Acetabular Cup Stiffness and Implant Orientation Change Acetabular Loading Patterns

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Abstract: Acetabular cup orientation has been shown to influence dislocation, impingement, edge loading, contact stress, and polyethylene wear in total hip arthroplasty. Acetabular implant stiffness has been suggested as a factor in pelvic stress shielding and osseous integration. This study was designed to examine the combined effects of acetabular cup orientation and stiffness and on pelvic osseous loading. Four implant designs of varying stiffness were implanted into a composite hemipelvis in 35° or 50° of abduction. Specimens were dynamically loaded to simulate gait and pelvic strains were quantified with a grid of rosette strain gages and digital image correlation techniques. Changes in the joint reaction force orientation significantly altered mean acetabular bone strain values up to 67%. Increased cup abduction resulted in a 12% increase along the medial acetabular wall and an 18% decrease in strain in inferior lateral regions. Imbalanced loading distributions were observed with the stiffer components, resulting in higher, more variable, and localized surface strains. This study illustrates the effects of cup stiffness, gait, and implant orientation on loading distributions across the implanted pelvis. **Keywords:** stress shielding, acetabulum, pelvis, biomechanics, THA.

Hip mechanics are a complex interaction of osseous and muscular forces across the joint. Joint reaction forces and articular contact mechanics have been previously studied [1-5]. Uncemented total hip arthroplasty (THA) components may uniquely alter the physiologic distribution of loads in the pelvis and femur and contribute to stress shielding and specific patterns of osseous remodeling. Femoral side effects have been studied clinically and in in vitro models; however, relatively few studies have quantified the distribution of loading in the pelvis after THA, particularly as it is influenced by component orientation, implant stiffness, and hip position during gait. Malalignment of the acetabular component has been correlated with clinical complications including increased dislocation rates [6-11], higher polymer wear, osteolysis, and hard-on-hard component noise generation [12-16]. Although these clinical correlations with cup alignment are well documented, insufficient information exists on the effect of acetabular cup orientation on the loading response and force distribution within the implanted pelvis.

Although extensive computational and bench testing has been published on pelvic loading in the intact pelvis [17-21], data regarding pelvic loading after THA have been primarily generated from computational methods [22-26]. Fewer studies have used in vitro laboratory testing for the study of post-THA pelvic loading; specifically with respect to the influence of acetabular cup stiffness and inclination on loading patterns [27-29]. The purpose of this study is first, to establish a simplified model to quantify changes in (1) peak location and (2) magnitude of periacetabular strains. The second purpose is to quantify the alteration of strain distribution in the hemipelvis model due to changes in cup position, component stiffness for a series of acetabular component designs, and the angle of hip flexion. We hypothesize that specimens implanted with press-fit acetabular components will exhibit significantly altered loading with (1) stiffer cups decreasing pelvic strains and (2) increased abduction angles increasing strain in the roof and lateral margin of the acetabulum.

Methods

Four groups of 8 composite left hemipelvis models (Model 3404, Large Left Fourth Generation Hemipelvis; Pacific Research Laboratories, Vashon, Wash) were fully

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Table. Acetabular Component Design and Geometry

Implant Design	Substrate Material	Surface Material	Substrate Thickness (mm)	Ingrowth Thickness (mm)	Overall Cup Thickness (mm)	Stiffness* (N/mm)	Articular Design
Regenerex Ringloc	Ti-6Al-4V	Ti-6Al-4V	3.54	1.5	5.04	4598	Modular
Ranawat/Burstein	Ti-6Al-4V	Ti-6Al-4V	3.42	0.76	4.18	2604	Modular
M2a-38	CoCr	Ti-6Al-4V	9.4	0.76	10.16	47244	Monoblock
M2a-Magnum	CoCr	Ti-6Al-4V	2.53/5.31 †	0.76	3.29/6.07 †	5629	Monoblock

* Stiffness assessed at 1-kN rim compression by the manufacturer.
† Thickness at rim/thickness at apex.

reamed with a 58-mm acetabular reamer and implanted with one 58-mm cup each of 4 designs: (1) Ranawat-Burstein (28-mm head size), (2) M^2a-38 (38-mm head size), (3) M^2a-Magnum (52-mm head size), or (4) Regenerex RingLoc (32-mm head size) acetabular components. The component features including materials and stiffness are listed in the Table. Acetabular reaming and component implantation were performed manually by a board-certified orthopedic surgeon.

The acetabular components were implanted with standard instrumentation into 1 of 2 orientations: (1) 35° of abduction and anatomical anteversion, with the cups implanted flush with the lateral acetabular rim; (2) 50° of abduction and anatomical anteversion leaving 1 cm of exposed bone on the lateral acetabular rim. To quantify interspecimen variability in cup orientation after implantation, anterior-posterior radiographs were taken of each implanted hemipelvis specimen. Specimens were positioned with a soft foam mold on a patient x-ray table to align implanted hemipelvis specimens for cup abduction angle approximation (Fig. 1). A standard cup inclination measurement is not possible without a full pelvic radiograph; however, a horizontal reference line was approximated as perpendicular to the pubic symphysis. An additional linear measurement was taken of the exposed reamed acetabulum from the edge of the acetabular shell to the acetabular rim at the lateral acetabular rim to provide a second method for orientation assessment.

Strain measurements were recorded via a grid of eight 3-element rectangular rosette strain gages (KFG-3-120-D17-11L3M2S; Kyowa, Tokyo, Japan) distributed across the surface of the implanted hemipelvis specimens as shown in Fig. 2. To ensure the repeatable placement of strain gages between each specimen, positioning and alignment guidelines were marked on the surface of each hemipelvis specimen before final gage fixation using a positioning mold rigidly affixed to the base plate of a coordinate measurement machine (BRM507; Mitutoyo America, Aurora, IL). This method of gage placement allowed for the repeatable placement of strain gages within ±1 mm between each specimen. Data were recorded from each hemipelvis specimen over the course of 10 trials in each of the 2 loading positions for a total of 20 experimental trials per specimen using a strain gage data acquisition system (System 5000; Vishay Micro-Measurements, Raleigh, NC).

In testing parallel to strain gage instrumented specimens, 4 hemipelvis specimens were implanted with 35° of abduction and anatomical anteversion and prepared

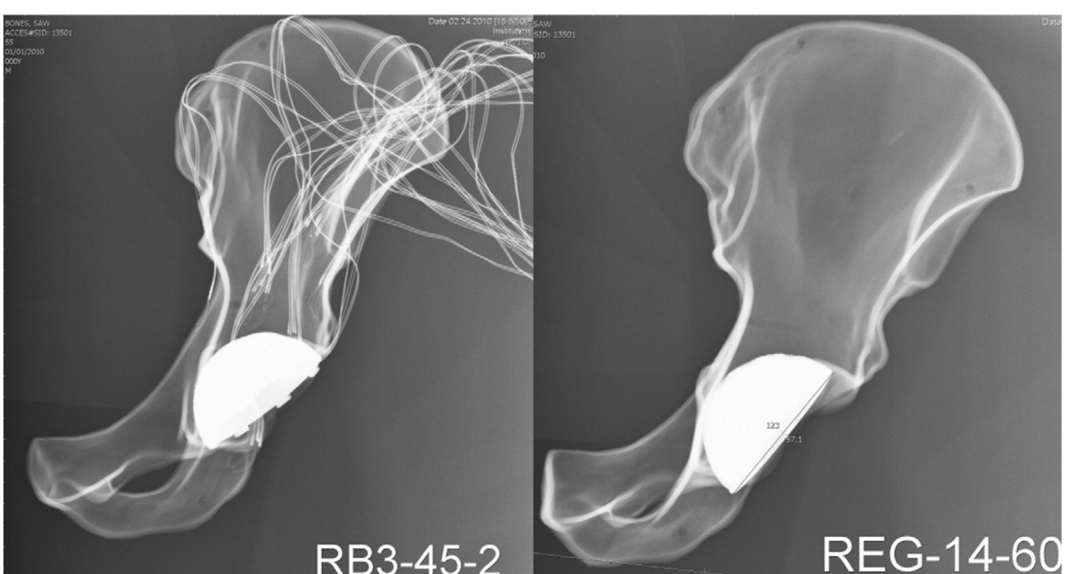

Fig. 1. Anterior-posterior radiographs of composite hemipelvis with (left) acetabular component implanted in 35° of abduction (strain gage wires visible) and (right) a component implanted in 50° of abduction.