Early Failure of a Cross-Linked Polyethylene Acetabular Liner

A Case Report

By K. David Moore, MD, Preston R. Beck, MS, Donald W. Petersen, PhD, John M. Cuckler, MD, Jack E. Lemons, PhD, and Alan W. Eberhardt, PhD

Investigation performed at the University of Alabama at Birmingham, Birmingham, Alabama

The use of highly cross-linked ultra-high molecular weight polyethylene in total hip arthroplasty has become a popular alternative to the use of conventional polyethylene. Evaluations with use of hip simulator tests¹⁻⁴ and clinical evaluations of total hip replacements⁵⁻¹⁰ have indepen-

dently shown that polyethylene materials processed with gamma irradiation followed by melting or annealing have extremely low wear rates. However, it also has been demonstrated that such cross-linking processes may reduce the fracture toughness and resistance to fatigue crack propagation of polyethylene¹¹⁻¹⁶.

Fig. 1-A

Fig. 1-B

Fig. 1-A Anteroposterior radiograph of the hip, made six weeks postoperatively, showing the femoral head to be asymmetrically seated within the shell. The length (Len) between the superior edge of the acetabular liner and the edge of the femoral head is 3.6 mm less than the length between the medial edge of the liner and the edge of the head. **Fig. 1-B** Radiograph made at the time of the revision, revealing severe asymmetry of the head in the cup consistent with catastrophic polyethylene failure. Len = length.

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Fig. 2

Photograph of the retrieved acetabular components, showing three broken cross-linked-polyethylene parts and three broken pieces of the metal locking ring. The arrow indicates the superior orientation.

Bradford et al.¹⁴ found that retrieved cross-linked polyethylene acetabular liners exhibited surface cracking that had not been predicted by in vitro hip simulator studies. Tower et al.¹⁷ observed fatigue failure at the superior aspect of the rim of four retrieved highly cross-linked acetabular bearings. They concluded that the factors contributing to these failures included thin polyethylene at the cup rim, a relatively vertical cup alignment, and compromised material properties of the cross-linked polyethylene in comparison with conventional polyethylene. In the current case report, we describe the failure of a highly cross-linked polyethylene acetabular liner less than three years after implantation. We believe that the mechanisms of failure were fracture of the cross-linked polyethylene where it was thin along the locking groove and abnormal loading of the cup because of improper seating of the liner in the shell at the time of the

original procedure. This study was conducted with institutional review board approval and in compliance with HIPAA (Health Insurance Portability and Accountability Act) requirements at our institution.

Case Report

A seventy-four-year-old woman underwent a primary right total hip replacement through a posterior minimally invasive approach. The femoral component was a VerSys Advocate cemented stem (Zimmer, Warsaw, Indiana) with a satin surface finish, a 34-mm neck length, and a 36-mm modular cobalt-chromium femoral head. The cup was a Trilogy component (Zimmer) with a 52-mm outer diameter containing a cross-linked polyethylene liner (Longevity; Zimmer). The cross-linking was performed with use of 100-kGy electron-beam radiation at 40°C, followed by six hours of heat treatment at 150°C and gas-plasma sterilization⁵.

Routine radiographs made six weeks postoperatively demonstrated appropriate positioning of the femoral stem (neutral alignment). The inclination of the acetabular shell was 48°, and the anteversion was approximately 20°. However, the femoral head was asymmetrically oriented with respect to the shell, which suggested that the liner was not appropriately seated (Fig. 1-A). The patient stated that she was able to discontinue using a cane by approximately twelve weeks postoperatively. However, at about six months postoperatively, she began having pain and started using a cane again. She reported falling fifteen months postoperatively and noted that the hip had “squeaked” since that time. Radiographs made seventeen months after the fall revealed marked asymmetry of the femoral head within the shell (Fig. 1-B).

A workup for infection revealed negative findings, and a revision total hip arthroplasty was performed at our institution, approximately two years and nine months after the original procedure. Intraoperative findings included extensive metallic staining of the pseudocapsule. The polyethylene was noted to be in multiple fragments, and the locking ring of the acetabular component was fractured. The femoral component was grossly loose. We examined three pieces of the fractured polyethylene liner, the retrieved metal acetabular shell, three pieces of the fractured titanium locking ring, and the femoral component. The external diameter of the acetabular shell, measured with digital calipers, was 52 mm. The external diameter of the polyethylene liner along the locking groove was 40 mm, and the polyethylene thickness at that site ranged from 2.6 to 3.3 mm. In contrast, the adjacent liner thickness was 4 to 4.6 mm. Gross visual and stereomicroscopic analyses were performed on all retrieved components, and photographs were made with a digital camera. Scanning electron microscopy (Philips XL30; Eindhoven, The Netherlands) was used to analyze the fracture surfaces of the broken polyethylene rim and locking ring.

The pieces of the failed acetabular component were arranged and photographed in anatomic position (Fig. 2). The superior aspect of the polyethylene rim had fractured along the locking groove. The rim piece showed no visible signs of wear,

Fig. 3-A

Fig. 3-B

Fig. 3-C

while a smaller, wedge-shaped piece of polyethylene showed considerable wear, comparable with that of the adjacent section of the liner. The liner was seen to have a large crack emanating from the locking groove adjacent to where the rim had fractured (Fig. 3-A). In addition, a groove was apparent along the inferior aspect of the backside of the remnant cup, which suggested that the locking ring had become repositioned from the locking ring groove in the acetabular shell (Fig. 3-B). Two additional blackened demarcations were visible on the backside of the remnant cup, which appeared to be the result of the two broken locking-ring pieces becoming wedged between the polyethylene liner and the metal cup. One such demarcation is shown in Figure 3-C.

Fig. 3-A The remnant polyethylene liner, revealing a crack emanating from the locking groove adjacent to where the rim had fractured (arrow). **Fig. 3-B** The arrows point to a groove along the backside of the remnant liner, which suggests that the locking ring had become dislodged from the locking-ring groove in the acetabular shell. **Fig. 3-C** One of two blackened demarcations visible on the backside of the remnant cup, which appeared to be the result of broken locking-ring pieces becoming wedged between the polyethylene liner and the metal cup.

The fractured edge of the half-ring of the polyethylene rim was analyzed with scanning electron microscopy, which revealed complex fatigue-fracture processes. Fatigue striations were clearly visible emanating from the locking-ring groove and propagating toward the articular surface, and along the circumferential direction around the rim (Fig. 4). Fatigue striations were not apparent along the ends of the fractured rim. Instead, the ends appeared smooth and polished, as if they had rubbed against their opposing fracture surfaces.

The metallic acetabular shell demonstrated evidence of burnishing consistent with metal-on-metal articulation at the section where the polyethylene liner locking-ring release was located on the rim of the shell. On repositioning of the liner

Fig. 4

Scanning electron micrograph ($\times 15$) of the fractured surface of the cross-linked-polyethylene rim. The fractured surface shows evidence of high-cycle, low-load fatigue (center and left arrows) and mixed-mode fatigue fracture (top right arrow). The planar fractures in the center of the figure suggest a predominantly mode-I (tensile) stress environment. Toward the upper-right side of the figure, the liner rim shows evidence of failure that had occurred along numerous planes, suggesting the presence of mode-II (shear) and mode-III (tearing) stresses as well.

within the shell, a clear line of demarcation was apparent along the edge of the smaller, wedge-shaped piece of polyethylene and the worn metallic shell (Fig. 5), suggesting that the smaller piece had remained attached to the remnant cup long after the rim had fractured off.

The metallic locking ring was in three pieces. The largest remnant was still located inside the locking-ring groove of the acetabular shell. The surface features of the fractured ends of the locking ring as seen on scanning electron microscopy were consistent with mechanisms of a single-overload, ductile fracture, with no evidence of fatigue.

The outside of the broken piece of the locking ring that matched up to the gouge on the backside of the polyethylene liner demonstrated evidence of burnishing, consistent with the finding that this piece was wedged between the polyethylene and the acetabular cup.

The loose femoral stem displayed no damage other than that caused by removal. No corrosion was observed between the stem and the head of the femoral component. The femoral head had large sections of the articulating region covered with an irregular metallic layer of debris transfer from articulation against the acetabular shell.

Fig. 5

The repositioned liner within the shell revealed a clear line of demarcation along the edge of the smaller, wedge-shaped piece of polyethylene and the worn metallic shell (arrows), which suggests that the smaller piece had remained attached to the remnant cup long after the rim had fractured off.

Fig. 6

An undamaged Trilogy metallic shell; the arrow highlights the gap between the locking ring and the shell.

Discussion

We report the catastrophic failure of a highly cross-linked acetabular liner with less than three years of service. The asymmetric positioning of the femoral head seen on the initial postoperative radiographs, the cracks and fatigue striations along the surfaces at the sites of the polyethylene failure, the broken locking ring, and the visible damage to the backside of the polyethylene liner led us to conclude that failure to properly seat the liner within the shell during the original procedure contributed to the initiation of the fatigue fracture of the liner.

Examination of an undamaged Trilogy implant reveals a locking ring that can protrude into the cup interior if the liner is not seated properly (Fig. 6). It is possible that, in this patient, the misaligned, protruding, and unsupported ring was broken on impaction of the polyethylene liner, which led to the embedding of the broken ring in the liner back, causing the liner to “sit proud” along its inferior aspect. The malpositioned liner then experienced tensile stresses along the superior aspect of its rim, which led to the initiation of the fatigue fracture along the locking groove that propagated around the rim. The large crack in the remnant cup suggests that the rim cantilevered at this section and then broke off. It is not clear how the patient’s fall contributed to the overall failure. It may be that the fall resulted in a fracture of the weakened rim or that the rim had already failed due to fatigue and the smaller piece of polyethylene was liberated by the fall. Regardless, the broken rim resulted in increased wear of the remnant cup, which ultimately allowed the femoral head to impinge on the metallic acetabular shell and caused the squeaking reported by the patient.

The radiographs revealing asymmetry of the femoral head in the cup were made with the patient in a supine position. Supine radiographs have been found to correlate strongly with measurements made with the patient bearing weight¹⁸. We do not believe, therefore, that the asymmetry observed on the radiographs was due to distraction of the head from the liner because the patient was supine.

The problem of thin polyethylene at the rim has been noted previously as a factor in liner failure. Berry et al.¹⁹ reported fractures of non-cross-linked polyethylene liners with rim thicknesses of <5 mm. Tower et al.¹⁷ reported thicknesses of <4 mm at the locking groove of cross-linked polyethylene liners associated with unanticipated fatigue fractures. The thickness values of the retrieved specimen from our patient were as low as 2.6 mm. These observations indicate that, in addition to material weakening of the polyethylene because of the cross-linking process, a certain minimal thickness of polyethylene may be necessary to prevent such a failure.

Despite promising results in terms of wear characteristics¹⁻¹⁰, it is well established that cross-linking and heat annealing result in a polyethylene with reduced resistance to crack initiation and propagation under tensile stresses¹¹⁻¹⁶. Although stresses in an acetabular insert are primarily compressive, tensile stresses may occur along the rim of the component from impingement secondary to malposition²⁰ or overly vertical alignment¹⁷ of the acetabular component. In the present case, a so-called minimally invasive technique was employed at the time of the index operation. It is possible that limited surgical exposure may have contributed to improper seating of the liner. ■

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K. David Moore, MD
Division of Orthopaedic Surgery, University of Alabama at Birmingham,
FOT 920, 510 20th Street South, Birmingham, AL 35294

Preston R. Beck, MS
Donald W. Petersen, PhD
Jack E. Lemons, PhD
Department of Prosthodontics and Dental Biomaterials, University of
Alabama at Birmingham, SDB 616 (P.R.B. and D.W.P.) and SDB 615
(J.E.L.), 1919 7th Avenue South, Birmingham, AL 35294

John M. Cuckler, MD
Division of Orthopaedic Surgery, University of Alabama
at Birmingham, 1709 Somerset Circle, Mountain Brook,
AL 35213

Alan W. Eberhardt, PhD
Department of Biomedical Engineering, University of Alabama at
Birmingham, Hoehn 370, 1075 13th Street South, Birmingham,
AL 35294. E-mail address: aeberhar@uab.edu

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