## Discussion

The limp salvage procedure is preferred for treating bone tumors. The tumor prosthesis is used to reconstruct the skeletal system many reports in the literature concerning the performance of massive distal femoral replacements (22,23). The prosthetic stem problems are primarily seen in bone tumor treatment. Common complications include wound problems, infection, aseptic loosening, fatigue fracture, dislocation/subluxation and mechanical failure (24,25).

Knowing the biomechanical characteristics of tumor prosthesis will clinically prevent most complications, especially insufficiency of implants. Transferring the load to the prosthesis and bones regularly makes having a more prosperous and long-lived prosthesis possible.

Aseptic loosening is primarily caused by increased local stress at the bone-cement and cement-prosthesis interfaces. Other factors that contribute include direct stress and increased local bending force. Shielding after extensive soft tissue resection is one cause of increased local stress. Other causes include biological local osteolysis response to wear particle disease, infection-induced granulation tissue accumulation, and wide excision of soft tissue, which reduces soft tissue constraints to compensate for torsion.

Transitioning from an early single axial fixed-hinge knee endoprosthesis to a rotation-hinged knee prosthesis dramatically reduced aseptic loosening. There are some finite element model (FEM) studies about different tumor prostheses to determine the effects of stem designs and sizes on stress distribution at the bone and the prosthesis. The FEM results showed increasing peak cancellous stress and decreasing average proximal cancellous stress with increasing stem length. A longer stem increased the load transfer and improved the implant's stability. The amount of unloaded surrounding bone increases near the insertion level as fixation length increases. This stress shielding may cause atrophy and finally lead to aseptic loosening. Aseptic loosening is the predominant cause of failure of distal femoral replacements.

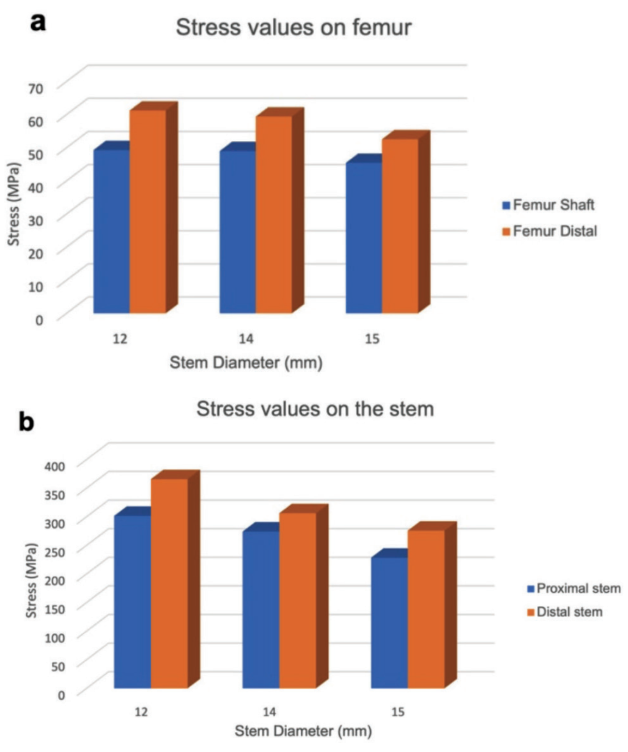


**Figure 2.** Stress values on **(a)** femur and **(b)** stem

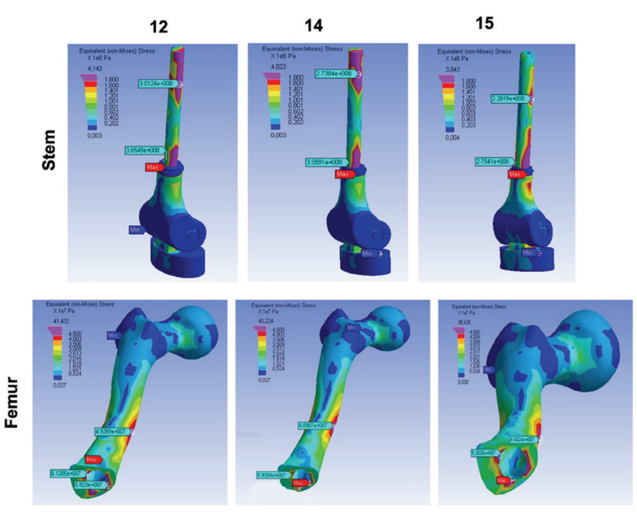


**Figure 3.** The finite element analysis on each diameter of the femur's stem and proximal medial cortex

## Conclusion

There are studies on stem diameters about the effects of stem diameters on bone-prosthesis systems. The effect of stem size on aseptic loosening and the rate of stem filling of the bone canal and durability are directly related. We think that stem diameter is a critical issue affecting the femur's stress distribution. To know the impact of stem diameter, we intended to make FEA on femur models. In this study, it is determined that increasing the diameter of the stem decreases the stresses at the femur cortex and stem of the prosthesis. When the diameter of the femoral stem is increased to the optimum value that the bone structure allows, it can be possible to reduce the stresses to the minimum levels.

### Ethics

**Ethics Committee Approval:** The current research does not require ethical approval as it involves no tissue and/or human material.

**Informed Consent:** This study does not require informed consent.

**Peer-review:** Externally peer-reviewed.

### Authorship Contributions

Concept: B.U., B.Ç., Design: B.U., Data Collection or Processing: B.U., Analysis or Interpretation: B.U., B.Ç., Literature Search: B.Ç., Writing: B.U., B.Ç.

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

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

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