PROBLEMATIC SITES OF THIRD BODY EMBEDMENT IN POLYETHYLENE FOR WEAR ACCELERATION IN TOTAL HIP ARTHROPLASTY

Hannah J. Lundberg 2, Kristofer J. Stewart 1, Douglas R. Pedersen 1, Thomas D. Brown 1,2

1 Department of Orthopaedics and Rehabilitation, University of Iowa, Iowa City, IA, USA
2 Department of Biomedical Engineering, University of Iowa, Iowa City, IA, USA
E-mail: hannah-lundberg@uiowa.edu  Web: mnypt.obrl.uiowa.edu/OBL_Lab_Website

INTRODUCTION

Total hip arthroplasty (THA) wear is highly variable within patient cohorts and can be accelerated by counterface roughening due to third body ingress. Scratching from third body debris, embedded in the polyethylene liner, is the primary means whereby femoral head roughening occurs. In this study, we identified acetabular sites most problematic for particle embedment, in terms of scratching kinetically critical regions of the femoral head. Gait-cycle traverse loci were calculated for acetabular sites corresponding to previously identified regions of femoral head roughening. Increased scratching severity from a third body embedded in the polyethylene would plausibly occur in proportion to contact stress and sliding distance at the site of embedment, so the index considered contributions from both factors.

METHODS

Gait-cycle acetabular traverse loci were calculated for 284 femoral reference points equally spaced over the femoral head. These points were determined from wear simulations using a sliding-distance-coupled finite element model for THA wear (Maxian et al., 1996), and corresponded to locations of putative femoral counterface roughening. Instantaneous local contact stress and sliding distance were included as factors influencing the severity of femoral head scratching for a given embedment site.

Femoral reference points (P_Fem) were defined in an anatomical anterior-lateral-superior coordinate system. Loci of acetabular points over-passing these reference points were calculated by transforming the points using rotation matrices corresponding to flexion, abduction, and external rotation angles (α, β, and ψ, respectively) of the gait cycle, per Equation 1. Sixteen rotation increments for each motion were used, taken from experimental data for the stance portion of one gait cycle (Pedersen et al., 1998). This resulted in 16 segments that defined each locus of P_Fem on the acetabulum. Each locus corresponded to a path on the acetabulum traversed by points overpassing the femoral regions.

\[
P_{\text{Loc}} = [R_{\text{Ext}}]^T[R_{\text{Abd}}]^T[R_{\text{Flx}}]^T \cdot P_{\text{Fem}}
\]

To determine the most problematic areas for polyethylene embedment, a damage propensity index (DPI) was identified. Increased scratching severity from a third body embedded in the polyethylene would plausibly occur in proportion to contact stress and sliding distance at the site of embedment, so the index considered contributions from both factors.

Instantaneous local contact stress, σ, was taken from previous finite element data. Contact stress data were available for each femoral reference point at 24 serial time points (41667-cycle intervals of habitual activities within each 1-million cycle wear simulation). Sliding distance, d, was calculated incrementally from the gait rotation angles. A weight factor (wf), based
on the volumetric wear that resulted from the corresponding 1-million cycle wear simulation, was also incorporated into the index. All variables were normalized from 0 to 1 based on the maximum value from each group.

To take into account the total effect of the variables throughout a 1-million cycle wear simulation, the product of the variables was taken for each femoral reference point for each of the 24 time increments (see Equation 2). The incremental index was then summed over all 24 increments to arrive at the total damage index at each femoral reference point. Because some femoral reference points resulted in loci points that intersected other such points, a final summation was performed to obtain a total damage propensity at each acetabular location. The resulting index identified areas of the acetabulum most problematic for debris embedment.

\[
\text{DPI} = \sum \sigma \cdot d \cdot w_f
\]

\[\text{Equation 2}\]

RESULTS AND DISCUSSION

Example traverse loci are displayed in Figure 1. Figure 2 shows the problematic acetabular areas. Areas of the acetabulum most critical for increased wear due to debris embedment (per the above DPI criterion) were concentrated on the supero-lateral aspect of the bearing surface.

![Figure 1. Gait-cycle \( P_{\text{Fem}} \) traverse loci on the acetabular cup for normal level walking.](image1)

Figure 2. Plot of the DPI over a projection of the acetabular surface. Problematic acetabular areas for debris embedment are on the supero-lateral-most aspect of the cup. Anatomical axes are shown on an example acetabular cup.

SUMMARY

A new analytical tool has been introduced to evaluate the relative damage propensity associated with various sites of third body embedment in polyethylene. Gait-traverse loci of femoral points on the acetabulum throughout the stance portion of a gait cycle have been calculated. The data show that the supero-lateral aspect of the acetabular cup is by far the most problematic area for debris embedment.

REFERENCES


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