INTRODUCTION

High prevailing stress levels pose a significant challenge to total ankle replacement. Not only are loads high, but they must be applied to a relatively small surface area compared to the hip and knee. Given what is already known about polyethylene wear rates and failure mechanisms in other joints, concerns have arisen about the long term prospects of polyethylene in the ankle joint, especially in more active patients. Increased wear, fatigue failure, and plastic deformation can result when loads exceed the limits of the material.

One of the supposed advantages of mobile bearing ankle replacements is their ability to avoid high polyethylene stresses by distributing loads across larger congruent contact surfaces. They purportedly avoid point and line contact stresses by maintaining congruency throughout flexion. In addition the mobile bearing limits the transmission of loads across the implant in certain degrees of freedom.

The goal of this study was to assess the contact pressures and internal stresses in the polyethylene bearings of a mobile bearing ankle replacement under conditions of static axial load near the high end of the physiologic range. Several variations in ankle replacement configuration and loading were examined for their influence on stress distribution. One of these was polyethylene insert thickness. Mobile bearing ankle replacements use different thickness of polyethylene bearing as a means of adjusting the overall polyethylene insert thickness. Mobile bearing ankle replacements use different thickness of polyethylene bearing as a means of adjusting the overall polyethylene insert thickness.

METHODS

Complementary FEM and Fuji film analyses were performed to determine the contact pressure distribution and internal stresses in the polyethylene bearings of the STAR implant (Waldemar Link), under various conditions of static loading. Parameters assessed included, (1) the effect of polyethylene thickness (6, 7, 8, 9, 10mm), (2) the effect of flexion angle (from 0 to 20 MPa scale) and (3) the effect of incomplete contact at the tibial contact surfaces (1, 2, 3, 4 mm overhang).

Fuji film was calibrated using uniform circular calibration samples imprinted at known loads representing increments of 1 to 25 MPa. From the scanned samples grayscale values were determined and used to identify corresponding grayscale fringes on imprints taken during ankle replacement loading trials. Both low and medium pressure Fuji films were used.

The finite element model (Fig 1) was formulated using Patran 9.0 and executed in ABAQUS 5.8. The polyethylene mobile bearing, modeled with a finite element mesh comprised of 8-node hex elements, included an elasto-plastic constitutive model. The tibial and talar components were modeled as rigid bodies and the contact surfaces as rigid smooth surfaces. A finite sliding contact formulation was used. Once loaded, the polyethylene was constrained solely by friction and the topography of the mating contact surfaces.

All Fuji specimens and FEM models were loaded with 3650 N axial force, representing 5 times body weight (75 kg person). The a-p dimensions of the poly and tibial component used were 27mm and 30mm respectively.

RESULTS

The Fuji film imprints corresponded well to contact pressure patterns predicted in the FEM model. Both methods revealed the maximum contact pressure on the tibial contact surface for the case of full contact under 3650 N to be approximately 10 MPa (Fig 2). Contact pressure on the talar contact surface was nearly uniformly distributed, ranging between 8 and 10 MPa, except on the anterior, posterior and internal edges. There, much higher high stresses were measured and predicted, up to and exceeding 20 MPa. (Fig 3)

Despite the slight variation found in the talar component contact topography as a function of flexion angle, little difference in the contact pressure distribution was observed as a result of loading with the components in different flexion angles.

Polyethylene thickness, however, did have a noticeable effect on the pressure distribution. Most notably, with thicker poly inserts, the pressure was more evenly distributed in the AP direction, but had substantially higher stress concentrations on the anterior and posterior edges. Thinner poly resulted in higher stresses at the midline of the insert.

DISCUSSION AND CONCLUSION

Material failure for medical grade polyethylene commonly occurs between 15 and 20 MPa, with the variant used in this study manufacturer-specified as being near the high end of that range. The STAR distributed load more evenly than anticipated across its talar contact surfaces, with the exception of the high loads seen on the anterior, posterior and internal edges. The angle of insert edge beveling is such that the anterior and posterior portions of the polyethylene are forced into the surface of the cylindrical component.

To avoid partial overhang of the tibial/insert interface, the choice of larger tibial components is desirable where practical. A better understanding of the effects of design choices and alterations may help to avoid early failure of polyethylene components.

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