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Basic Science

Does Increased Coefficient of Friction of Highly Porous Metal Increase Initial Stability at the Acetabular Interface?

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ABSTRACT

Background: Highly porous metal acetabular components illustrate a decreased rate of aseptic loosening in short-term follow-up compared with previous registry data. This study compared the effect of component surface roughness at the bone–implant interface and the quality of the bone on initial pressfit stability. The null hypothesis is that a standard porous coated acetabular cup would show no difference in initial stability as compared with a highly porous acetabular cup when subjected to a bending moment. Second, would bone mineral density (BMD) be a significant variable under these test conditions.

Methods: In a cadaveric model, acetabular cup micromotion was measured during a 1-time cantilever bending moment applied to 2 generations of pressfit acetabular components. BMD data were also obtained from the femoral necks available for associated specimen.

Results: The mean bending moment at 150 μm was not found to be significantly different for Gription (24.6 ± 14.0 N m) cups vs Porocoat (25 ± 10.2 N m; $P > .84$). The peak bending moment tolerated by Gription cups (33.9 ± 20.3 N m) was not found to be significantly different from Porocoat (33.5 ± 12.2 N m; $P > .92$). No correlation between BMD and bending moment at 150 μm of displacement could be identified.

Conclusion: The coefficient of friction provided by highly porous metal acetabular shells used in this study did not provide better resistance to migration under bending load when compared with a standard porous coated component.

Initial stability for press-fit acetabular components ideally minimizes micromotion at the bone–implant interface to maximize osseointegration and improve implant longevity. Contributing variables for initial stability include surgical technique, bone quality, type of acetabular component, and supplemental fixation. Surgical technique is generally accepted as the most important variable for primary and revision total hip arthroplasty [1-3]. Registry data reveal a significant incidence of early aseptic loosening of press-fit cementless acetabular components with short-term follow-up [4-10]. Acetabular component design is another factor that may affect this. This has led to many manufacturers attempting to improve initial fixation through a variety of methods.

Acetabular components using metal implants with highly porous surfaces were developed not only to increase surface area for tissue ingrowth (as well as decrease the modulus of elasticity of the substrate to minimize the difference in this mechanical property with host bone) but also to increase the surface roughness of the component [11]. Increasing the surface roughness is argued to be of benefit for improving initial fixation. Compared with other implants, limited 5-year results also trend toward decreased aseptic loosening rates for highly porous-surfaced implants [12-18] (Table 1). Even when there is less than 50% of host bone, good results are still achievable [19]. Long-term follow-up of these implants are not currently available.

The uncemented acetabulum's implant–bone interface relies on hoop stresses, the quality of the bone, and component design such

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Table 1
Early Aseptic Loosening Rates for Highly Porous Metal Acetabular Cups.

Author	Number of Hips	Average Follow-Up (mo)	Aseptic Loosening (%)
Fernandez-Fairen et al [13]	263	74	0
Malkani et al [15]	25	39	0
Skyttä et al [16]	827	36	2
Unger et al [17]	60	42	2
Van Kleunen et al [18]	97	45	0

as the type of coating, shape of the shell, presence of screw holes, and placement of screws or pegs [20]. Micromotion greater than 150 μm at the interface has been shown to create a fibrous ingrowth pattern and a potential for implant instability [21,22]. Unstable initial fit is a factor that can result in unsuccessful implantation [1,23]. It has been theorized that a higher coefficient of friction from a rougher surface would lead to improved initial stability of press-fit hemispheric acetabular components. Newer proprietary technologies altering the type of acetabular coating with increased porosity and surface roughness have focused around increasing initial stability to promote bony rather than fibrous ingrowth [24-26]. There are substantial design differences between different types of "highly porous" components so it is not clear that results are generalizable; however, biomechanical studies of one specific design of highly porous metal cup tested in a synthetic model have shown 23%-65% increase in initial stability as a result of surface roughness [25,26]. Furthermore, animal studies have demonstrated neovascularization within the pores [27]. To date, no studies have evaluated the degree of micromotion at the bone–implant interface at the time of insertion and its effect on long-term clinical results.

This study used a previously published cadaveric model to evaluate press-fit initial stability in 2 commercially available acetabular cups, which only differ by the type of surface coating. The null hypothesis was that a standard porous coated acetabular cup (DePuy Pinnacle Porocoat) inserted without screws after 1-mm underreaming would show no statistical difference in initial stability as compared with highly porous acetabular cup (DePuy Pinnacle Gription) inserted without screws after the same reaming conditions when subjected to a bending moment. Our second research question was whether bone mineral density (BMD) was a significant variable under these test conditions.

Methods

Experimental methodology was derived from a previously published study [28]. Ten matched pairs of cadaveric hemipelvises (9 males and 1 female) were obtained and stored at −20°C until the time of testing. Femurs associated with 7 pairs of hemipelvises were available and evaluated for femoral neck BMD by dual-energy X-ray absorptiometry using Hologics QDR-4500A (Hologics Inc, Waltham, MA). Before testing, specimens were thawed at room temperature, and all soft tissues removed except for the transverse acetabular ligament. The iliac crest and posterior superior iliac spine of each hemipelvis was trimmed as needed to fit into a 2" × 3" polyvinylchloride (PVC) connector. Two 3.2-mm transfixing pins were placed through the PVC and bone approximately 90° apart to secure the hemipelvis to the PVC. In addition, a #8 wood screw with fender washer was then mounted through the iliac fossa into the PVC connector. Polymethylmethacrylate was then poured into the connector and allowed to harden.

The PVC connector was attached to a custom fixture that allowed for stable reaming and implantation of the specimen. Starting with a hemispherical reamer approximately 6 mm smaller than the diameter of the denuded acetabulum, each specimen was sequentially reamed in 2-mm increments until achieving an odd-numbered reamer size that resulted in removal of all cartilage, appropriate medialization, and concentric reaming at the acetabular rim. A Food and Drug Administration–approved DePuy Pinnacle Porocoat or DePuy Pinnacle Gription screwless acetabular component (DePuy Synthes Orthopaedics, Warsaw, IN) was then chosen from available sizes ranging in 2-mm increments from 52 mm to 64 mm to be 1 mm larger than the last reamer resulting in a 1 mm press-fit. This created hoop stresses in the surrounding bone which affect implant stability. Implantation of the Porocoat or Gription component was alternated between left and right hemipelvises for each pair. The cup diameters were measured at multiple different points around the rim using digital calipers. Components were seated in native anteversion and approximately 40° of abduction using the pubis, ischium, and transverse acetabular ligament as reference [29]. The gap between the dome of the acetabular cup and underlying bone was visualized and measured at the cup's screw hole to ensure consistent seating of the component. The amount of superior acetabular rim overhang was estimated for each specimen by measuring exposure length along the implant rim circumference and the maximum distance from the implant's edge to the acetabulum. After appropriate placement, the stability of the implant was checked with manual bending moment using the insertion handle to mimic what is done intraoperatively. Furthermore, the stability of each cup was assessed in the coronal plane, as defined by the transverse acetabular ligament and superior acetabular margin, by applying a 6.8 N m (60 in-lb) bending moment through a specialized torque wrench applied to the insertion handle [28,30].

Each specimen was then mounted on biaxial servohydraulic materials testing equipment (Model 1321; Instron Corp, Canton, MA) retrofitted with digital controls (MTS TestStar II; MTS Corp, Eden Prairie, MN). A custom-made device with 3 linear variable differential transformers (LVDTs, Model 0242-00000; Trans-Tek Inc, Ellington, CT) was attached to the hemipelvis using four 4.8-mm diameter partially threaded Schanz pins. Linear variable differential transformer measurement points contacted the cup rim at the superior, inferior, and anterior margins as close as possible to

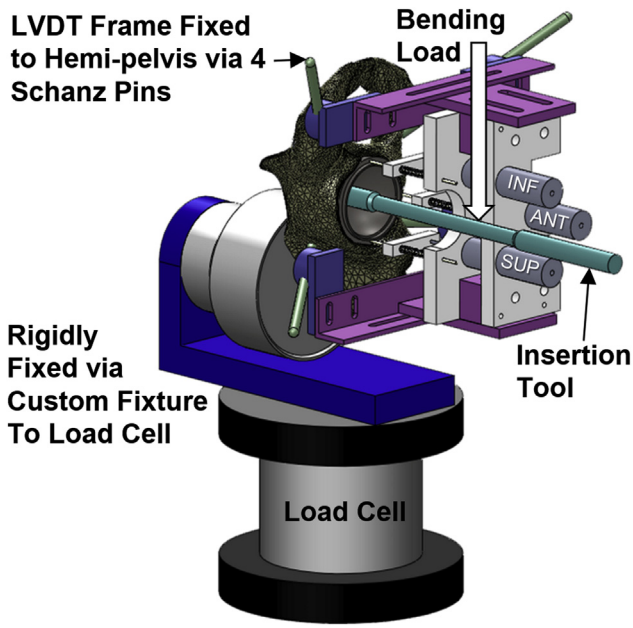

Fig. 1. Specimen setup before testing. Three linear variable differential transformer (LVDT) pins contacting cup rim inferiorly, superiorly, and anteriorly. Anterior pin not visible in photo.