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Effect of Locking Mechanism on Fluid and Particle Flow Through Modular Acetabular Components

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Abstract: Six modular acetabular components were evaluated to determine whether screw holes in the metal shell offer a route for fluid and debris into the acetabular bone stock. A 56-mm acetabular shell for each trial was mounted to a sealed chamber and loaded at a 25° angle under axial loads of 270–2,700 N and ± 2.5-N-m torsional load. Polystyrene microspheres (average diameter, 0.5 μm) were placed in double-deionized water at 300 mmH_2O pressure in a sealed chamber above the component. The only channel between the fluid above and the collecting chamber below was through the cup–liner interface and 1 screw hole. Fluid and debris in the collecting chamber were harvested after 1,000,000 cycles. The collected sample was filtered through a 0.2-μm-pore filter and analyzed under electron microscopy for evidence of microspheres. Water and polystyrene microspheres were isolated in the collecting chamber for all trials except the Reflection cup (Smith & Nephew Orthopaedics, Memphis, TN) with a screw hole cover and the Micro-Seal cup (Whiteside Biomechanics, St. Louis, MO) with a peripheral seal. A screw placed in the screw hole of the Reflection cup failed to seal the interface. The peripheral seal around the rim of the Micro-Seal polyethylene prevented fluid and particle flow between the metal shell and polyethylene liner. **Key words:** total hip arthroplasty, acetabular component, implant design, uncemented, particulate debris, polyethylene.

Osteolysis remains a major concern in joint arthroplasty surgery. Periprosthetic bone loss secondary to osteolysis can cause loosening and failure in otherwise well-implanted components. Aggressive granulomatous lesions were first thought to be a consequence of host reaction to polymethyl methacrylate, but when similar osteolytic lesions were found in uncemented joint arthroplasties, it became apparent that other factors were involved [1–5]. It is now generally accepted that submicron polyethylene wear debris is an important factor contributing to the synovitis and synovial reaction that contribute to osteolysis [5–8]. Improved bearing surfaces such as ceramics and ultrahigh-molecular-weight polyethylene have reduced polyethylene wear, whereas enhanced fixation of polyethylene liners into metal cups has reduced significant backside wear and dissociation of the liner from the cup; however, even with the most modern designs, a certain amount of polyethylene debris is liberated as a result of wear. Early reports of osteolytic lesions in cementless acetabula suggested that the screw holes acted as conduits for debris migration into the pelvic bone stock [9,10]. Debris generated at the articular surface can migrate between the liner and shell and gain access to the pelvic bone stock through the screw holes. Loss of bone support secondary to osteolysis can lead to loosening and eventual failure

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of the acetabular component. Recent design modifications to help prevent migration of wear debris into the acetabular bone stock include sealing the screw holes with modular caps and eliminating the screw holes altogether; however, the metal shell often requires augmented fixation, and screws inserted through the shell offer a simple solution to an otherwise complex problem. If the interface between the polyethylene and the metal shell were sealed, then the joint fluid and articular wear debris would not have access to the screw holes and the use of screws and screw holes would be safer.

The purpose of this study was to evaluate currently available acetabular components in their capacity to allow submicron debris to enter the interface between the metal shell and the polyethylene liner.

Materials and Methods

Components

Six modular acetabular components were evaluated: a Precision Osteoloc (Howmedica, Rutherford, NJ), a Trilogy (Zimmer, Warsaw, IN), a Reflection (Smith & Nephew, Memphis, TN) with a tapered metal insert covering the screw hole, a Reflection with a taper-head screw, and two different versions of the Micro-Seal (Whiteside Biomechanics, St. Louis, MO) component (Fig. 1). The tapered surface in the metal cup and peripheral ridges on the liner are designed to provide a watertight seal between the polyethylene and the metal cup. One Micro-Seal polyethylene had the sealing ridges removed.

One Reflection component was tested with a tapered metal insert over the collecting screw hole. Another Reflection component was tested with a 40-mm taper-head screw placed through the collecting screw hole and driven into a 1 × 1 × 4-cm block of wood inside the collecting chamber. The screw was placed at an angle perpendicular to the surface of the shell. The wood was in contact both with the bottom of the collection chamber and with the bottom of the acetabular component. After the test with this component was complete and the fluid was removed from the collection chamber, the polyethylene insert was removed and a linearly variable differential transducer (LBB-375-PA-060, Schaevitz, Pennsauken, NJ) was mounted to the rim of the acetabular shell with the tip against the screw head. A metallic probe was attached to the Instron actuator in place of the prosthetic femoral head such that the tip was in line with the screw head. The probe was cycled against the screw head under the same load conditions described above. Motion of the screw head relative to the acetabular component was recorded on a chart recorder.

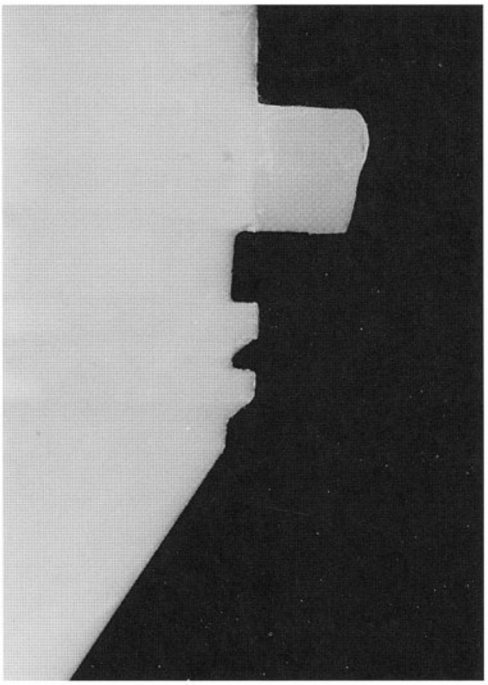

Fig. 1. A locking tab and the 2 peripheral ridges on the Micro-Seal polyethylene liner (Whiteside Biomechanics, St. Louis, MO). The peripheral ridges were removed with a scalpel from one liner for the purpose of this study.

Test Setup

The acetabular cup for each trial was mounted with epoxy to a sealed collecting chamber at a 25° angle to horizontal. All screw holes except 1 were filled with epoxy. A 28-mm cobalt–chrome prosthetic femoral head was cemented with polymethyl methacrylate into the polyethylene liner, and the apparatus was placed into a servohydraulic testing device (Instron 8501, Instron, Canton, MA). An axial preload of 270 N was applied, and the housing was secured to the base with 4 quadrant screws. A cyclical axial load of 270–2,700 N was applied with a torsional load of ± 2.5-N-m in a sinusoidal waveform at 10 Hz. The components were run dry for 1,000 cycles under test conditions to ensure proper seating of the liner into the cup. A sealed chamber was placed over the acetabular component and secured to the collecting chamber with silicone sealant (Fig. 2).

Polystyrene microspheres (1.87×10^{14} particles/mL) with an average diameter of 0.5 μm (Structure Probe, Westchester, PA) were placed in 2 mL of double deionized water and inserted into the sealed chamber encasing the acetabular component (Fig.

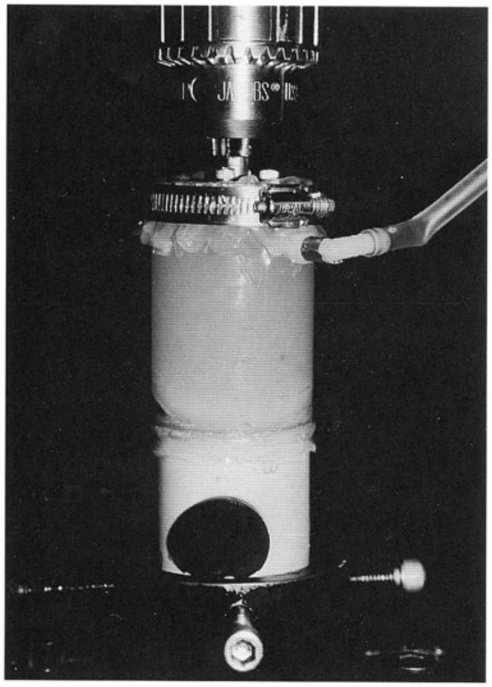

Fig. 2. Test setup showing the sealed upper chamber, which is filled with water and microspheres, and the lower collecting chamber. The test apparatus was held in place with 4 quadrant screws. Three hundred millimeters of water pressure was supplied through the plastic tubing.

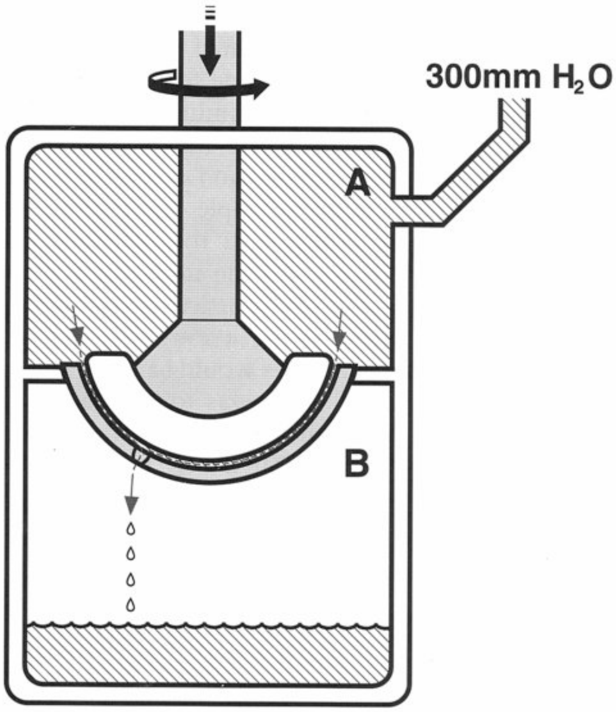

Fig. 3. (A) The upper chamber was sealed and pressurized to 300 mmH_2O. The loading ram was glued to the liner to allow axial and torsional loads to be applied directly. The metal shell is sealed and fixed to the floor of the pressurized chamber. (B) The only route to the nonpressurized chamber below is through the potential space between the polyethylene liner and the metal shell (small arrows).

3). The pressure within the chamber was maintained at 300 mmH_2O pressure [11] by means of a fluid column. The only channel between the fluid chamber above and the collecting chamber below was through the cup–liner interface. Fluid and microspheres present in the collecting chamber were harvested after 1,000,000 cycles. If no fluid was present, the inside of the collection chamber was irrigated with 20 mL of double deionized water, which then was collected and analyzed.

Specimen Analysis

The collected sample was filtered through a 0.2-μm-pore filter. The filters were prepared for scanning electron microscopic evaluation (JEOL 35, JEOL, Peabody, MA) by air-drying for 48 hours in individual containers. They were affixed to aluminum mounts by copper adhesive tape and sputter coated with gold and palladium to impart conductivity. They were examined individually under an electron microscope at low (1,000×–2,000×) and high (12,000×) magnifications for evidence of microspheres.

Results

After 1,000,000 cycles, water and polystyrene microspheres were isolated in the collecting chamber of the Precision Osteoloc, the Trilogy, the Reflection with the taper-head screw, and the Micro-Seal cup without the peripheral ridge. No resistance to the flow of fluid was apparent in these components and the collecting chambers quickly filled with water. The taper-head screw in the Reflection did not impede the flow of fluid, even though less than 100 μm of micromotion was observed between the component and the screw. The filtrate of these trials was a fine white powder. Scanning electron microscopy analysis showed this powder to consist of polystyrene microspheres (Fig. 4). The collection chambers of the Reflection with the tapered metal insert over the screw hole and the Micro-Seal with the intact peripheral seal were dry after 1,000,000 cycles. The irrigant of these two trials was devoid of microspheres (Fig. 5).

The inside of the metal shells and the backside of the polyethylene inserts for all trials except that of

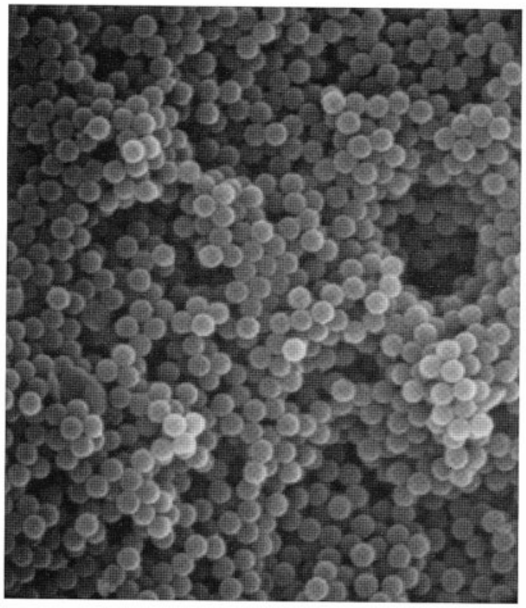

Fig. 4. The 0.5-μm microspheres are evident in this scanning electron microscope image of a filter at 12,000×.

the acetabular component with the intact peripheral seal had evidence of microspheres in the form of a fine white powder. In the component with intact peripheral ridges, the cup–liner interface was dry after 1,000,000 cycles.

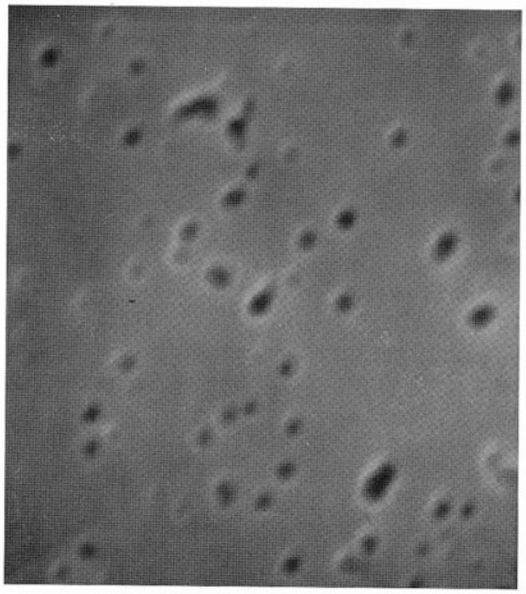

Fig. 5. No microspheres are seen on this scanning electron microscope image of a filter from the Micro-Seal component (Whiteside Biomechanics, St. Louis, MO), the liner of which had intact peripheral ridges. The dark areas are holes in the filter. 20,000×.

Discussion

Osteolysis is currently the most important issue in total hip arthroplasty (THA). Loosening secondary to osteolytic bone loss is a frequent cause of failure in otherwise well-implanted components [1,12]. Although wear characteristics in THA have improved with better design and improved bearing surfaces, the liberation of particulate wear debris is inevitable. Polyethylene debris particles produced in THA have been estimated to number in the billions per year [6,13,14].

Wear particles can migrate within the effective joint space to areas of exposed bone, where they can induce an osteolytic response [12]. The osteolytic potential of submicron polyethylene debris is well documented [5,8,15]. Extracellular and intracellular polyethylene particles are present in histologic samples taken from focal areas of osteolysis around cementless cups, including osteolytic cysts around screw holes [2,4,10,13].

In THA, polyethylene wear debris is produced at the articular surface and also on the backside of the liner. Significant backside wear is reduced with effective peripheral locking mechanisms [16], and therefore, the majority of debris is generated at the articular surface [4,14,17]. In cementless acetabula, the areas of bone susceptible to debris migration include the bone at the periphery of the component and that underlying the screw holes [9,12]. Debris migration at the periphery of the metal shell is effectively blocked by fibrous ingrowth [12,13,18]. Debris generated at the articular surface can gain access to the pelvic bone stock underlying the acetabular component by migrating between the cup and liner and through the screw holes. As shown in this study, this phenomenon occurs even if screws are used. Acetabular components without screw holes are available; however, they preclude the use of screws and thus limit surgical options for fixation. In this study, all of the components, except the component with the intact peripheral sealing mechanism, allowed microspheres and fluid to enter the cup–liner interface, and thus the particles had access to the underlying bone through the screw holes. The tapered metal insert provided an effective seal over the screw hole in the Reflection implant; however, in the presence of screws, debris and fluid flowed freely through the screw holes. In the acetabular component with the peripheral seal, there was no evidence of microspheres penetrating beyond the seal.

Because we were most interested in the migration of microspheres, we wanted to ensure that other coincidental debris would not interfere with our results. Therefore, it was necessary not only to quantify but also to qualify any debris that was collected. This was achieved with visual inspection of the filtrate from the collection chamber. Microspheres, when present, were easily observed on the mounted filter.

The actuator position on the Instron testing device necessitated the upside-down configuration used in this study. This raises the concern that gravity may have influenced the migration of the fluid and microspheres; however, hydrostatic forces present in the effective joint space are known to allow migration of debris against gravity clinically. In any case, the experimental configuration serves to demonstrate that a potential route for fluid and debris migration to the pelvic bone exists at the periphery of the polyethylene liner and through the screw holes in the metal shell. This route appears to be eliminated in components with a peripheral polyethylene seal.

Conclusion

The results of this study indicate that, with an effective peripheral seal, screws and screw holes in the shell can be used without fear of articular wear debris migration into the underlying pelvic bone stock. When coupled with an effective polyethylene locking mechanism that minimizes backside wear of the liner and a contiguous porous coating around the periphery of the metal cup, the acetabular bone stock is much less susceptible to osteolytic attack.

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