



## Research Article

# Biomechanical Study of Simulated Metastatic Peri-Acetabular Defects

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## ABSTRACT

Peri-acetabular metastasis presents the risk of fracture. However, the relationship between bone loss and fracture risk is unknown. Utilizing fresh frozen intact cadaver pelvis, Harrington class I lesions were simulated. Lesions were categorized as small (<40%) or large (>40%) Axial loading was applied in a quasi-static mechanism by a mechanical testing system to catastrophic failure, with the load-to-failure force being measured. There was statistical difference in the load-to-failure force between hemi-pelves with large defects and their matched controls. It was found that mean load-to-failure strength of a hemi-pelvis with a Class I defect was more than 2.3-2.45 times the calculated hip joint reactive force. Thus, it was concluded that a pelvis with a peri-acetabular defect of greater than 40% has a significantly lower load-to-failure strength compared to an intact pelvis. However, even this large Class I defect will fracture only at supra-physiologic loads and the hip joint may not normally be exposed to forces that high.

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## Introduction

Metastatic bone disease is a common ailment referred to the orthopaedic oncologist. The pelvis represents one of the most common sites of metastasis second only to the spine [1, 2]. A review done by Picci et al. showed that at one institute, 18.8% of 4431 archived bone metastases occurred in the pelvic region [3]. As metastatic defects increase in size, the relative bone strength decreases leading to pathologic fractures as a common impending complication. Additionally, the risk of pathologic fracture may also be tied to the amount of force, or loading force, placed on the defect. Thus, involvement of weight-bearing structures such as the pelvis, and more specifically the acetabulum, pose an increased risk of pathologic fractures [4]. In the event pelvic fractures occur, they may cause significant pain for patients, debilitating injuries, and ultimately reduced quality of life [5]. While cure is often not attainable for patients

with metastatic lesions to the bone, the potential for complications necessitates the need to evaluate for surgical intervention prior to complications [4-6].

The pelvis in conjunction with the sacrum facilitates the transfer of weight from the upper body to the hips. Depending on the activity, forces as high as 5.5 times body weight may be transferred from the femur to the acetabulum, with the major portion of the load transferred through the cortical shell [7-9]. Previously, finite element models have explored load distribution of the hip during normal daily activities such as walking. By deconstructing the movements of walking, including walking upstairs, force distribution throughout the hip may be investigated. Studies have shown the stresses in cortical bone to be about 50 times higher than those of underlying trabecular bone, with the highest stresses occurring in the superior acetabular wall during the single leg stance [9]. Given this, it follows that fractures or any cortical

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defect in this region may impede with critical daily activities, making their prevention ever more important.

Surgical intervention with acetabular involvement poses a unique challenge to surgeons due to the region's complex anatomy and proximity to neurovascular structures [10]. There have been several reports on the treatment of metastatic acetabular lesions, most of which employ the Harrington Classification System [4]. Based on this classification system, defects are categorized into one of four categories depending on the extent of pelvic involvement and treated accordingly (Table 1). Despite management of these various stages being previously studied, there remains a lack of a reliable data demonstrating the

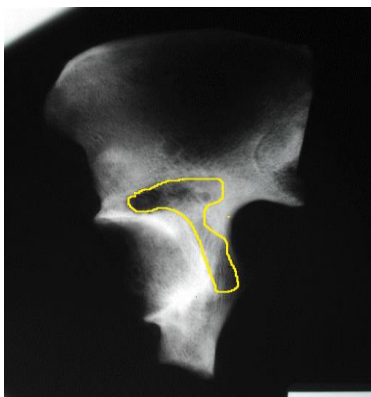
**Table 1:** The Harrington Classification

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

## Materials and Methods

### Lesion Simulation

Eight (8) fresh frozen intact cadaver pelvis and their associated proximal femora were obtained from the Musculoskeletal Transplant Foundation (MTF). Harrington Class I lesions were simulated by making 1 cm<sup>2</sup> cortical perforation in the supra-acetabular region using a tube saw and manually curetting out cancellous bone in the peri-acetabular area (Figure 1). The volume of the defects created was measured 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 adjoining the top of the greater sciatic notch and the anterior inferior iliac spine was drawn, and axial images reconstructed parallel to this line. This reference line served to control for the pelvic tilt in each specimen. Axial images were taken at one-millimeter increments and the area of the defect and the intact bone measured on each axial cut. By summing the defect areas versus the total bone area excluding the cortical bone, defect volumes are reported as a percentage of the entire ilium volume. This in turn normalized the peri-acetabular volumes because the pelvic specimens are of different sizes (Figure 2).



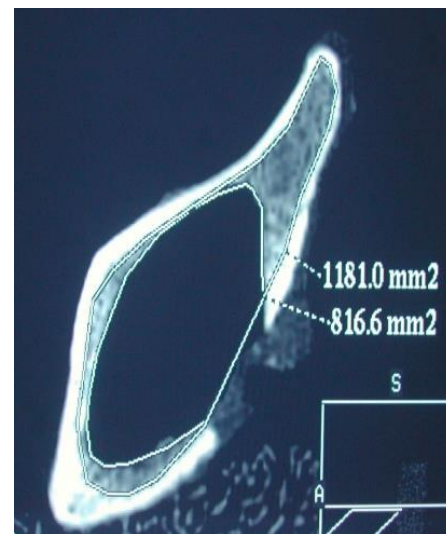
**Figure 1:** X-ray of Simulated Class 1 defect

indication for surgical management in relation to the amount of bone loss and the risk of pathologic fracture [5, 10, 11].

Our proposed study aims to derive data that will help predict the interconnection between lesions and fracture risk in metastatic acetabular lesions. Class I lesions simulated in hemi-pelvis cadaver specimens were subjected to quasi-static loading forces. Force was applied to these specimens as well as their non-defect matched pairs to catastrophic levels, allowing fracture to occur. Our hypothesis is that contained defects within the peri-acetabular bone without cortical destruction do not significantly increase the risk of fracture.

### Sample Preparation

The hemi-pelves were mounted on a servo-hydraulic mechanical testing system (MTS Systems Corp., Minneapolis, MN) in the following orientation: in the lateral view, the ASIS and pubic tubercles are vertically aligned; in the AP view, the femoral shaft is adducted 15° relative to the horizontally level pelvis. Following the technique described by Levine et al, each hemi-pelvis was potted via the sacroiliac (SI) joint in poly-methylmethacrylate (PMMA) and re-inforced by wood screws [12]. The symphyseal body was stabilized with a bolt connected to the mounting construct. The femur and acetabulum were then rotated as a unit by 15° to approximate the angle of the resultant joint reaction force vector during normal walking; the proximal femur was potted on the loading platform with PMMA, at a level 4 cm distal to the lesser trochanter (Figure 3) [13]. Thus, when axial loading was applied to this construct, the force vector applied to the hip joint simulated the vector of the joint reaction force during the single-leg stance phase of walking.



**Figure 2:** Method of volume calculation



**Figure 3:** Loading Apparatus

### Mechanical Testing

For the mechanical testing, the cortical perforation was covered with a thin layer of bone cement. Axial loading was applied in a quasi-static mechanism by a mechanical testing system (MTS) to catastrophic failure at a rate of 20mm/min (Figure 3) as described by Levine et al. [12]. The load to failure force was measured in Newtons and the location of failure was noted (Table 2). The mean load-to-failure was analyzed for the whole group, as well as for lesions less than 40% volume (small defect) and lesions more than 40% volume (large defect).

**Table 2:** Results

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

### Discussion

The present study aims to help predict the interconnection between lesions and fracture risk in metastatic acetabular lesions. Quasi-static loading forces were applied to Class I lesions simulated in hemi-pelvis cadaver specimens. Catastrophic loading forces were applied and measured, allowing for the risk of pathologic fracture to be assessed. Pelvic bone metastases continue to be a concern of the orthopaedic surgeon, as reduced structural integrity of diseased bone continues to raise concerns of pathologic fractures. Previously, the risk of pathologic fracture has been proven to depend on the location of the lesion, bone properties, as well as force of loading [14]. In a study of nine different daily living activities which were assumed to cause high hip joint load, no forces or moments were more critical than during fast walking or stair climbing, with the exception of stumbling where forces of up to 870% body weight (BW) were in play [8]. The average peak force during normal walking at 4 km/hr was between 211 and 285 % BW. The highest (compressive) normal stress occurs during the one-legged stance

### Statistics

Statistical analysis was performed using a student's t-test using  $p < 0.05$  to evaluate for significant differences in the load-failure rates between defected hemi-pelves versus their matched controls, as well as between large and small defects.

### Results

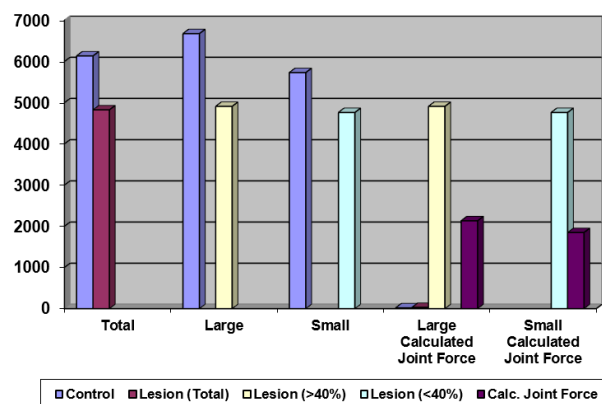
Of the eight matched hemi-pelves utilized in this study, five were considered to have small lesions and three large lesions. When subjected to catastrophic loading forces, all but one of the pelves (specimen 1) failed. All three specimens in the large defect group failed in the peri-acetabular area, while only one of four specimens in the small defect group failed in the peri-acetabular region (Table 2). There was no significant difference in the load-failure between controls ( $M = 5589.38$ ,  $SD = 2239.21$ ) and defects ( $M = 4486.5$ ,  $SD = 2130.6$ ) for the study as a whole;  $t(14) = 1.0092$ ,  $p = 0.33$ . There was no statistical difference between hemi-pelves with small defects ( $M = 4231.6$ ,  $SD = 2774.94$ ) and their matched controls ( $M = 4936.8$ ,  $SD = 2622.91$ );  $t(8) = 0.4130$ ,  $p = 0.6905$ . There was statistical difference between hemi-pelves with large defects ( $M = 4911.3$ ,  $SD = 233.14$ ) and their matched controls ( $M = 6677.0$ ,  $SD = 975.12$ );  $t(4) = 3.0503$ ,  $p = 0.0380$ . Specifically, our results suggest that only large defects (>40%) cause a significant risk of pathologic fractures compared to intact pelves.

of the walking cycle with the loads mainly transferred from the acetabulum through the lateral cortical shell to the SI joint and the pubic symphysis [13, 15]. While it is uncommon in the everyday life of a cancer patient for the hip joint to be subjected to catastrophic loading, stumbling remains an exception. Given the distribution of force, it holds that maintaining acetabular structure, as well as cortical structure, is imperative in decreasing fracture incidence.

To the author's knowledge, the present study is the first of its kind. Previously, distribution of force through pelvic anatomy has been studied in finite element models [16-25]. These studies have largely focused on quantity and distribution of forces in specific positions, such as sitting or walking, and their relation to safety, comfort, disease processes, as well as treatment. By investigating the connection between extent of metastatic lesions and pathologic fracture risk, our hope was to expand on current knowledge as well as help guide whether or not prophylactic surgical intervention is warranted for class I defects. Based on our results, only large defects resulted in increased risk of fracture,

requiring an average of 6677 N to do so. Even so, the fact remains that this quantity of force is unlikely to be encountered by a cancer patient during normal daily living activities. Previously, a biomechanical study by Bergmann et al. demonstrated hip joint reactive forces in two patients during walking, jogging, and stumbling [8]. There was one male and one female subject in the study, weighing 650 N and 470 N respectively. They were able to show hip reactive forces to be the greatest during stumbling, peaking at about 870% body weight (BW). Even so, the hip joint reactive force remained between 280% BW and 480% BW depending on the speed at which the patient was walking. Utilizing this data, the expected joint reactive force was calculated for our cadaver specimens. It was found that mean load-to-failure strength of a hemipelvis with a Class I defect was more than 2.3-2.45 times the calculated hip joint reactive force. Thus, it was concluded that a pelvis with a peri-acetabular defect of greater than 40% has a significantly lower load-to-failure strength compared to an intact pelvis. However, even this large Class I defect will fracture only at supra-physiologic loads and the hip joint may not normally be exposed to forces that high.

The results of this study warrant the discussion of whether current industry standards for the management of Class I lesions need to be change. Given the surgical complexity of peri-acetabular fixation, the benefit of doing so must be carefully weighed against the risk of pathologic fracture. In the author's opinions, volumetric measurements of lesions via CT-scanning should be conducted as part of pre-operative evaluation. In the event lesions are found to comprise  $\leq 40\%$  of peri-acetabular structure, and cortices are intact, it is advisable to forgo prophylactic fixation. Further evaluation of large ( $>50\%$ ) lesions to determine whether they cause clinically relevant pathologic fractures remains to need further investigation.



**Figure 4:** Graph of Mean Load-to-Failure Strengths and Calculated Joint Reactive Force

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