In Vivo Femoral Head Damage and Its Effect on Polyethylene Wear

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Abstract: The purposes of this study were to determine the spectrum of femoral head damage in patients undergoing revision total hip arthroplasty and to determine the impact of that damage on polyethylene wear. One hundred eight consecutive modular metal femoral heads were retrieved at revision surgery. The mean roughness (Ra) value was 0.18 ± 0.18 μm. The roughest femoral heads (mean Ra, 0.56 μm) were from retrievals correlated with mode 2 wear (recurrent dislocation and complete wear through of the polyethylene liner). Five million cycles of wear tests were performed using retrieved femoral heads against both new conventional and highly cross-linked polyethylene. The mean wear rate of conventional polyethylene was 15.9 ± 4.3 mg and that of highly cross-linked polyethylene was 0.04 ± 0.14 mg per 1 million cycles ($P < .001$). Highly cross-linked polyethylene was more resistant to wear than conventional polyethylene, even when mated against roughened femoral heads. **Keywords:** total hip arthroplasty, surface roughness, wear, highly cross-linked polyethylene, conventional polyethylene.

Previous experimental and retrieval studies indicated that roughening of the femoral head surface increased the wear rate of conventional polyethylene wear [1-10]. Surface roughness of the metal femoral head has been reported to increase with time after implantation [7-14]. Case reports have documented that recurrent dislocation can cause severe damage to the surface of the femoral head [15,16]. Despite these reports, few data exist on the surface damage of femoral heads in vivo and the impact of time and wear mechanism on the degree of damage.

Recent advances in polyethylene preparation have resulted in the development of highly cross-linked polymers. Good experimental results [17] and early to midterm clinical results [18-20] have been reported. Although experimental studies indicated that the wear rate of highly cross-linked polyethylene was less than that of conventional polyethylene when mated against intentionally roughened femoral heads [3-5], no studies described the wear rate of highly cross-linked polyethylene against retrieved femoral heads with various degrees of surface roughness.

The purpose of this study was (1) to determine the distribution and degree of the surface roughness of metal femoral heads retrieved from a large number of patients undergoing revision hip arthroplasty, (2) to correlate surface roughness of the femoral head with wear mode [21], and (3) to use a hip joint simulator to determine the effect of in vivo damage on wear of conventional and highly cross-linked polyethylene.

Materials and Methods

Patient Data

One hundred eight consecutive modular metal femoral heads were retrieved at revision surgery. All the retrieved heads were made from cobalt-chromium (CoCr) alloy and mated against conventional or highly cross-linked polyethylene. The demographic characteristics of the patients are listed in Table 1.

Failure Mechanism and Wear Mode

Failure mechanism and wear mode [21] of total hip arthroplasty were assessed. Mode 1 wear results from the motion between the intended 2 primary bearing surfaces such as the prosthetic femoral head against the polyethylene acetabular bearing surface. Mode 2 wear refers to the condition of a primary bearing surface that moves against a secondary surface that is not intended to move against. Mode 3 wear refers to the condition of the primary surfaces with the interposition of third-body particles. Mode 4 wear refers to 2 nonprimary surfaces

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Table 1. Demographic Characteristics of the 108 Patients (108 Hips)

Characteristics	
Mean age (range) (y)	61 (22-90)
Mean weight (range) (kg)	77 (41-110)
Sex (no. of patients)	
Male	71
Female	37
Etiology (no. of hips)	
Osteoarthritis	86 (80%)
Developmental dysplasia of the hip	6 (6%)
Osteonecrosis	5 (5%)
Posttraumatic osteoarthritis	5 (5%)
Rheumatoid arthritis	4 (4%)
Femoral neck fracture	1 (1%)
Slipped capital femoral epiphysis	1 (1%)
Reasons of revision (no. of hips)	
Aseptic loosening (femoral and/or acetabular component)	63 (58%)
Osteolysis (femur and/or acetabulum)	15 (14%)
Recurrent dislocation	10 (9%)
Broken polyethylene liner locking mechanism of the acetabular component	6 (6%)
Periprosthetic infection	6 (6%)
Complete wear through polyethylene liner of the acetabular component	4 (4%)
Broken femoral component	2 (2%)
Heterotopic ossification	2 (2%)

rubbing together, such as impingement of the prosthetic femoral neck on the rim of the acetabular component.

Factors Measured Against Wear

Several factors including diameter of the head, prosthesis fixation, manufacturer of the head, and duration of implantation were assessed in terms of impact on femoral head damage. The diameter was 22 mm in 6 heads, 26 mm in 1 head, 28 mm in 64 heads, and 32 mm in 37 heads. The prosthesis fixation was cementless in 61 (57%) hips, cemented in 21 (19%) hips, and hybrid (cementless acetabular component and cemented femoral component) 26 (24%) hips. The manufacture of the metal femoral head was Zimmer (Warsaw, Ind) in 37 hips, Striker Howmedica Osteonics (Allendale, NJ) in 25 hips, DePuy, a Johnson and Johnson (Warsaw, Ind) in 23 hips, Smith and Nephew Orthopedics (Memphis, Tenn) in 7 hips, Centerpulse Orthopedics (Austin, Tex) in 3 hips, Wright Medical Technology (Arlington, Tenn) in 3 hips, Biomet (Warsaw, Ind) in 2 hips, and unknown in 8 hips. The average duration of implantation before retrieval was 5.8 years (range, 1 day to 10.1 years) (Table 2).

Technique Used to Measure the Surface Damage

Surface roughness of the femoral head was measured using a laser profilometer (Perthometer Concept, Mahr Inc, Göttingen, Germany). Five parallel traces were taken on each sample, with a tracing length of 0.56 mm and a cutoff length of 0.08 mm. Scratched areas were evaluated by visual inspection to ensure measurements of the roughest areas were included. Tracings were obtained through predetermined grids, and arithmetic mean surface roughness (Ra) and the mean peak to valley height (Rz) [14] were calculated. Femoral heads with less than 0.08 μm (3 μin) of Ra value were classified as having low Ra, those with 0.08 to 0.25 μm (3-10 μin) were classified as having intermediate Ra, and those with more than 0.25 μm (10 μin) were classified as having high Ra. Scratched surface area was characterized by fine surface scratches with or without maintenance of the reflective surface on visual inspection and demonstrated a loss of the original surface finish. The femoral head was fixed on a rotatable jig, and scratched area was manually measured using calipers. The percentage of scratched area was calculated as the ratio of scratched area to the whole bearing surface area of the femoral head.

Table 2. Duration of Implantation of the 108 Patients (108 Hips)

Year	No. of Hips
0-1	8
1-2	8
2-3	7
3-4	4
4-5	8
5-6	12
6-7	17
7-8	12
8-9	21
9-10	9
≥10	2

Laboratory Wear Testing

Polyethylene wear was assessed using the AMTI Hip simulator (Advanced Mechanical Technology, Inc, Watertown, Mass). Retrieved femoral heads were classified into 3 groups depending on measured Ra values. Three 28-mm-diameter femoral heads were randomly selected from each of the 3 groups. Three new 28-mm-diameter CoCr femoral heads with less than 0.05 μm (2 μin) of Ra value were tested for the control study. These 12 femoral heads were tested against unaged conventional polyethylene and unaged highly cross-linked polyethylene (Longevity, Zimmer, Warsaw, Ind). Conventional polyethylene was made of unaged GUR 1050 (Zimmer). Highly cross-linked polyethylene

Table 3. Ra and Rz Values of Each Femoral Head Diameter Group

	22 mm (n = 6)	26 mm (n = 1)	28 mm (n = 64)	32 mm (n = 37)	Total (N = 108)	*P*
Ra (μm)	0.29 ± 0.23	0.07	0.18 ± 0.20	0.17 ± 0.15	0.18 ± 0.18	.298
Rz (μm)	2.19 ± 1.54	0.88	1.32 ± 1.38	1.38 ± 1.03	1.38 ± 1.28	.144

The values are given as mean and SD.