INTRODUCTION

A finite element (FE) model has been developed to study the stresses found in the meniscal insert of a total knee replacement (TKR). A primary reason for implant failure of TKRs is failure of the UHMWPE meniscal insert due to delamination and wear of the articulating surface (Heim 1996) under cyclic compressive loads and shear stress. This finite element model was used to investigate what factors contribute to higher stresses in the meniscal insert and hence to earlier failure.

METHODS

The 3D finite element model was developed, solved and analysed in the FE software ANSYS 6.1. The model was based on the specifications for set-up found in the ISO draft standard for wear testing of TKRs, ISO 14243-1.4. The geometry of the TKR used was based on the Active Knee System by ASDM, Australia. The meniscal insert was modelled utilising 20 node hexahedral elements with multi-linear elastic material properties for GUR 1050 UHMWPE. The femoral component was modelled as a rigid surface with contact modelled between the articulating surfaces. Two springs were used to control the anterior-posterior motion and the internal-external rotation. All forces and torques were applied to the inferior meniscal surface and rotation was applied to the femoral component through a pilot node to simulate flexion-extension.

Two different types of analysis were used to look at the effect of different parameters. Firstly, a static analysis was used to look at the effect of different meniscal thickness and patient body weight on the stresses in meniscal insert. The TKR was loaded in the stance position (full extension) with an axial load of 3 times body weight. Secondly, a pseudo-dynamic analysis was used to look at the effect of friction, cross-sizing and surgical misalignment. The gait curves used in the draft standard, ISO 14243-1.4, to describe flexion, axial load, anterior-posterior translation and medial-lateral rotation were used to simulate one gait cycle. The maximum equivalent stress was used as a comparison indicator.

RESULTS AND DISCUSSION

The static analysis compared the effects of different meniscal insert thicknesses as well as body weight. The modelling was based on the size 3 femoral and meniscal components of the Active Knee System. As expected, the stress in the meniscal insert decreased as the meniscal thickness was increased (Figure 2a). The same size system, with 6mm minimum thickness, was loaded with three times various body weights, from 80kg to 150kg. Figure 2b shows a relatively linear relationship up until 130kg where there is a significant rise in stress, which leads to the question of whether there is a safe implantation environment or does the thickness need to be increased to allow for the higher loads.

The gait model analysis showed the effects of varying friction as well as the effect of cross sizing and surgical misalignment. The coefficient of friction values used in the analysis were 0.03, 0.1, and 0.16 representing the variation in published values for the coefficient of friction of CrCo on UHMWPE (McKellop 1981). Figure 3a shows only a small variation from lowest to highest friction, suggesting that in this range the coefficient of friction is not a significant variable. The effect of cross sizing a size 4 femoral component with a size 3 meniscal component, shown in Figure 3b, is a small increase of 12 percent in the equivalent stress. Surgical misalignment is a realistic error that may occur in surgery. To look at the effects of this the femoral component was rotated 5 degrees and the gait cycle applied. The results in Figure 3b showed a significant increase in stress especially at initial full weight bearing and toe-off points of the gait cycle.

SUMMARY

Through finite element modelling and analysis it has been possible to observe the effects of different variables and the extent of those effects on polyethylene stresses, information which can lead to better design and increased longevity of a TKR. It was shown that the patient bodyweight may have a significant effect on the results of TKR surgery, leading to the need for better implant information for size selection. The most important result is the considerable increase of stress due to surgical misalignment, which highlights the need for manufacturers to develop accurate fixture and cutting guides.

REFERENCES

Heim, C. S., et al. (1996). Instructional Course Lectures, 45, 303-312