Numerical Simulation of Contact Pressure in Fixed- and Mobile-Bearing Total Knee Arthroplasty

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Abstract

In this paper, a comparative study of total knee arthroplasty (TKA) between fixed- and mobile-bearing implants is presented. Reverse engineering techniques including finite element analysis were used to evaluate the mechanical characteristics in terms of the stress distribution. A virtually bearing load based on four different stages of gait cycle (0° to 60° flexion) was performed. The maximum contact pressure and contact area of tibial inserted component were evaluated. According to the results, the magnitude of maximum contact pressure in fixed-bearing implant increased significantly when compared to a mobile-bearing implant from 0° to 60° flexion. The contact area of mobile-bearing implant tended to decreased from 0° to 60° flexion of gait cycle. However, the contact area of the tibial inserted component in a mobile-bearing implant was significantly higher than those of a fixed-bearing implant. The body bearing weight had less influence on the maximum contact pressure as well as contact area in the mobile-bearing implant than fixed-bearing implant.

Keywords: Total Knee Arthroplasty, Tibial inserted component, Contact pressure, Finite element analysis.

1. Introduction

Total knee arthroplasty (TKA) has become a widely accepted surgical procedure in which parts of the knee joint are replaced with artificial parts. However, the failure of TKA has been widely reported, for example there are common failures related to polyethylene wear and aseptic loosening.

First wear of the polyethylene is affected by the abutting surfaces, the thickness of the polyethylene insert and the mechanical properties of the polyethylene⁽¹⁾. It is also a result of loads, contact friction and kinematics⁽²⁾. Multidirectional motions on the insert-femoral joint cause to more polyethylene wear. The mechanical wear of polyethylene is also related to contact areas and to the dimension of contact pressure. The contact pressure and contact areas lie to the flexion of according and operative techniques. It is found that aseptic loosening usually results from malalignment⁽³⁾. A set of TKA components include: an anatomically shaped distal femoral, a nearby tibial inserted component. That is usually made of ultra high molecular weight polyethylene (UHMWPE).

Commercially, TKA devices can be classified into two groups: fixed- and mobile-bearing⁽⁴⁾. According to design principals, fixed-bearing concept was designed based on the snapped insertion or press fitted into the tibial component. As, the design concept of mobile-bearing knees was used the motion of the knee at two articulating surfaces. Such designs vary according to the kinematics and cause axis of rotation of the knee⁽²⁾.

The finite element method was used to forecast the stress distribution in TKA during the gait cycle⁽⁵⁾. This study is based on the assumption that the form of contact pressure at the tibial insert component of TKA at each step of the gait cycle maybe descriptor of the wear of tibial inserted component. The knowledge of contact pressures and contact areas in TKA are deem a dependable tool for predicting the wear of insert.

2. Finite Element Modeling of TKA

2.1 TKA Modeling

Fig.1. Mobile-bearing (left) Fixed-bearing (right).

The mobile-bearing system is characterized by a large surface contact of the articulating components. The high congruency allows for optimal load distribution resulting in an increased longevity of the implant. There are UHMWPE-inserts of different congruency available.

The fixed-bearing is used for the functional replacement of the posterior cruciate ligament. The presence of the femoral spindle and the UHMWPE-peg results in a posterior stabilization of the knee joint during articulation between femoral and tibial component.

Fig. 2. Reverse engineering.

Fig. 3. The insert fixed-and mobile-bearing component.

Reverse engineering techniques were used to create the models seem as prototypes. There are uses of the principles of reverse engineering to simulate the finite element method of total knee arthroplasty (as shown in fig 2 and fig 3.).

2.2 FE Modeling

Fig. 4. Composition of TKA tests.

Fig. 5. Composition of TKA tests.

Finite element models of fixed- and mobile-bearing knee implants were developed in ANSYS Workbench as shown in figure 4 and figure 5.

2.3 Material properties

The material for the femoral component, tibial insert component and tibial order are Cr-Co alloy, UHMWPE and Cr-Co alloy⁽⁶⁾. (Table 1. and Fig.6.)

Table 1. Mechanical properties of TKA materials.

Materials	$E(MPa)$	ν
Co-Cr	240,000	0.3
UHMWPE	550	0.46
Steel	200,000	0.3

Fig. 6. Non-linear true stress-strain behavior of UHMWPE.

2.4 Boundary conditions

This is research the mesh topology used for the model is the shell element type defined for the solid force and the solid element type femoral, insert and tibial for the TKA.

The total number of elements in the model is 42,639 elements, which yield stability of the computational result in terms of the contact pressure and contact area. A coefficient of friction between Cr-Co femoral and polyethylene insert of 0.04 was chosen to be consistent with the literature ⁽¹⁾. Four different stages of the gait cycle (0°, 15°, 45°, 60° flexion) were simulated (fig. 7). At each load stage, the tibial was fixed to the ground and a vertical axial load was applied at the femoral component. The vertical loads were 2000 N, 2200 N, 3200 N and 2800 N at 0°, 15°, 45° and 60° flexion, respectively as shown in fig. 7.

Fig. 7. The four configurations tested.

3. Results and Discussion

The results of the contact pressure distribution of the neutral and malalignment positions are shown in fig. 8 and fig. 9. The position of knee joint 0 to 60 flexion. The maximum contact pressure (IC) of fixed-bearing was 28.7 MPa and mobile-bearing was 12.85 MPa. The contact pressure of the fixed-bearing was found to be greater than the mobile-bearing. Contact area is important to the wear rate of the insert UHMWPE. The mobile-bearing contact area was found to be greater than the fixed-bearing. Therefore, the mobile-bearing has a longer lifetime than the fixed-bearing.

Fig. 8. Contact pressure of mobile-bearing TKA.
Values in MPa.

Fig. 9. Contact pressure of fixed-bearing TKA.
Values in MPa.

Fig. 10. Contact pressure of tibia inserted component.

Fig. 11. Contact area of tibia inserted component.

4. Conclusions

This research has compared mobile- and fixed-bearing contact pressures using numerical simulation method. It found that the contact pressure of a fixed- bearing was greater than that of a mobile-bearing. The mobile-bearing system is characterized by a large surface contact of the articulating components. The contact pressure of mobile-bearing spread around, however, in terms of fixed-bearing is the concentration in narrow area. The mobile-bearing design has lower maximum contact pressure than the fixed-bearing design. The mobile-bearing presents the benefit of stance over the fixed-bearing. The evaluation of contact areas and contact pressures in total knee replacement is important to prevent early failure. This is contact area of insert UHMWPE of fixed- and mobile-bearing. It is important to add lifetime the UHMWPE inserts. A result of mobile-bearing contact area is more than fixed-bearing. It is also a result of fixed-bearing contact area is relatively constant.

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