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Original Article

Are Radiographic and Direct Measures of Acetabular Polyethylene Wear Comparable?

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ABSTRACT

Background: All polyethylene acetabular liners wear over time, and numerous methods for calculating linear wear rates exist. The objective of this study was to compare 2-dimensional wear rates between direct, micrometer measurements and the computerized, edge-detection method using Hip Analysis Suite (HAS) 8.0.4.3.

Methods: Two groups of retrieved acetabular liners from Harris-Galante Prosthesis I and Harris-Galante Prosthesis II implants in situ for more than 10 years were evaluated. Group 1 (n = 18) contained liners with both early postoperative (<6 months) and prerevision radiographs taken within 1 month of explantation. Group 2 (n = 55) included liners with only prerevision X-rays (ie, 1 radiograph for wear assessment). Average and maximum direct linear wear was calculated from thicknesses measured at 6 consistent, well-separated locations (3 in the worn and 3 in the unworn regions) using a calibrated, digital micrometer. HAS 8.0.4.3 was used to calculate 2-dimensional wear from anteroposterior pelvic radiographs.

Results: Aggregate wear rates calculated by HAS were higher than those calculated by the average of direct measurements for group 1 ($P = .020$) and group 2 ($P < .001$). However, comparing the maximum direct micrometer measurements to HAS showed no difference for either group 1 ($P = .351$) or group 2 ($P = .451$). Linear regression analysis showed a strong correlation between HAS and both average and maximum direct wear measures for both groups, though the coefficient for the direct maximum measurement comparisons were closer to one, indicating a better one-to-one correspondence between HAS and direct maximum wear.

Conclusion: To our knowledge, this is the first study to compare and validate 2-dimensional wear rates in polyethylene acetabular liners between direct measurements from retrieved components and a radiographic computer-assisted technique (as opposed to comparison against a phantom component). Wear rates determined by direct measurements from retrievals were consistent with computer-assisted 2-dimensional methods when comparing maximum wear measurements. In addition, a single prerevision radiograph appears to be sufficient to assess 2-dimensional in vivo wear.

Ultra–high-molecular-weight polyethylene acetabular liners in total hip arthroplasties wear over the service life of the implant. Even in the era of wear-resistant, highly cross-linked polyethylene materials, wear and osteolysis have been reported [1–4]. The wear debris that is generated can stimulate macrophages to synthesize proinflammatory cytokines which results in osteoclast differentiation and can ultimately progress to osteolysis, aseptic loosening, and implant failure necessitating revision [5–8]. A dose-response relationship exists between polyethylene wear rate and the development of osteolysis, thus underscoring the importance of reliably assessing wear rates [9].

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There have been numerous methods developed to calculate acetabular liner wear rates, which indirectly assess the amount of polyethylene burden in the effective joint space, durability of the polyethylene liners, and likelihood of a patient developing osteolysis [10–22]. The earliest methods used manual measurements of anteroposterior (AP) radiographs [10–14]. However, today, several computer algorithm–based methods have been applied to the measurement of liner wear; these methods include digital edge detection, radiostereometric analysis, and other computer-assisted techniques [15–22].

Hip Analysis Suite (HAS) utilizes an edge-detection method developed by Martell and Berdia [18] for determining 2-dimensional polyethylene wear based on femoral head penetration into the polyethylene liner. This technique has been shown to be an accurate and reproducible method for detecting approximately 90% of 3-dimensional wear [23–25]. It has been reported that its 2-dimensional wear measurements are 4 times more repeatable than similar 3-dimensional methods, which require cross-table lateral radiographs in addition to AP radiographs [25]. When implant components are retrieved at revision or removal surgery, the component itself can be directly evaluated (eg, using a micrometer) for wear [14,26–30]. However, it is unclear how well direct micrometer measurements of retrieved polyethylene liners ex vivo correspond to in vivo radiographic analyses that use these computerized edge-detection techniques.

The primary aim of this study was to compare the linear wear rate calculated from direct measurement of retrieved polyethylene acetabular liners to the 2-dimensional linear wear rate calculated by HAS. The secondary aim was to determine if the linear wear rate could be assessed using a single prerevision radiograph.

Methods

This study evaluated wear in retrieved acetabular liners from Harris-Galante Prosthesis I (HGPI) and HGPII implants (Zimmer, Warsaw IN). Fifty-five HGPI and HGPII acetabular liners (in 55 patients, 28 women) with implantation times greater than 10 years were retrieved between 1997 and 2010 at 4 institutions as part of a multicenter retrieval program. There were 16 HGPI and 39 HGPII liners. All polyethylene liners were made from GUR 4150 resin (Ticona, Auburn Hills, MI) and were gamma irradiated in air with 25 kGy. These liners were selected for this study for their likelihood of exhibiting substantial wear owing to their long implantation time and their manufacture from a polyethylene formulation and sterilization technique that exhibited high wear. After visual examination and confirmation of the implant design, the implants were cleaned, catalogued, photo documented, and stored either at room temperature or in a −80°C freezer. For both the HGPI and HGPII liners, the inner diameter was either 28 mm or 32 mm with a mean original, unworn liner thickness of 7.75 ± 2.6 mm (range: 4.3-15.3 mm), as provided by the manufacturer. Liners in both groups had similar inner diameter and thickness of the polyethylene liner (Table 1; $P > .05$). The femoral head material was known for 54 of the 55 retrieved liners: cobalt-chromium alloy (n = 44), zirconia ceramic (n = 7), alumina ceramic (n = 2), and titanium alloy (n = 1).

All liners had radiographs taken within 1 month before explantation, while the availability of earlier radiographs varied. Two groups were therefore classified based on the number of radiographs available for assessment (Table 1). Group 1 (n = 18) consisted of liners that had at least 2 AP radiographs and included an AP radiograph from within the first 2 years of implantation as well as an AP radiograph taken before explantation. The liners in group 1 were implanted for 15.3 ± 2.6 years. To evaluate wear using only a single prerevision radiograph, we created a second group (group 2, n = 55) which was composed of the 18 liners from group 1, with an additional 37 liners for which we only had an AP radiograph available from the last month before explantation. For the 55 liners that composed group 2, the mean implantation time was 18.5 ± 4.6 years. There was no difference in the implant lifetime for acetabular liners, nor the type of acetabular component (HGPI vs HGPII) in either group. Patients in both groups were of similar gender distribution, age at primary surgery, and body mass index (Table 1, $P > .05$).

Linear femoral head penetration of implants in both groups was assessed directly from the retrieved components. Liner thickness was measured using a calibrated digital micrometer (Mitutoyo, Kawasaki, Japan, accuracy 0.001 mm) in 6 consistent and distinctly separated locations within each polyethylene liner by 2 independent observers. Measurements were taken at 3 locations in the worn region and at 3 locations in the unworn region. A linear wear rate was calculated by averaging each region and dividing the difference in thickness by the time implanted as previously described [29,30]. No difference between measurements made by the 3 observers was found ($P = .51$); thus, the measurements from the 2 observers were pooled for a total of 6 measured thicknesses in each of the unworn and worn regions. In addition, a maximum linear wear rate was calculated by finding the difference between the maximum and minimum measured thicknesses of the unworn and worn regions, respectively, and dividing that difference by the time implanted.

A 2-dimensional linear wear rate was also calculated from anteroposterior pelvic radiographs using HAS v8.0.4.3 (University of Chicago, Chicago, IL). With this version of HAS, the accuracy of the linear wear measurements is expected to be approximately 8 microns as per our analysis of the accuracy of HAS v8.0.3.0 [31]. Wear rates for group 1 were calculated by comparing 2 radiographs: the first taken within the first 2 years of implantation and the second taken within a month of revision surgery. Wear rates for group 2 were calculated in HAS from a single radiograph taken within a month of revision surgery. (This measure assumes that the center of the hip is congruent with the center of the femoral head, which is a reasonable assumption for the HGPI and HGPII designs). Intraobserver reliability was assessed from 2 sets of measurements taken by the primary observer and found not to be different ($P = .61$). Subsequently, measurements were taken by the primary observer and an additional 3 independent observers, and there was no difference in interobserver reliability between measurements taken by any 2 observers ($P = .83$, $P = .46$). Thus, the measurements from the 4 observers were pooled.

Comparisons between group 1 and group 2 in terms of patient's age, body mass index, implant lifetime, and liner thickness were determined using Student's *t* test and comparisons between groups of patient gender, implant generation (HGPI:HGPII) ,and liner inner

Table 1
Clinical Demographics and Implant Characteristics for the 2 Groups.

	Group 1[a] (N = 18)	Group 2[a] (N = 55)	*P* Value
Patient's age (y), mean ± SD	69.7 ± 14.8	68.4 ± 14.4	.777
Gender (male:female)	6:12	27:28	.244
BMI (kg/m^2), mean ± SD	26.5 ± 3.9	26.7 ± 3.9	.840
Implant lifetime (y), mean ± SD	15.5 ± 3.0	16.5 ± 3.6	.235
Harris-Galante implant generation	3 HGPI: 15 HGPII	16 HGPI: 39 HGPII	.297
Inner diameter (mm) (28:32 mm)	14:4	41:14	.782
Liner thickness (mm)	7.4 ± 1.9	7.8 ± 2.6	.551

BMI, body mass index; HGP, Harris-Galante Prosthesis; SD, standard deviation.
[a] Note that group 1 is a subset of group 2.