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THA Retrievals: The Need to Mark the Anatomic Orientation of the Femoral Head

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Abstract

The hypothesis of this study was that the rotational orientation of femoral head damage would greatly affect the volumetric wear rate of the opposing polyethylene (PE) liner. Damage on twenty retrieved cobalt-chromium femoral heads was simulated in a validated damage-feature-based finite element model. For each individual retrieval, the anatomic orientation of the femoral head about the femoral neck axis was systematically varied, in 30° increments. The PE wear rate differential between the maximum-versus minimum-wear orientations was often sizable, as high as 7-fold. Knowing the correct femoral head anatomic orientation is therefore important when analyzing the effects of femoral head damage on PE liner wear. Surgeons retrieving modular femoral heads should routinely mark the anatomic orientation of those components.

Keywords

Damage; femoral head; finite element analysis; retrieval analysis; total hip arthroplasty; wear

Introduction

Damage to the femoral head of a total hip arthroplasty (THA) can cause accelerated wear of the opposing polyethylene (PE) acetabular liner, which can then result in osteolysis, aseptic

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loosening, and THA failure. In addition to the damage severity per se, the location of a roughened site on the femoral head affects the wear rate of the opposing PE liner [1]. The rotational orientation of damage on the femoral head, based on the anatomic orientation of the femoral head about the femoral neck axis, would therefore be expected to have an effect on liner wear rate.

For studies involving retrieved modular femoral heads, specification of an anatomic orientation of the femoral head or its damage [2, 3], illustration of an anatomic orientation marking on a head [4, 5], or a statement that the anatomic orientation was marked [6] is rare. Without knowledge of femoral head anatomic orientation, documentation of femoral head damage is incomplete.

Knowledge of the anatomic orientation of retrieved femoral heads, and of the resultant rotational orientation of femoral head damage, would enhance subsequent retrieval analysis. For example, this knowledge would appear to be essential for accurate calculation of liner wear. Recent advances in damage-feature-based finite element (FE) modeling allow for quick and efficient evaluation of patient-specific femoral head damage [7, 8]. The hypothesis of this study was therefore that rotational orientation of damage on retrieved femoral heads has a marked influence on the volumetric wear rate of the opposing polyethylene liner, as predicted by finite element analysis.

Materials and Methods

Twenty retrieved cobalt-chromium modular femoral heads (Table 1, Figure 1) that had articulated against a PE liner, had a variety of damage levels, and did not have an indication of anatomic orientation were analyzed. Retrieval components and clinical data were collected and analyzed with IRB approval. Damage was localized and quantified on these heads, using a combination of diffused-light photography [9], image analysis [7], and optical profilometry. Canny edge detection was performed on the photographs to detect regions of damage. A Hough transform was used to discretize scratches into straight-line segments. Regions showing scrape damage were segmented into quadrilateral-shaped patches. Damage severity was determined by scratch lip heights and scrape average roughness (R_a) values, which were measured via optical profilometry scans of the damaged regions.

These damage data were then used to simulate femoral head damage in a damage-feature-based FE wear model [8]. Femoral head scratches and scrapes, along with their corresponding lip heights and R_a values, were modeled at their respective damage locations. A finite element model for PE liner wear, experimentally validated for conventional polyethylene [8, 10, 11], was then implemented in ABAQUS v6.9.1, using the adaptive meshing capabilities of the UMESHMOTION subroutine. PE liner wear was computed using the Archard wear formula [12], which calculates the spatial distribution of wear depth as a function of local contact pressure, sliding distance, and a wear coefficient based on the tribological properties of the surfaces in contact. When an area of the acetabular liner was overpassed by a femoral head damage feature, the wear coefficient was elevated, based on the damage feature severity and on the angle between the orientation of the damage feature and its direction of motion. The anatomic orientation of the femoral head about the femoral

neck axis was systematically varied, in 30° increments. Wear simulations were run to one million standard gait cycles. All femoral head diameters were normalized to 28-mm diameter for comparison to a simulation with an undamaged 28-mm femoral head.

Polyethylene wear acceleration, defined as the wear volume caused by a damaged head relative to that caused by an undamaged head, was computed for each simulation. For each femoral head, wear rate differential was defined as the maximum wear value divided by the minimum wear value. Spearman's rank correlation coefficient (ρ) was calculated between the wear rate differential and the maximum wear acceleration.

Results

Depending on the damage on and the posited anatomic orientation of the femoral head, PE liner volumetric wear acceleration ranged from 1× baseline (no increase over undamaged head) to 12× baseline (Figure 2). For each individual retrieval, the wear rate differential between the maximum-versus minimum-wear orientations was often sizable, as high as 7-fold (Figure 3). Wear rate differential and the maximum wear acceleration had a Spearman's ρ of 0.7.

The highest maximum wear accelerations generally occurred when the majority of the femoral head damage was oriented quasi-superiorly, within about 30° of the coronal midline (Figure 4). The femoral heads with the highest wear rate differentials (#15, #16, #17, #19) had the majority of their damage in the lower hemisphere (Figure 5). Femoral heads with a very low wear rate differential relative to their maximum wear acceleration (Figure 3), heads #18 and #20, had substantial damage in the upper hemisphere, visible from a polar view of each head (Figure 6). With these two femoral heads excluded, the correlation of wear rate differential and maximum wear acceleration was 0.96.

Discussion

The rotational orientation of the femoral head damage on the trunnion contributed substantially to the severity of the effect of this damage on liner wear. The difference between the maximum and minimum wear rate acceleration was often substantial. Knowing the correct femoral head anatomic orientation is therefore important when analyzing the effects of femoral head damage on PE liner wear.

Most of the retrieval heads studied had the majority of their damage concentrated in one local area, as opposed to being dispersed widely around the head. For these specimens, the highest liner wear acceleration was calculated when this predominant damage area was posited to be near the superior direction. Likewise, in a previous parametric finite element study of posited roughening patch locations [1], the sites of femoral head damage resulting in maximal volumetric liner wear were located superiorly. Per the Archard wear formula, liner wear depends on contact pressure, which tends to peak quasi-superiorly. When the damage area was rotated toward the inferior direction, into locations experiencing much lower contact pressures, only minimal wear accelerations were calculated. Femoral head retrievals with most of their damage located nearer the polar region of the head (Figure 6) displayed less predicted PE wear variability between posited anatomic orientations. For the

latter heads, damage tended to remain near the superior direction (an area of high contact pressure) regardless of head rotation.

Polyethylene liner wear is best determined physically, either by hip simulator testing or from retrieved liners. However, hip simulator testing is expensive and time-consuming, especially if the femoral heads were tested in each of twelve rotational orientations. Also, the damage on a retrieved femoral head could wear down [13] over the course of those twelve wear tests, thus weakening the rotational orientation comparisons. For a retrieved liner, its wear result would be valid for only one femoral head rotational orientation. Computational wear simulation avoids these problems, and the FE wear formulations used in this study have been well-validated against physical wear simulations [8, 10, 11]. For femoral heads that were undamaged, had scratches, or had a roughened area (similar to a scrape), wear calculation errors between the physical and computational models were less than 5% [11], 10% [8], and 10% [10], respectively. These validations were based on conventional PE; similar wear acceleration results, relative to undamaged cases, would be expected for highly crosslinked PE. The current FE model is limited in that only level walking gait cycles were modeled, rather than also including other activities of daily living. A further limitation, associated with working with retrieval specimens, is that the damage apparent on retrieved femoral heads constitutes only a snapshot of damage at the time of the revision surgery (or autopsy retrieval). No information is available regarding how long any particular damage feature may have been present, or to what extent the initial damage may have been worn down with articulation over time [13]. These limitations, however, are intrinsic to the physical retrieval specimens being simulated, rather than to the wear algorithm per se.

Intraoperative (or postmortem) marking of femoral head anatomic orientation would greatly enhance the information and knowledge obtainable from subsequent retrieval analysis [14–16]. Identification of the anatomic orientation of retrieved femoral heads would allow investigators to better correlate component damage with phenomena such as bearing surface wear, dislocation, subluxation, and taper-trunnion interactions. Likewise, intraoperative marking of acetabular liner anatomic orientation is also desirable. Acetabular liner anatomic orientation could be determined by the location of screw hole impressions on the backside of the liner [17], or by an elevated rim [18] or wire marker [19] seen on preoperative radiographs. However, those features might not be available or visible on a radiograph [18, 19], or may not allow sufficient accuracy for a particular study.

Marking of arthroplasty components prior to their removal is a simple process. A line or scribble can be drawn on the femoral head, with a surgical marking pen such as a DevonTM Utility Marker (Covidien, Mansfield, MA) (Figures 7A&B), and the corresponding anatomic orientation noted on a retrieval information sheet. The orientation can also be written on the femoral head itself (i.e., write a “P” to indicate posterior orientation) (Figure 7A).

Alternatively, if both the modular femoral head and stem are to be revised, if practical the head could be left on the stem during their removal. Acetabular liner and shell orientations can be marked on their rims, to indicate anatomic directions, or Wasielewski’s Line can be drawn between the ASIS and ischial tuberosity [20, 21] (Figure 7C). Documentation of any component damage resulting from the retrieval process is also desirable. When the components are received in a retrieval laboratory, before the components are cleaned and

sterilized (actions that may remove the intraoperative marker), the anatomic orientations are permanently scored on the components. For a femoral head, a specific orientation, as documented on a retrieval information sheet, is indicated with a scribed line on the bottom of the head (Figure 7D).

Retrieval program coordinators and participating surgeons are advised to give increased attention to the issue of component anatomic orientation. This is easily obtainable information that more completely documents the component, and that could prove critical to accurate retrieval analysis. Surgeons retrieving arthroplasty components with rotational symmetry should routinely mark the anatomic orientation of those components, especially the femoral head.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Retrieved femoral heads analyzed, shown from the view displaying the highest severity of visually-observed damage. This was the polar direction for heads #1, #7, and #20. The photographs for heads #1, 3–10, 12, and 14–20 have appeared in previous publications [7–9, 22, 23].

Figure 2.

Polyethylene liner volumetric wear acceleration (compared to that of an undamaged head simulation) caused by damaged femoral heads, for 30° increments of anatomic orientation of the femoral heads about the femoral neck axis, arranged by maximum wear acceleration. Box midline = median; box = 25th–75th percentile; whiskers = maximum and minimum.

Figure 3.

Polyethylene liner volumetric wear rate differential (maximum wear orientation / minimum wear orientation) versus maximum wear acceleration, for liners articulating against damaged femoral heads. Femoral head numbers for the six highest maximum wear accelerations are indicated. Spearman's rank correlation coefficient was 0.7 for all heads, and was 0.96 when heads #18 and #20 were excluded.

A

B

Figure 4.

A) Retrieved femoral heads arranged by maximum polyethylene liner wear acceleration, and showing the anatomic orientation for which this maximum was calculated, as viewed from the B) superolateral axis indicated. The photographs for heads #3 and #4 have appeared in a previous publication [23].

Figure 5.

Circumferential variation in damage patterns of the four femoral heads with the highest wear rate differentials (in parentheses), illustrated in 90° increments of viewing direction. The leftmost picture shows the posited orientation with the maximum wear acceleration, as viewed from the superolateral axis (Figure 4B). The second-to-the-left photograph for head #19 has appeared in a previous publication [9].

Figure 6.

Polar views of femoral heads with a very low wear rate differential compared to their maximum wear acceleration. Heads are shown in the anatomic orientation for which this maximum was calculated, with the lateral direction to the right. The photograph for head #20 has appeared in previous publications [7, 23].

A

B

C

D

Figure 7.

Marking the anatomic orientation of the femoral head and acetabular liner. A) Femoral head marking options indicated on a retrieval information sheet. B) Intraoperatively-marked femoral head, as received by the retrieval laboratory. C) Intraoperatively-marked acetabular liner. D) A scribe mark (arrow) indicating posterior orientation on a retrieved, cleaned, and sterilized femoral head.

Table 1

Retrieved femoral heads studied. All heads were modular cobalt-chromium and articulated against polyethylene.

Femoral head number	Time to retrieval (years)	Reason(s) for retrieval
1	6.2	Dislocation
2	10.5	Aseptic loosening
3	0.8	Dislocation
4	5.1	Septic loosening
5	0.4	Dislocation
6	13.5	Aseptic loosening
7	0.2	Dislocation
8	14.8	Wear
9	3.0	Dislocation
10	9.8	Dislocation
11	4.4	Chronic dislocation and aseptic loosening
12	5.6	Recurrent subluxation
13	16.0	Wear
14	0.4	Dislocation
15	5.4	Dislocation
16	7.4	Dislocation
17	1.5	Dislocation
18	18.9	Dislocation
19	0.2	Dislocation
20	8.9	Wear