The Effect of Poly Thickness on Contact Stress in Low Stiffness Porous Metal-backed Acetabular Component: Is 4mm Minimum Thickness Poly a Gold Standard?

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Introduction: Surface damage including creep, fracture and pitting in acetabular polyethylene components for total hip replacement is associated with large contact stress. For conventional metal-backed acetabular components, previous studies have shown that poly thickness and conformity between femoral head and poly liner play a significant role in contact stress [1]. For highly conforming acetabular component design, the contact stress in the poly liner is very sensitive to the poly thickness when that thickness is small. It has been demonstrated that contact stress increases rapidly when the poly thickness decreases to approximately 4-6 mm [2]. Therefore, it was suggested that a minimum poly thickness of 4-6 mm should be maintained for metal-backed acetabular components. The 4mm minimum thickness has been widely accepted as an industry design guidance for acetabular component polyethylene liner design.

Currently, there are some acetabular component designs that do not have the metal-backed feature. Instead, poly resin is direct compression molded into and integrated with a low stiffness porous metal (porous tantalum) to form a monoblock type structure [Fig.1a]. It is unclear weather 4mm minimum thickness poly design guidance is still applicable to porous metal-back monoblock acetabular component design. In this study, the Finite Element Method (FEM) was used to investigate this issue and study the effect of poly thickness on contact stress in porous metal-backed monoblock acetabular components.

Materials and Methods: A 2-D parametric axisymmetric FE model was developed using commercially available FE software ABAQUS 6.6 (ABAQUS, Inc, Providence, RI, USA). As shown in Fig.1b, the FE model includes a femoral head (made of CoCr), poly, porous tantalum back and bone. The poly thickness can be changed parametrically from 1mm to 12mm while other parameters are kept constant. To compare with conventional metal-backed acetabular component, FE model with titanium alloy back with same geometry was also constructed.

Per Bartel et al [2], a 14mm radius femoral head size was used in the model. A 2000N axial load was applied on the femoral head and the far sides of the bone were constrained. All interfaces except femoral head with poly were simulated as bonded. The contact between femoral head and poly was modeled as frictional contact with coefficient of friction of 0.04. All models were meshed using 8-node quadrilateral elements and each model has approximately 2000 elements.

Two conformity levels (defined as the ratio between the radius of femoral head and the radius of poly cup) were considered in this study, poly radius (R0) 14.05 mm representing high conformity (99.6%) and 14.5mm representing low conformity designs will lower the contact stress. As previous studies have shown for metal-backed acetabular components, the contact stress is highly sensitive to poly thickness when it is lower than 4-6mm. The contact stress increases rapidly with decreasing poly thickness. When the thickness is large, the contact stress becomes less sensitive to changes in poly thickness. The transition between these regions occurs for values of thickness of 4-6mm.

However, for porous-metal backed acetabular components, the contact stress is much less sensitive to the poly thickness even when the thickness is smaller than 4mm. There is no obvious transition zone where contact stress becomes sensitive to poly thickness. Moreover, for porous metal-backed monoblock acetabular component, the contact stress is generally lower than a metal-backed component when the poly thickness is smaller than 8mm. For example, to achieve the same contact stress level in metal backed component with 4mm minimum thickness poly, the porous metal-backed monoblock acetabular component can have only 2mm thickness poly. This suggests that 4mm minimum thickness poly design guidance for metal-backed-acetabular component may not be applicable to a porous metal-backed monoblock component. The reason that the contact stress is lower and is less sensitive to the poly thickness for porous metal-backed monoblock acetabular component is the lower stiffness for porous tantalum (1.7 GPa [3]) compared to Titanium alloy (110 GPa). Under same loading, a porous metal-backed monoblock acetabular component will deform more increasing the contact area so peak contact stress is lowered.

The results also suggest that when poly thickness is larger than 10mm, the contact stresses for both components are equivalent.

As in Ref. 2, all materials were modeled as linear elastic. The material properties used are tabulated in table 1.

Results: Fig. 2 shows the peak contact stress plotted against poly thickness. For both metal-backed and porous metal-backed acetabular components, higher conformity designs will lower the contact stress. As previous studies have shown for metal-backed acetabular components, the contact stress is highly sensitive to poly thickness when it is lower than 4-6mm. The contact stress increases rapidly with decreasing poly thickness. When the thickness is large, the contact stress becomes less sensitive to changes in poly thickness. The transition between these regions occurs for values of thickness of 4-6mm.

Discussion: Compared with a conventional metal-backed acetabular component, a low stiffness porous metal-backed monoblock acetabular component has less contact stress and the contact stress is much less sensitive to poly thickness. The results suggest that the 4mm minimum thickness poly design guidance may not be applicable for a low stiffness porous metal-backed acetabular component.


<table>
<thead>
<tr>
<th>Materials</th>
<th>Elastic modulus (GPa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly</td>
<td>0.557</td>
<td>0.47</td>
</tr>
<tr>
<td>Titanium alloy</td>
<td>110</td>
<td>0.3</td>
</tr>
<tr>
<td>CoCr</td>
<td>220</td>
<td>0.3</td>
</tr>
<tr>
<td>Bone</td>
<td>1.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Porous Tantalum</td>
<td>1.7</td>
<td>0.3</td>
</tr>
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</table>