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Initial Stability of Press-Fit Acetabular Components Under Rotational Forces

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ABSTRACT

The primary goal of this study was to determine the initial press-fit stability in acetabular components without screw fixation. Mechanical testing was performed with the implantation of press-fit acetabular components in cadaveric specimens. No significant difference was found in load to failure testing between 1 and 2 mm of under-reaming. However, there was significant variability in bending forces required to create 150 μm of micromotion ranging from 49.3 N to 214.4 N. This study shows that cups implanted in a press-fit fashion, which are felt to be clinically stable, have high degrees of variability in resisting load and may be at risk for loosening. There is a need for more objective intra-operative techniques to test cup stability.

While primary cementless total hip arthroplasties may fail in many ways including aseptic loosening of the stem, stress shielding, infection, dislocation, fracture, and osteolysis, the major complication is aseptic loosening of the acetabular component [1–8].

Registry data have shown rates of aseptic loosening in cementless acetabular components of 2%–12.3% at short term follow up [8–17]. Reliable registry data do not exist for the United States, and the data published by authors in the United States are often the result of expert high volume surgeons in the field of joint arthroplasty [4,18-19]. Consequently, aseptic loosening of press-fit, porous acetabular components may be a larger problem in the United States than is currently realized.

Initial stability of the acetabular component can be defined as the lack of relative micromotion between the prosthesis and bone in the first 90 day post-operative period [20–22]. Initial stability is necessary to achieve bone ingrowth, which will then predict long-term stability and success of the implant [20–26]. Vertical migration of the cup has been a proposed failure mechanism and an indication of loosening of cementless acetabular components [20]. Canine studies performed by Pilliar et al showed that bone ingrowth is inhibited and a fibrous ingrowth results if there is greater than 150 microns of micromotion between the bone–prosthesis interface [27–29]. To minimize micromotion and provide initial stability, acetabular components are designed to be press-fit which relies on an intimate rim fixation of the cup. Ideally, this press-fit technique would negate the need for supplemental screw fixation [30].

Surgeons will often associate adequate stability when no gross motion is perceived to occur at the cup when a force is manually applied to the insertion handle. This manual method is highly subjective, does not accurately assess the initial fixation of the component, and should likely be replaced by more objective testing measures. This study seeks to answer two questions: 1. What is the range of initial press fit stability in cementless acetabular components using standard techniques for total hip arthroplasty? 2. Is there a difference in this stability when cups are under-reamed 1 vs. 2 mm?

Materials and Methods

Nine adult cadaveric pelvis specimens (average age 68.8 years; range 39 to 87) were obtained from subjects free of musculoskeletal disease at the time of death and stored at −20 °C. In preparation for testing, specimens were thawed at room temperature and dissected of all soft tissues. Two Schanz pins were inserted through the ilium towards the ischial spine to define the anterior pelvic plane using the Schanz pin, the pubis, and the anterior superior iliac spine. The innominate bones were then isolated from the sacrum and separated at the pubic symphysis using an oscillating saw yielding two hemi-pelvises.

Each hemi-pelvis specimen was mounted in a 2" × 3" PVC connector by first trimming the iliac crest and posterior superior iliac spine as needed to fit. Three 1/8" diameter transfixing pins were then inserted across the PVC and into the bone, followed by a #8 wood screw with fender washer through the iliac fossa. Polymethylmethacrylate (PMMA) filled the connector after which it was attached to a custom fixture to securely hold the specimen during cup insertion and subsequent testing.

The acetabulum of each specimen was prepared using powered hemispherical reamers beginning with 46 mm and increasing at 1 to 2 mm increments until the reamer created evidence of concentric reaming at the acetabular rim while preserving the anterior and posterior rims. A porous coated acetabular component (Tritanium, Stryker Orthopaedics, Mahwah, NJ) ranging in cup size from 52 mm to

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60 mm, depending on the size of the specimen, was then selected to be either 1 or 2 mm larger than the sized reamer to reflect 1 or 2 mm of under-reaming, respectively. The amount of under-reaming was randomly alternated between right and left hips. The cup was press-fit into the acetabulum to properly seat the component. Accurate positioning of the component was achieved by placement in approximately 45° of abduction and 15° of anteversion while using the pubis and ischium as reference points. A bony landmark method, with relation to the ilium, ischium and pubis, measurements of acetabular rim overhang, as well as the transverse acetabular ligament were also used to aid in proper cup orientation [31]. The same surgeon prepared each specimen and implanted the components to minimize variability in surgical technique. Acetabular screws were not used.

Adequate seating of the component was assessed by direct visualization through the screw holes in the acetabular cup. When a well-fixed acetabular cup was manually checked for stability in a similar fashion to that performed intra-operatively, bending moments of approximately 60 in-lb (6.8 N-m) were measured. Thus, a torque wrench to measure the applied bending moment was applied to each seated acetabular component through the insertion handle and tested to 60 in-lb to manually confirm clinical stability of each specimen in a consistent manner (Fig. 1).

Each specimen was rigidly held in a biaxial servohydraulic Instron 1321 materials testing equipment (Instron Corp., Canton MA), retrofitted with MTS TestStar II digital control/data acquisition (MTS Corp., Eden Prairie MN). A custom designed device was attached to the specimen to measure the amount of micromotion at the bone–prosthesis interface during testing (Fig. 2). Linear variable differential transformers (LVDTs, Model 0242-00000, Trans-Tek Inc, Ellington, CT) contacted the rim of the component as close as possible to the acetabular interface to measure micromotion on the superior, inferior, and anterior aspects of the rim. A rod perpendicular to the insertion tool shaft at 14.3 cm from the tool attachment site in the center of the cup then applied a one-time, controlled displacement until failure. The force applied was directed in a vertical plane directly perpendicular to the acetabular component based on a pelvic tilt of 5° of flexion. The resulting bending moment experienced at the cup simulated what would be experienced during the intraoperative assessment of initial stability. The bending forces and micromotion at the acetabular cup rim locations were collected at 100 Hz throughout testing. After testing, cups were cleaned with an appropriate cleaner (MC-2, Branson Ultrasonics Corp., Danbury, CT) of bony debris and an ultrasonic cleaner (Model 100004, SPER Scientific, Ltd., Scottsdale, AZ) before use in subsequent specimens.

Results

Of the 18 acetabulums designated for this experimental design, one cup under-reamed by 1 mm could not be tested due to fracture during component implantation. All other specimens were successfully implanted and deemed clinically well-seated by having sustained a moment of 60 in-lb (6.8 N-m) with no gross instability using the aforementioned moment wrench to simulate manual, intra-operative stability testing. Bone mineral density data from cadavers used in this study suggested comparable bone quality between hips ($P > 0.2$).

During load to failure testing, cup movement typically occurred as a vertical rotation of the cup indicated by negative (inward) displacement of the superior LVDT and positive (outward) displacement of the inferior LVDT, which occurred simultaneously during testing (Fig. 3). Failure was defined as 150 μm of motion at any of the LVDTs.

When a simulation of force used during manual intra-operative testing, 60 in-lbs (6.8 N-m) was applied, there was resultant mean displacement of less than 50 μm at the superior and inferior LVDTs. However, there were large variations (1.04 μm to 139.02 μm) in the mean displacement of these LVDTs during testing. We found a large range of forces necessary to cause greater than 150 microns of motion in this study. The overall mean bending force at failure for all 17 specimens was 126.9 N, equivalent to an overall bending moment of 18.2 N-m (Fig. 4).

Stability was found to be similar between 1 mm and 2 mm of under-reaming as the mean load to create 150 μm of micromotion for 1 mm of under-reaming was not statistically different from 2 mm of under-reaming ($P > 0.95$) (Fig. 5). A power analysis revealed that more than 100 matched pairs would be required to achieve 80% power. The failure loads equate to bending moments of 17.3 ± 7.0 N-m for 1 mm of under-reaming and 18.9 ± 8.5 N-m for 2 mm of under-reaming, representing a modest 9.4% increase in the bending moment

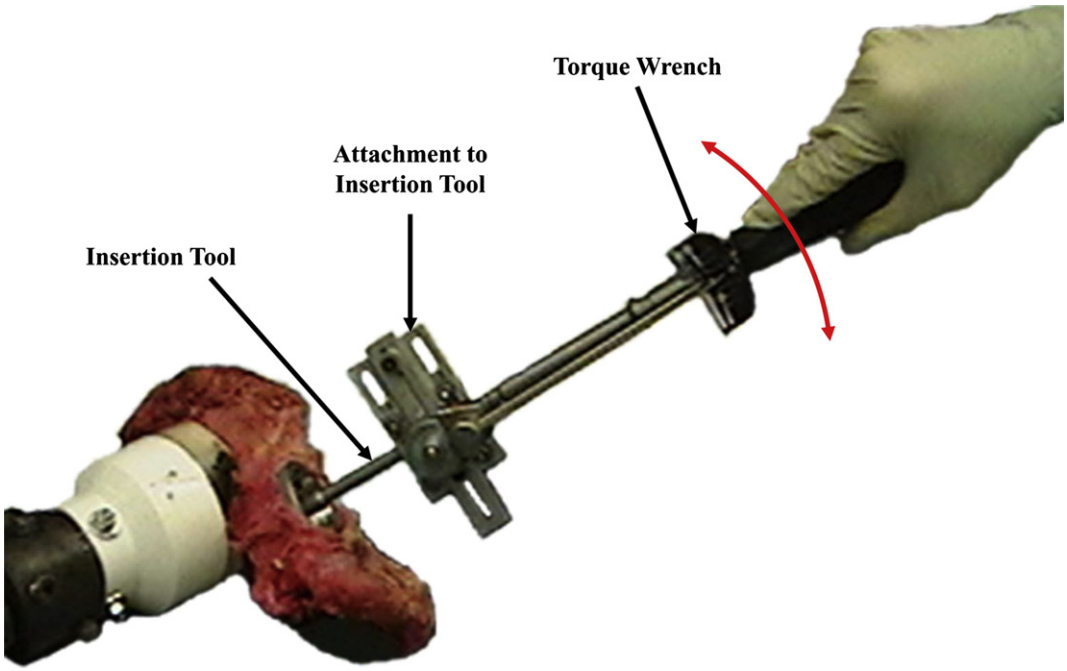

Fig. 1. A wrench was applied to the well-fixed, acetabular component through the insertion handle and tested to 60 in-lb (6.8 N-m) to test for gross stability of the component.