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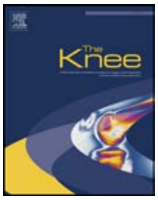

How does the inclination of the tibial component matter? A three-dimensional finite element analysis of medial mobile-bearing unicompartmental arthroplasty

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ABSTRACT

Background: Medial unicompartmental knee arthroplasty (UKA) using Oxford mobile-bearing prosthesis is performed in the treatment of medial compartmental arthritis of the knee. However, little is known about the stress distributions for mobile-bearing UKA on the medial tibial plateau.
Methods: In this study, the stresses on the coronal plane were calculated in a three-dimensional model of the proximal tibia. The features of the stress distribution were investigated when the tibial tray was placed in 15°, 10°, six degrees, and three degrees varus, neutral (0°), and in three degrees, six degrees, 10°, and 15° valgus on the coronal plane of the medial plateau.
Results: The peak von Mises stress was found on the cortex below the medial plateau while the stresses of cortical bone increased gradually as the inclination of the tibial tray was changed from varus to valgus. The amount of peak stress was almost the same as that in the normal knee model when the tibial tray was placed in six degrees valgus and consistently lower in varus inclination than in the normal knee model. Conversely, the peak stress of soft bone was found at the bottom of the slot.
Conclusions: This study demonstrates that the inclination of the tibial component affects stress distribution in the proximal tibia after UKA. Slight varus inclination of the mobile-bearing tibial component is acceptable as it lowers the peak stress on the medial cortex. Additionally, placing the tibial tray in slight varus avoids a rise in stress between the tip of the keel and the medial tibial cortex.

1. Introduction

Unicompartmental knee arthroplasty (UKA) has been performed in the treatment of unicompartmental arthritis of the knee for over 30 years, with 10 year survival rate reported as 83.7–94.4% [1–3]. There are two different designs for the tibial component, namely fixed-bearing and mobile-bearing platforms. Some believe that fixed-bearing UKA is desirable for unicompartmental arthritis [4,5], while others have reported better clinical outcomes of patient satisfaction and survival rate with mobile-bearing [6–8]. However, the surgical techniques and long-term survival rate have always been significant concerns, as Jeer et al. attributed up to 10% postoperative failure to surgical mistakes [9], and malalignment as well as imbalance resulted in higher revision rate and accelerated degenerative arthritic changes on the lateral side [5]. The mobile-bearing components are highly congruent so that the bearing contact area is maximized, resulting in thinner polyethylene (PE) insert design and lower wear rate; yet it is a technically demanding procedure that requires better soft tissue balancing and higher surgical accuracy. Although the mechanical

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axis of the lower extremity does not change as the tibial tray placement varies from varus to valgus position on the coronal plane, as long as the height of the medial joint line is maintained, it is generally believed that neutral (square) inclination is the best for mechanical stress, which has been well demonstrated in total knee arthroplasty [10]. Inappropriate inclination of the tibial component would place undue stress on both cortical and cancellous bone, which in turn compromises the stability and long-term survivorship of the prosthesis [11,12].

Previous studies on load transmission and stress distributions via finite element (FE) analysis have focused on the fixed-bearing tibial compartmental component on the medial side, which claimed that a slight valgus placement of tibial component would be preferable to varus as far as stress distribution was concerned [10,13]. In contrast, little is known about the stress distributions on the medial tibial plateau for mobile-bearing UKA and its influence on component stability. This study analyzed the effects of the inclination of the tibial component in the coronal plane on the stress profile in the proximal tibia, with the use of Oxford mobile-bearing prosthesis.

2. Materials and methods

2.1. Normal knee model

A three-dimensional (3D) model of the proximal tibia and femoral condyle was reconstructed from computed tomography (CT) scan of a healthy knee joint. The CT images were obtained from a 25 year old male (height 176 cm, weight 65 kg, right side) without any known diseases of the knee, using a high-resolution CT scanner (AQUILION64, SAHZJU; CT parameters: 120 kV, 250 mA, slice thickness of 0.5 mm and a scanning speed of 0.875 s/r). The model was established based on a parametric-combined modeling method with concordant shape and high precision. CT data were imported into Mimics (version 13.1; Materialise, Leuven, Belgium) to generate the digital models of the femur, tibia, fibula, and patella at full extension, and export them as the initial graphics exchange specification (IGES) files. Then the IGES files were imported into Rhinoceros (version 5.0; Robert McNeel & Assoc., America) to build the 3D model of the healthy knee, which was saved as standard ACIS text (SAT) files. Finally, the FE model of the healthy knee was developed using Abaqus (version 6.10; ABAQUS, America) with SAT files.

2.2. UKA model

Once the healthy normal knee model was developed, a mobile-bearing UKA (Oxford Partial Knee System, Biomet, Warsaw, IN) was selected and virtually implanted in the medial compartment of the knee model using Rhinoceros. In the simulation, cutting and punching were performed on the distal femur to fully bond the femoral component to the femur model. The mobile-bearing PE insert was free to shift and rotate with respect to the surface of the femoral component. The tibial model was reconstructed where the tibial tray was placed in full contact with the undersurface of the PE insert. The stress profiles in nine orientations were tested in the model, where the tibial tray was placed in 15°, 10°, six degrees, and three degrees varus, neutral, and in three degrees, six degrees, 10°, and 15° valgus with a constant seven degree posterior slope. At each degree of inclination of tibial tray, a corresponding amount of the bone stock on the medial plateau was removed to maintain the height of the medial joint line and thus the mechanical axis of the lower extremity. When the cutting plane changed, the PE insert between the components moved medially or laterally in an effort to maintain a congruent and stress-balanced joint. The test results were stored in SAT files for the establishment of FE model with Abaqus.

2.3. Loading and boundary conditions

Abaqus was used to perform all the FE simulations, and all material properties incorporated into the FE model are provided in Table 1. Contact condition was applied between the PE insert and metal while the coefficient of friction was set at zero. Although the value zero is impossible in real life, we tried to simulate the perfect static status of the mobile-bearing knee system in full extension. The rationale is that stability is maintained not because of the friction between the components, but the balance achieved by all the forces contributed by the ligaments, capsule, surrounding muscles, and so on, as was described in literature [14]. The prosthetic components and bone were tightly bonded. The interfaces between prosthetic components and bone were assumed to be rigidly and perfectly fixed, so the cementing or bone ingrowth was not taken into consideration in the computing model, similar to previous studies [15,16].

Table 1
Material properties incorporated into the finite element model.

	Young's modulus (MPa)	Poisson's ratio
Cortical bone	17,000	0.30
Cancellous bone	400	0.20
Prostheses	200,000	0.30
Polyethylene insert	700	0.30
Meniscus	59	0.46

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