THE EFFECT OF POLYETHYLENE LINER THICKNESS ON STRESSES IN TOTAL ANKLE ARTHROPLASTY

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Introduction

The large loads transmitted by joints of the lower extremity lead to polyethylene component wear after arthroplasty. The wear of the polyethylene component has been studied in hip and knee replacement and it has been suggested that thicker polyethylene components reduce stresses and therefore reduce wear.[1] There are similar concerns in ankle replacement yet there is little work on the effect of polyethylene liner thickness on stresses. A thicker liner has the significant disadvantage of requiring increased bone removal in the ankle, so that benefits of increased thickness must be explicitly quantified for the ankle rather than relying on studies of the hip and knee.

Commonly used semi-constrained ankle prostheses have nearly concentric articulating surfaces and an example of this type of implant is the Agility™ ankle system (Depuy, Inc.). The liner stresses were computed using finite element analysis for different three liner thicknesses: 3mm (the standard design thickness), 5mm and 7mm, where thickness is measured as the minimum thickness of the liner.

Methods

A finite element model of the tibia and fibula was created by sectioning and digitizing the distal lower right leg of a 69-year old female. Finite element models of the implant components were constructed and positioned in the bone model under the direction of a surgeon. The implant included a tibial-fibular syndesmosis fusion where the cortical bone was removed according to the surgical procedure and the finite elements of the cancellous bone of the tibia and fibula were bonded. No soft tissues of the joints were included in the model. Two 4 mm bone stainless steel screws were represented using beam elements that overlaid the bone in the location of the screws.

The bone and metal implant components were assumed to have isotropic, linear elastic material properties. Nonlinear isotropic properties were used for the polyethylene [2]. Contact surfaces were defined between the rigid talar component and the polyethylene linear while all other material interfaces were bonded. The distal surface of the talar component was constrained in all directions. The proximal ends of the tibia and fibula were constrained in the transverse plane. A five times body weight (body weight = 666 N) vertical load was applied to the proximal tibia and fibula with the fibula bearing 7% of the load. Displacements from the full model were applied to the submodel of the polyethylene linear and talar component. The element size of the talar component was kept fixed at 0.25 mm while the polyethylene element size was varied. A convergence study showed reducing the element size from 0.25 mm to 0.1 mm changed the contact pressure at the medial and lateral edges of the talar component by less than 10%.

Results

The contact pressure (CP) and von Mises stress (vM) in the polyethylene as a function of liner thickness are shown in Table 1.

<table>
<thead>
<tr>
<th>Thickness [mm]</th>
<th>Contact pressure at edge [MPa]</th>
<th>Contact pressure at sagittal midline [MPa]</th>
<th>Von Mises stress at edge [MPa]</th>
<th>Von Mises stress at sagittal midline [MPa]</th>
</tr>
</thead>
<tbody>
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<td>3</td>
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<td>19.8</td>
<td>16.1</td>
<td>9.2</td>
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<tr>
<td>7</td>
<td>29.1</td>
<td>14.9</td>
<td>16.9</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Table 1. The effect of polyethylene thickness on contact pressure and von Mises stress

Discussion

Contact pressure has implications for polyethylene wear. Higher pressures mean higher wear rates. Increasing the liner thickness reduced the contact pressure at some locations but increased the pressure at others. The kinematics of the articulating surfaces dictate the wear patterns. The Agility system incorporates the possibility of lateral-medial translation with dorsi-plantar flexion. Furthermore, edge loading could occur if the mating cylindrical surfaces are not aligned due to ankle inversion-version.

Simple dorsi-plantar flexion with high edge pressure should lead to wear that approximates the pattern due to the average contact pressure. The wear of the liner cannot occur just at the edges with dorsi-plantar flexion: all areas must eventually experience similar wear depth as the talar component advances into the polyethylene surface. Areas with initially high wear should experience lower wear rates as the worn surfaces conform to produce a more uniform wear rate.

Ankle kinematics that include movements other than dorsi-plantar flexion, however, could mean increased wear rates due to the edge contact pressures. As the talar component sweeps across the polyethylene, no reduced average wear pattern would emerge because no region would experience the same higher wear rate with each cycle. An overall higher wear rate could emerge because the high contact pressures would be the leading and trailing edges of a contact area where wear would occur. However, the contact pressures at all locations were less than the result of 55 MPa computed for knee replacements [1]. One should therefore expect that the wear and failure rates associated with contact pressures may be less than those experienced in knee arthroplasty.

The von Mises stress levels for all thicknesses exceeded the yield stress (11 MPa) so that cold flow of the polyethylene could occur in small subsurface regions at the edge of the contact region. The cold flow could also create a change in the wear patterns and could lead to cracking and pitting. Increasing the thickness caused small increases in the von Mises stress, which would be detrimental.

Based on these results, it is clear that increasing liner thickness could lead to small increases in wear and an increased likelihood of failure. Thickness should not be increased to improve wear or failure characteristics.

Acknowledgements

The partial support of the first author by Depuy Inc. is gratefully acknowledged.

References