Mechanical Failure of Marathon Cross-Linked Polyethylene Acetabular Liner After Total Hip Arthroplasty

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Polyethylene wear and resultant particulate debris can lead to failure through osteolysis, late loosening, instability in total hip arthroplasty (THA), and other modes.[1,2] Cross-linked polyethylene was developed as a potential solution to the problems created by wear. The increased resistance to adhesive and abrasive wear with this bearing surface has been well documented in laboratory hip simulator studies.[3-5] Early results of in vivo clinical studies also have shown the decreased wear advantage of cross-linked polyethylene.[6-8] The major disadvantage of cross-linking is its deleterious effect on mechanical properties, such as fracture toughness, fatigue resistance, and resistance to crack propagation.[9-11] Indeed, extensive surface cracks were found in Durasul (Sulzer Orthopaedics, Austin, Texas) highly cross-linked acetabular retrievals.[12] These defects were thought to be caused by a decrease in the mechanical properties of the polyethylene. These liners had not failed clinically; they were revised for reasons other than mechanical failure. However, such reduction in mechanical properties can lead to catastrophic large-scale polyethylene failure, particularly in weight-bearing joint arthroplasty.

Tower and colleagues[13] documented mechanical failure and fracture in 4 Longevity (Zimmer, Warsaw, Indiana) cross-linked acetabular bearings. To our knowledge, the failure mode we describe in the present case report has not been reported with other cross-linked polyethylene brands. We document a case of a retrieved Marathon (DePuy, Warsaw, Indiana) acetabular liner that had fractured at the superior rim. The patient provided written informed consent for print and electronic publication of this case report.

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Case Report

A 46-year-old woman (weight, 95 lb; body mass index, 19.6 kg/m^2) underwent left primary THA at an outside facility 2 years earlier. The original diagnosis was degenerative disease secondary to hip dysplasia. Severe scoliosis and a significant fixed pelvic obliquity were noted. An S-ROM (DePuy) femoral component was used. The patient presented to our clinic 2 weeks after the THA with severe pain in the left groin and was found to have a grossly displaced acetabular shell. Her contralateral right THA was clinically functioning well 18 years after surgery, despite significant osteolysis and wear (Figure 1). She expeditiously underwent revision of the loosened acetabular component without complication. A Pinnacle Bantam (DePuy) acetabular shell with an outer diameter of 46 mm was placed and augmented with a dome screw (Figure 2). A Marathon (DePuy) cross-linked liner with an inner diameter of 28 mm and an offset of +4 mm was placed. A 10° face changing liner with posterosuperior oriented elevation was used to enhance stability. Postoperative radiographs showed cup abduction angle of 64°. Two years and 10 months after THA, she presented acutely to our clinic with painful popping in the operative hip. Clinical examination revealed palpable clicking and popping in the hip with passive range of motion.

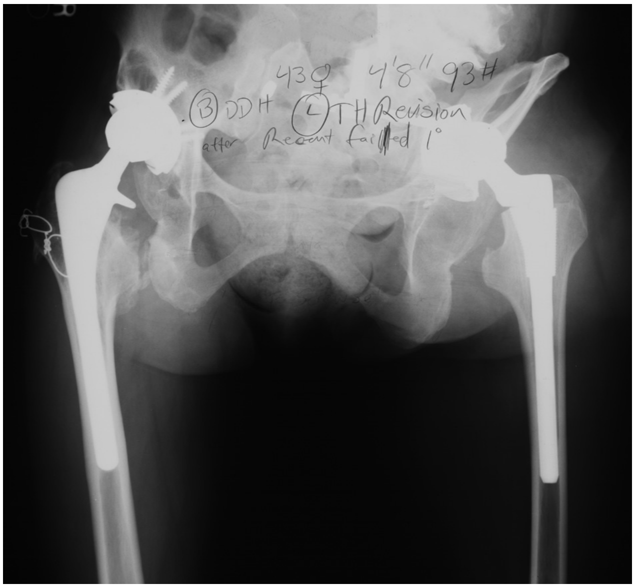

Figure 1. Anteroposterior pelvis radiograph shows displaced left acetabular component and contralateral osteolysis and wear.

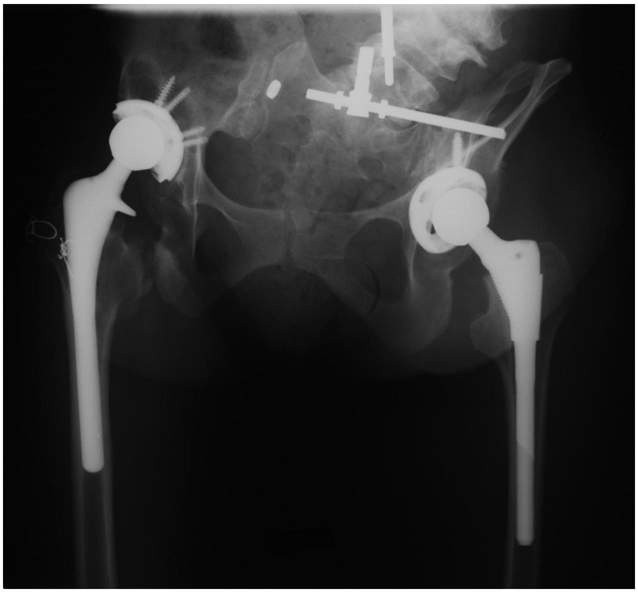

Figure 2. Anteroposterior pelvis radiograph after revision of loosened acetabulum. Cup abduction angle, 64°. Note significant scoliosis and pelvic obliquity.

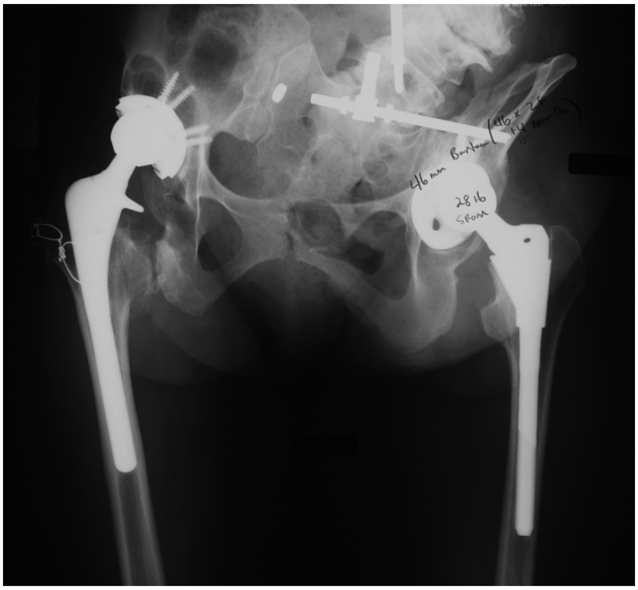

Figure 3. Anteroposterior pelvis radiograph. Left femoral head has migrated into apparently well-fixed acetabular shell.

Radiographs showed acute superior migration of the left femoral head into the well-fixed acetabular shell (Figure 3). Revision of the liner was undertaken. The polyethylene was found to be fractured at the anterosuperior margin (Figure 4), and the shell was stable and was left intact. Polyethylene thickness was increased, particularly in the areas of highest stress, by downsizing the ball to 26 mm and superiorly orienting a 10° face changing liner with offset of +4 mm (Figure 5). The patient sustained an early postoperative dislocation, but at 1-year follow-up was doing well.

Retrieval Analysis

Laboratory retrieval analysis was performed to determine possible mechanical events leading to failure. The explanted device was photographed and graded for clinical damage according to a modified Hood scoring system.[14] Analysis of the burnishing pattern on the articular surface showed smoothing of the original machining marks but no evidence of material removal. The burnishing occurred in the anterosuperior quadrant of the cup.

Almost half of the nonarticular backside of the cup showed extensive abrasive wear on the posterosuperior surface, indicating relative motion between the cup and the rim of the acetabular shell (Figure 6). Of the 4 original alignment pegs at the outer diameter of the cup, only 2 were intact.

The cup was fractured in the anterosuperior quadrant. Fracture analysis showed that the failure was fatigue related and that the crack had begun at the outer diameter and propagated inward. The locus of crack initiation was the site of one of the missing alignment pegs.

Fourier transform infrared spectroscopy documented no significant oxidation of the polyethylene, indicating no in vivo degradation of the material.[15] Review of the manufacturing lot revealed no other mechanical failures with this batch of material.

It was hypothesized that the initial event leading to failure of the THA was mechanical failure of the anterior alignment peg and the locking mechanism. This failure allowed the liner to rotate, imposing high stresses on the remaining alignment pegs. As the device rotated in its shell, the nonspherical rim of the device was articulated against the spherical interior of the shell. The lack of geometrical conformity, coupled with the loads imposed by the patient on the superior rim during gait, led to substantial tensile stresses in the region of the sheared-off alignment peg. These stresses were sufficient to cause crack propagation.

Discussion

Use of cross-linked polyethylene in hip arthroplasty is promising in that it decreases the long-term consequences of wear. However, with improved wear comes a reduction in the mechanical strength of the material. The factors that likely contributed to the failure of the liner in our patient's case include reduction in the mechanical properties of the material, minimal thickness at the rim, and relatively vertical cup alignment.

Highly cross-linked polyethylene is created by irradiating ultra high molecular weight polyethylene (UHMWPE). Carbon–hydrogen bonds are broken and free radicals created. In an oxygen-poor environment, cross-links are then formed. The uncombined free radicals that remain in the polyethylene eventually cause oxidative degradation, which ultimately reduces the fatigue properties. The free radicals can be removed by annealing or melting the polyethylene. Unfortunately,

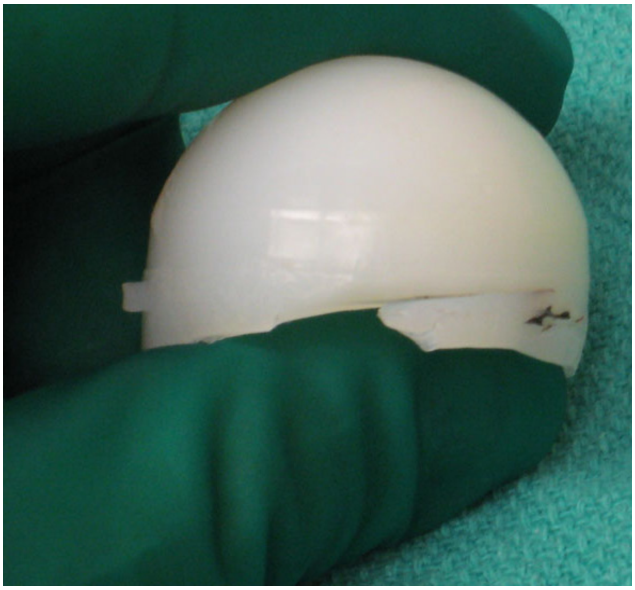

Figure 4. Intraoperative photograph of failed highly cross-linked acetabular liner. Fracture is at anterosuperior rim.

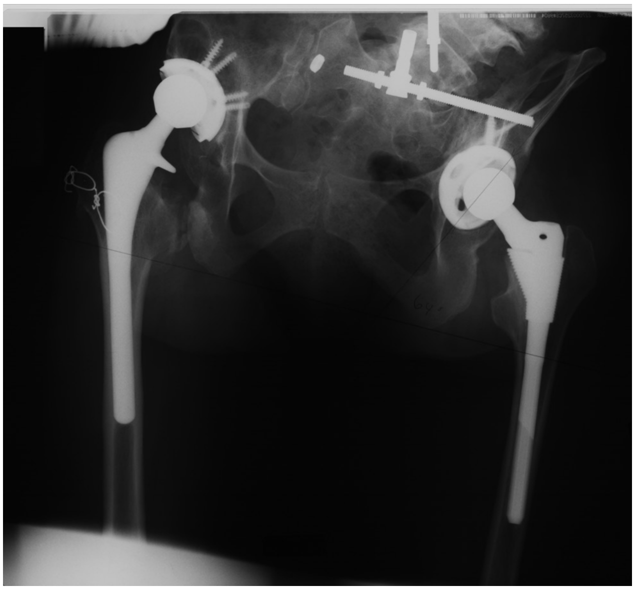

Figure 5.. Anteroposterior pelvis radiograph after revision of fractured acetabular liner and downsizing of femoral head.

this process reduces the mechanical properties as well. Increasing the dose of radiation leads to increased cross-linking.[16] As the amount of cross-linking increases, there is a concomitant dose-dependent reduction in the mechanical properties.[11,17] The optimal dose for balancing these 2 factors is not known.

Marathon polyethylene is an UHMWPE that is treated with 5 Mrad (50 kGy) of gamma radiation to induce cross-linking. The polyethylene is subsequently annealed above the melting temperature (140°C), which increases cross-linking and eliminates free radicals. The cross-linked polyethylene is machined and terminally sterilized with gas plasma—a non–cross-linking chemical surface treatment.[18]

Tower and colleagues[13] documented 4 cases of fracture and early failure with Longevity acetabular bearings, which had an in vivo duration of 7 months to 27 months. These liners failed at the superior rim in the groove that engages the locking ring of the Trilogy shell. In all cases, the thickness of the polyethylene at the rim was less than 4 mm. No in vivo oxidative degradation was noted. In our patient's case, the acetabular liner failed after only 34 months. No oxidation was noted during the retrieval analysis. The rim thickness of the liner in this case was 4 mm.

With the improved wear characteristics of cross-linked polyethylene, surgeons are increasingly using larger heads to improve stability and decrease the rate of dislocation. When larger heads are used in smaller acetabular cups, the polyethylene decreases in thickness; it may be thinnest at the periphery of the cup because of the presence of the locking mechanism. This peripheral region is often the area of most mechanical stress, particularly when the acetabular component is placed

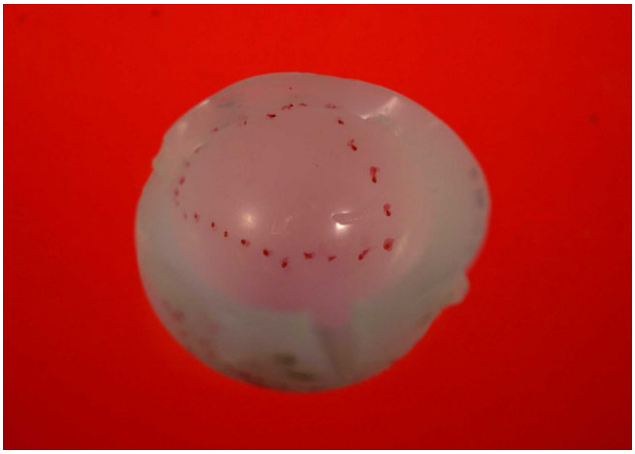

Figure 6. Retrieval analysis photograph shows extensive wear on backside surface of polyethylene.

in a relatively vertical position. This material triad of reduced mechanical strength, decreased thickness, and increased force (in a vertical cup) appears to be the combination of factors observed in the few cases of failed cross-linked liners. All these factors were present in our patient's case.

Surgeons should be aware of the minimum polyethylene thickness, particularly the thickness at the rim. Manufacturers often report thickness at the dome, not at the rim. We cannot recommend a minimum threshold but exercise caution when the polyethylene is less than 6 mm thick. In such cases, downsizing the femoral head in favor of thicker polyethylene may be prudent. We chose this option when revising our patient's fractured liner. Unfortunately, doing so decreased hip stability, and the patient sustained a postoperative dislocation. In hindsight, removing the acetabular component to improve alignment may have been the wiser decision.

Hard-on-hard bearings are usually not a forgiving articulation from the surgeon's or patient's perspective. Both ceramic and metal bearing surfaces have been shown to not tolerate malpositioning.[19,20] Impingement, equatorial loading, or both, may cause failure with these bearing options. Similarly, cross-linked polyethylene is a less-forgiving articulation. Appropriate alignment of the acetabular shell is particularly crucial with cross-linked polyethylene. With a vertical cup, there is equatorial loading at the superior rim. An extreme amount of stress is then placed on a polyethylene with reduced mechanical properties—a recipe for failure. Crowninshield and colleagues[21] showed that, with high abduction acetabular component orientation, use of larger femoral heads contributes little to joint stability, but considerably elevates tensile stress within the polyethylene that may result in implant failure. High abduction angles were noted in the earlier report of Longevity polyethylene failure.[13] The abduction angle in our patient's case was 64°. Vertical cup orientation with equatorial loading is clearly undesirable with cross-linked polyethylene.

Our report seems to indicate that early mechanical failure of cross-linked polyethylene is a "class effect" and is not brand- or manufacturer-specific. However, this case must be placed in proper perspective. A query of our database yielded no similar failures in more than 2700 uses of Marathon polyethylene, indicating that the properties of the material are almost always sufficient. Nevertheless, we continue to exercise caution when using this material. In cases in which the polyethylene is necessarily thin (<6 mm) because of the shell size, we often opt for a smaller head. Only in the most low-demand patients or in patients with severe dislocation risk will we compromise and use thin polyethylene.

Authors' Disclosure Statement

Dr. Van Citters reports receiving laboratory funding and being a member of the speaker's bureau for DePuy, Inc. Dr. Hamilton reports being a consultant for and member of the speaker's bureau for DePuy Orthopaedics. Dr. Barrett reports no actual or potential conflict of interest in relation to this article.

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