BIOMECHANICAL ANALYSIS OF PERI-ACETABULAR LESIONS TO PREDICT PATHOLOGIC FRACTURE

Michael N. Kang, M.D.
Insall-Scott-Kelly Institue for Orthopaedics and Sports Medicine, New York, NY
mkang@iskinstitue.com

Francis Patterson, M.D.
Department of Orthopaedics, Rutgers New Jersey Medical School, Newark, NJ
patterfr@njms.rutgers.edu

Steven Rivero, M.D.
Department of Orthopaedics, Rutgers New Jersey Medical School, Newark, NJ
riverosm@njms.rutgers.edu

Kathleen S. Beebe, M.D.
Department of Orthopaedics, Rutgers New Jersey Medical School, Newark, NJ
beebeka@njms.rutgers.edu

Joseph Benevenia, M.D.
Department of Orthopaedics, Rutgers New Jersey Medical School, Newark, NJ
benevejo@njms.rutgers.edu

Correspondence to:
Kathleen S. Beebe, M.D.
140 Bergen Street
ACC Suite D-1610
Newark, NJ 07103
(973) 972-3534 (973)
972-5296 (fax)
beebeka@njms.rutgers.edu

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Abstract—The classification and treatment of pathologic peri-acetabular lesions was initially described by Harrington[5]. However, the ability to predict impending pathologic fractures is difficult. Proposed treatment in the literature has included external beam radiation and cemented total hip arthroplasty. Based on a cadaveric biomechanical model, our goal is to delineate the risk of pathologic fracture in contained Harrington class 1 lesions.

Eight paired hemi-pelvises were utilized to create peri-acetabular defects with its paired side to serve as a control. Volumetric measurements were taken via computed tomography then converted to a percentage of the peri-acetabular volume. Each paired specimen was axially

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loaded to catastrophic failure via Material Testing System (MTS, Minneapolis, MN).

The results demonstrate that larger (>40%) contained peri-acetabular defects can support significant less load than an intact acetabulum. Smaller defects did not fail at significantly less load, and their location of failure was not consistent. Though the load to failure was significantly less than the intact controls, the levels were found to be nearly 2.5 times the normal physiologic loads that the hip encounters at its peak[3]. These results do indicate that volumetric measurements via CT scan is a simple technique, and its clinical relevance as a tool to predict pathologic fracture of peri-acetabular lesions must be further investigated.

Level of evidence: Level I

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1. Introduction

Each year, approximately 1.2 million new patients develop cancer in the United States. Nearly half of them will develop bone metastasis at some stage of the disease process with the most common carcinomas being breast, lung, and kidney. The most common locations include: spine, pelvis, ribs, and proximal limb girdles[1].

Metastasis to the pelvis and acetabulum is common and presents a challenge for orthopaedic surgeons. Patients can present with considerable pain and loss of the ability to ambulate. Management can be difficult as location and accessibility make surgical treatment high risk. Isolated lesions about the pubis, ischium, and sacro-iliac region can usually be treated non-operatively with medical management of chemotherapy, bisphosphonates, or external beam radiation. Treatment of lesions in the peri-acetabular region may be unsuccessful due to the high biomechanical stresses in the region and the associated clinical symptoms and functional deficit[9]. Harrington has published the largest experience with these lesions, and proposed a classification system with recommendations of surgical options (Table 1)[5].

Table 1. Harrington Classification

Class	Defect	Treatment
1	Peri-acetabular lesion with intact cortices	Radiotherapy vs. cemented THA
2	Medial wall defect	Protrusio cage with cemented THA
3	Deficient lateral, superior, medial	Harrington reconstruction with
	walls	Steinman pin fixation and protrusion cae/cemented THA
4	Isolated lesion	En bloc excision for cure

While the Harrington classification system provides guidelines towards treatment, it does not predict the risk of pathologic fracture. The purpose of this paper is to explore, in a biomechanical cadaveric model, the integrity of the peri-acetabular region to axial loading with artificially created contained defects (Class I lesions). To our knowledge, no prior data has been published on this subject.

2. Materials & Methods

Eight pairs of cadaveric hemipelvises with associated proximal femurs were obtained by donation from the Musculoskeletal Transplant Foundation (Edison, NJ). Each hemi-pelvis was disarticulated at the sacro-iliac joint and included the ipsilateral proximal femur. The age range was from 22 to 48 years old. The specimens were from four men and four women (Table 2).

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Table 2. Demographics and DEXA scan results

Specimen	Gender	Weight (kg)	T-score
1	M	75	-0.6
2	F	90.9	-0.6
3	F	77.7	1.1
4	M	68.2	2.8
5	M	95.5	1.5
6	F	66.4	-0.6
7	M	65	1.0
8	F	79.5	1.9

Dual Energy X-ray Absorptiometry (DEXA) scan was performed on each proximal femur in order to account for any variability in the bone mineral density of each specimen (GE Prodigy Lunar, Tappan, NJ). The T scores measured for all specimens were greater than minus 1.0 indicating that none had to be excluded for osteopenia and/or osteoporosis[2].

All peri-acetabular lesions were created in the left hemi-pelvis, with its right pair remaining intact as a control. An approximate one centimeter area cortical defect was made directly lateral over the supra-acetabular region. The underlying cancellous bone was curetted out manually with care to prevent any cortical perforations. Bone was removed from the supra-acetabular region extending proximally up the tables of the ilium as well as distally down the anterior and posterior columns. Specimens were randomly assigned to be in either the large or small defect group. The amount of bone that was to be removed was initially determined on a qualitative basis. The defects were measured by computed tomography, and the group was stratified into two categories – large and small defect – based on whether the percent defect volume was greater or less than forty percent.Defect volume was measured by utilizing three dimensional reconstruction of the hemi-pelvis with standard axial computed tomography images (GE Light Speed Plus). From a true lateral view of the hemi-pelvis, a line from the top of the greater sciatic notch to the anterior inferior iliac spine was drawn, and axial images were reconstructed parallel to this line (Figure 1A). This reference line was employed to control pelvic tilt in each specimen and to standardize peri-acetabular volumes of each pelvis.

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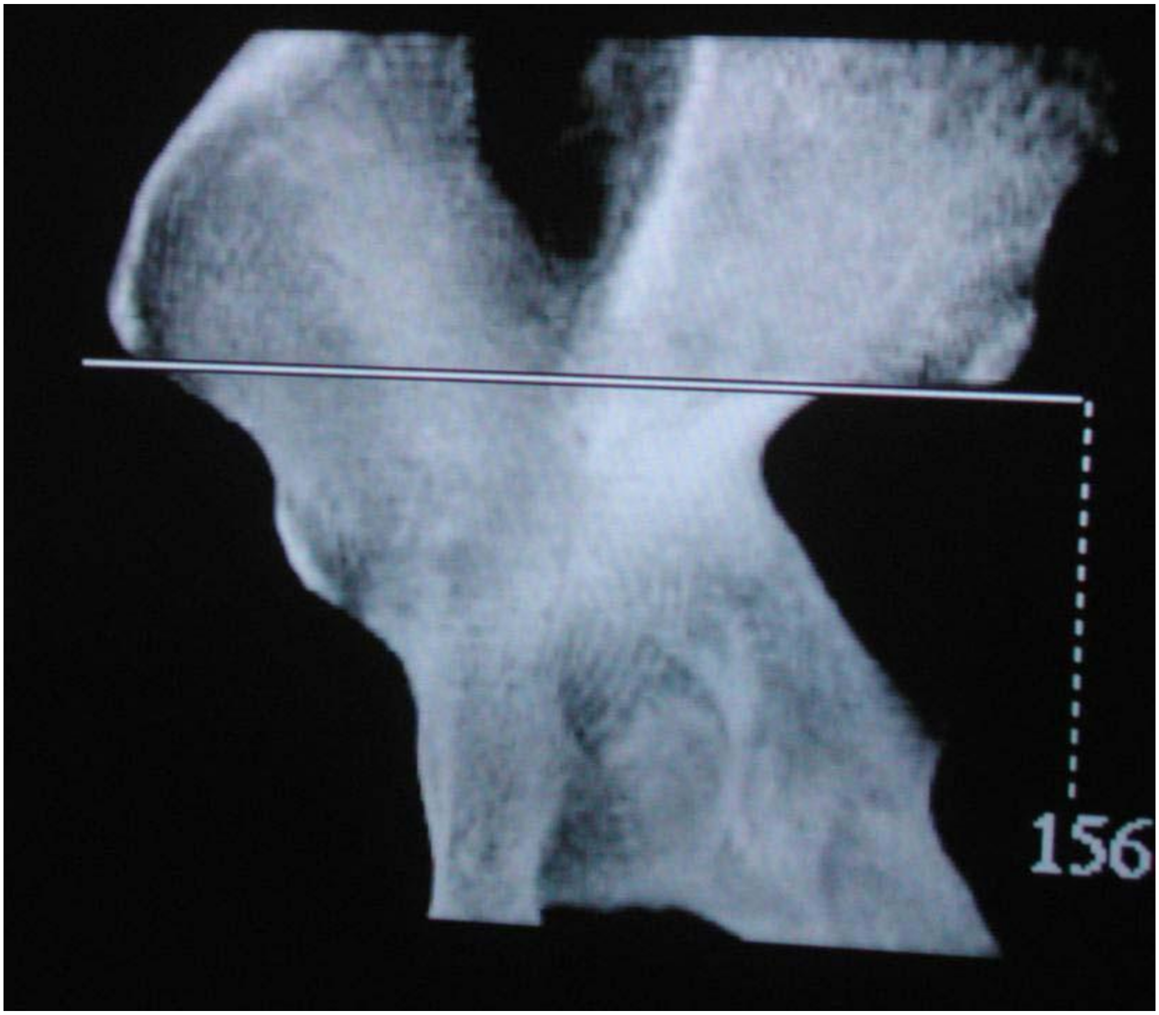

Figure 1A: Standard line from the top of the greater sciatic notch to the anterior inferior iliac spine

Axial images were taken from this reference line at one millimeter increments and extended distally one centimeter inferior to the acetabular weight-bearing dome as described by Olson and Matta in their subchondral arc technique for acetabular fractures[8]. The area of the defect and the intact bone was then measured on each axial cut (Figure 1B). By summing the defect areas versus the total bone area excluding the cortical bone, defect volumes were measured as a percentage of the entire bone volume. The specimens were stratified into large (>40% volume defect) and small (<40% volume defect) lesions.

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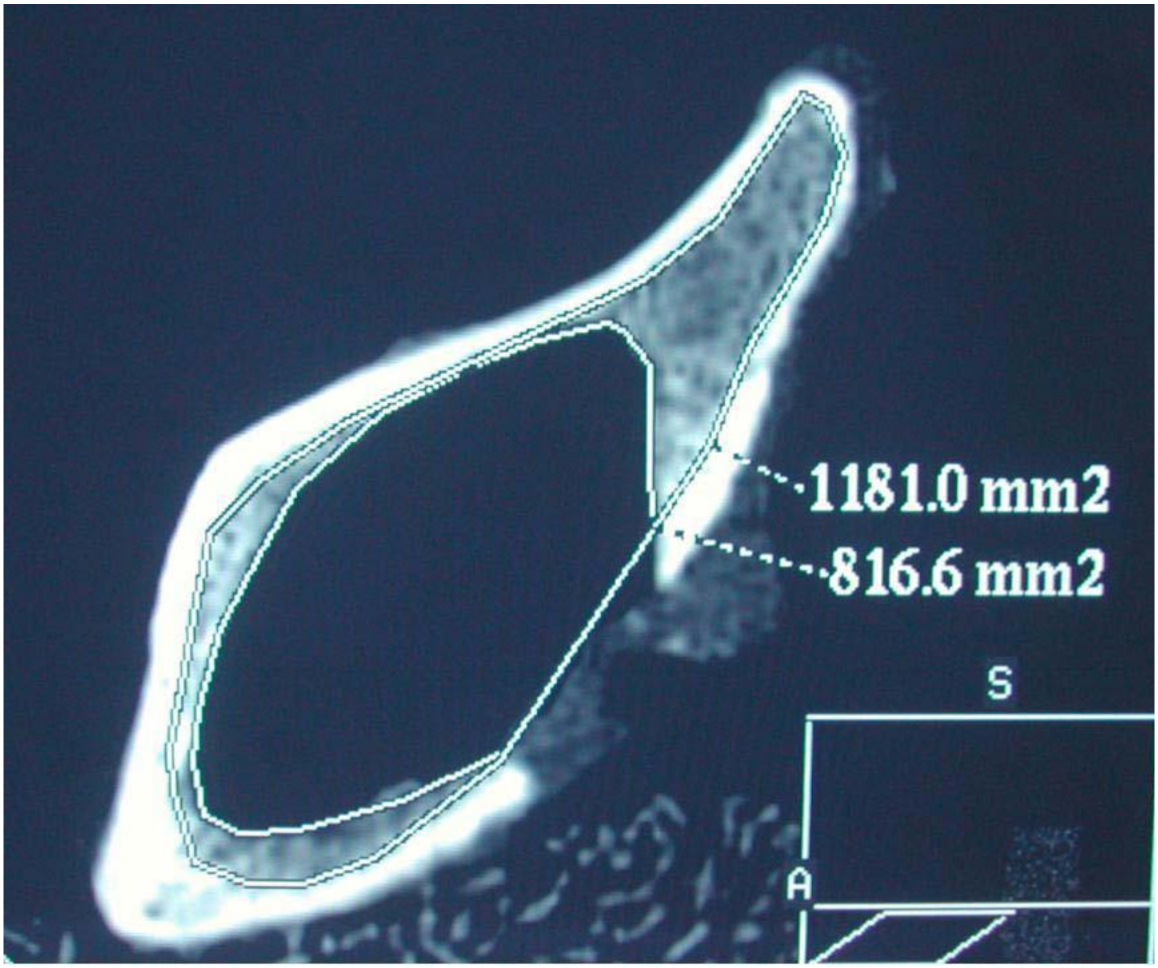

Figure 1B: Method of volume calculation

Each hemi-pelvis and its proximal femur were potted in polymethyl methacrylate (PMMA) bone cement to prepare for biomechanical evaluation. The hemi-pelvis was potted via the iliac wing, and its proximal femur was potted up the shaft 4-cm distal to the level of the lesser trochanter (Figure 2). The cortical window of the peri-acetabular lesion was patched with PMMA, avoiding extravasation of the cement into the cancellous defect in an attempt to minimize any effect this small cortical defect may have on mechanical testing. Employing a servohydraulic material testing system (MTS Systems Corporation, Minneapolis, MN) each hemi-pelvis and its proximal femur were loaded in compression at a rate of 20 millimeters per minute until grossly observed catastrophic failure or up to 10,000 N, utilizing methods described by Levine et al[6]. The applied compressive force for each loading trial was recorded in Newtons (N) and reviewed to determine the force at failure. The gross mode and location of specimen failure was documented.

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Figure 2: Loading Apparatus

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Statistical analysis was performed (StatView, SAS Institute Inc., Cary, NC) utilizing ANOVA with Fisher's Protected Least Significant Difference and a p value of 0.05 comparing load to failure of total defects, large and small defects versus their contralateral intact control hemi-pelvises, and calculated hip joint reaction force.

3. *Results*

3.1 DEXA Scan

Each paired pelvis underwent a DEXA scan of the proximal femurs to control for differences in the bone mineral density of each specimen. The results are in Table 2. The T scores were all greater than minus 1.0, indicating that none of the specimens had osteopenia or osteoporosis.

3.2 Axial loading tests

Each hemi-pelvis was loaded to failure employing the force vector as described by Levine et al[6]. Table 3 shows the loads to failure of the eight paired hemi-pelvises as well as the location of failure. Specimen 6 was removed from data analysis as the paired hemi-pelvis had failures unrelated to the peri-acetabular region at relatively low loads. The mean load to failure in the lesion group was 4826 N, while the control group failed at a mean of 6136 N (p=0.135).

Table 3. Lesion Size and Load-to-Failure of Pelvic Specimens

Specimen	% Lesion volume (Cancellous)	% Lesion (including cortical)	Load to Failure(N) (Control)	Load to Failure(N) (Lesion)	Location Of Failure (Control)	Location of Failure (Lesion)
1	45%	25%	6208	4843	Iliac wing	Superior Dome
2	43.8%	25%	6025	5171	Iliac wing	Superior Dome
3	34.9%	20%	5312	3042	Iliac wing	Superior Dome
4	18.9%	11.6%	8989	9089	No failure	No failure
5	44.2%	26.3%	7798	4720	Proximal femur	Superior Dome
6	31.7%	16%	1760	2105	Iliac wing	Proximal femur
7	34.9%	20%	4107	3259	Iliac wing	Iliac wing
8	34.5%	17.8%	4516	3663	Femur fracture	Iliac wing

The data was further stratified into small (<40%) versus large (>40%) defects. Four pairs met the criteria of small defects. Three pairs were included in the large defect group. Small defects failed at a mean of 4763 N versus their controls failing at 5731 N (p=0.533). For large defects, the controls failed at a mean of 6677 N versus 4911 N (p=0.012) for the hemi-pelvises with a defect.

To correlate this data clinically, expected hip joint reactive forces

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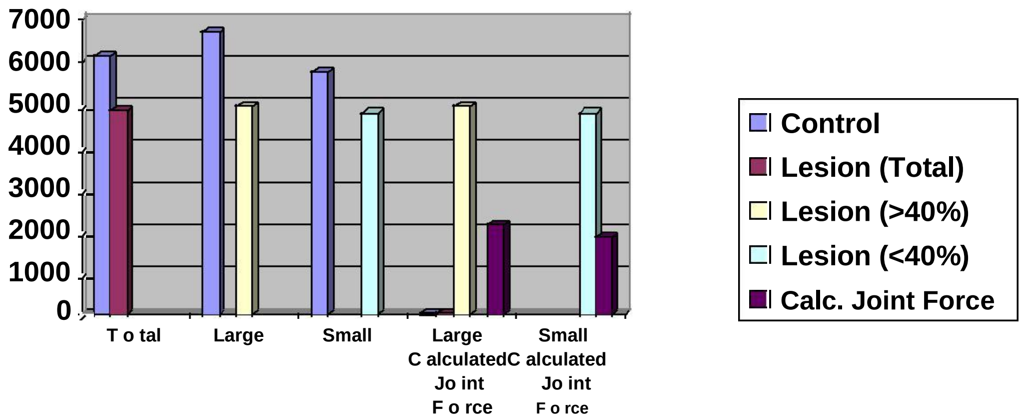
were calculated and compared to the actual load prior to failure. Bergmann et al.[3] described maximal hip joint forces during stair descent at approximately 250% of the body weight. The maximal hip joint forces were estimated by the formula of 250% of the Body Weight (BW) multiplied by 9.8 (acceleration constant). As a whole, the mean calculated hip joint forces were 1970 N compared to the mean load to failure of 4826 N in the lesion group (p=0.003). In the small defect group, the calculated hip joint force averaged 1848 N (p=0.083) versus actual load to failure in the defect group being 4763 N. In the large defect group, the calculated hip joint forces were 2134 N, while the actual load to failure was 4911 N. (p=0.011)(Table 4).

Table 4. Graph of Load-to-Failure and Calculated Joint Reaction Force



3.3 Gross Failure Mode

All three of the large defect hemi-pelvises failed in the supra-acetabular region. In the small defect group, failure was not consistently in the supra-acetabular region. Only one out of four small defect hemi-pelvises had collapse in the supra-acetabular region. Among the four specimens which failed in the supra-acetabular region, three were classified as large defects and the fourth subject had a lesion volume of nearly thirty-five percent. Only one specimen (#4) did not have failure with a maximum force possible by the MTS load cell of 10,000 N, and this had the smallest defect volume of 18.9%.

4. Discussion

Metastatic carcinoma to the periacetabular region is a challenging problem due to the issues that may arise with pain, functional deficit, and pathologic fractures. Multiple factors and treatment options must be considered in the management of these patients[9]. Harrington established a classification system to describe and aide in the treatment of metastases in the peri-acetabular region[5].

Though the need for surgical intervention is more likely with cortical disruption, there is difficulty determining when a peri-acetabular lesion is at high risk of causing a

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pathologic fracture. Harrington published his results of 58 operatively treated patients with metastatic disease to this region and reported that 72% of his patients had minimum pain at 6 months. Furthermore, 39/51 patients were able to ambulate with at most one cane or crutch. The average survival was nineteen months. Vena et al.[10] and Marco et al.[7] reported similar results with good pain and functional scores, but limited follow-up due to the nature of the disease process. However, the majority of the patients had Class 3 lesions.

As oncologic treatment has progressed, the life span of patients with advanced metastatic disease has also increased. In the evaluation of patients with peri-acetabular lesions, the functional deficits and pain associated with pathologic fractures about the acetabulum make the decision to undergo reconstruction somewhat unclear. However, in the patient with a Harrington class 1 lesion, the surgeon must assess when a lesion is large enough to cause a pathologic fracture warranting operative treatment versus non-operative management.

In our cadaveric model, in which defects were made in a controlled fashion, there was a difference between the control hemi-pelvis (6136 N) versus the defective hemi-pelvis (4826 N), though not statistically significant. When the specimens were stratified into two groups based on the size of the lesion, the large defect group (greater than 40%) failed at significantly lower loads than their controls (p=0.012). The small defect group (less than 40%) did not fail at a significantly lesser load. From this data, it can be concluded that larger lesions will fracture at loads significantly less than the intact acetabulum.

Though there is a significant difference in the large lesion group, the values are considered to be above the “normal” physiologic levels that the hip encounters.

Bergmann et al. described normal hip forces in an *in vivo* model[3]. By implanting total hip implants in four patients with sensors, the authors determined that hip joint forces averaged 238% of body weight (BW), respectively. When walking up and down stairs, the forces were 251% and 260% of BW. Thus, in the average 70kg person, 2.5 times body weight would be approximately 1800 N. The expected hip joint reactive forces were calculated at 250% of BW for each specimen and analyzed against the actual load to failure. As a group, the average load to failure was 4826 N which is 245% greater than the calculated joint reactive forces of 1970 N. The mean load to failure in the large defect group was significantly greater than the expected hip joint reactive forces calculated by 230%.

The loading tests showed that four out of the seven pairs included had fractures in the supra-acetabular region. There was a significant difference between the control and large lesion group; however the 4911 N may not be clinically significant when compared to a physiological value of 2134 N. Of note, three out of the four pairs that had supra-acetabular fractures had cancellous lesion volumes greater than 40%, and the fourth had a defect volume of nearly 35%. Furthermore, only one pair did not fail at loads near 9000N, and the lesion size of that specimen was the smallest of the group at 18.9%.

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Dalstra and Huiskes[4] described the forces that load across the pelvis in a three-dimensional finite element model and described the pelvic bone as a "cortical sandwich" in which 50 times more stress was loaded on the cortical bone than the cancellous bone. Load transfer is the greatest in the antero-superior quadrant of the acetabulum with subsequent loading to the rest of the pelvis. This concept is consistent with our results as without cortical disruption larger lesions around the acetabulum may cause fracture at significantly lower loads, but not at loads that are encountered clinically.

As with all biomechanical studies, this study has limitations. The lesions were not of uniform shape, and the actual shape of the lesion may affect the integrity of the supra- acetabular region. Furthermore, though attempts were made to create lesions as large as possible, nearly fifty percent lesions were all that was possible without affecting the integrity of the cortical window. A concern prior to loading was premature fracture through the cortical window. The window was cemented with a thin layer of PMMA in an attempt to re-establish cortical continuity. No hemi-pelvis fractured through this cortical window, and after loading to failure, this cortical window was opened once more to identify the location of the failure.

A second problem is that four out of the eight subjects had failure in areas other than the supra-acetabular region such as the iliac wing and proximal femur. Fractures in these regions were attributed to the high forces that would usually cause pelvic ring disruptions or proximal femur fractures, however, there does exist the possibility that failure may occur due to improper potting technique or loading at force vectors that are not physiologic. Finally, as with all cadaveric biomechanical studies, the clinical relevance must be questioned from the conclusions of the study, though we did attempt to correlate our findings against current literature describing normal hip joint reactive forces.

In summary, this study does show a statistically significant difference between the control hemi-pelvis versus the hemi-pelvis with a defect greater than 40%, and these larger lesions consistently caused earlier failure in the supra-acetabular region. However, they may not clinically cause pathologic fracture as the loads were well above normal joint reactive forces. We must consider that considerably larger defects greater than forty percent that were not able to be imitated may cause clinically relevant pathologic fractures. However, lesions less than forty percent do not seem to increase the risk of pathologic fracture. Clinical studies must be performed in order to confirm this conclusion, and the volume measuring CT scans that were performed may be an effective tool to the clinician to determine whether a pathologic lesion in the supra-acetabular region is at risk for pathologic fracture.

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