INTRODUCTION

In the United States, there are over 300,000 hip fractures annually, resulting in over $13 billion in medical costs (1). About 90% of these have been reported to be the consequence of falls (1). The remaining 10% are thought to be the result of fatigue of the bone tissue (spontaneous fracture). Repeated falls may increase fracture risk by affecting the integrity of the bone tissue; microscopic cracks may propagate to full-scale fractures during cyclic loading. Microstructure, bone geometry, and bone material properties are important in the mechanical behavior of bone (2,3). Specifically, bone mineral density (BMD) has been directly related to bone strength, and is measurable by dual-energy x-ray absorptiometry (DXA).

Monotonic strength of the proximal femur has been attributed to the strength, and is measurable by dual-energy x-ray absorptiometry (DXA). Important mechanical concerns that influence the incidence of hip fracture include the tissue; microscopic cracks may propagate to full-scale fractures during cyclic loading. Microstructure, bone geometry, and bone material properties are important in the mechanical behavior of bone (2,3). Specifically, bone mineral density (BMD) has been directly related to bone strength, and is measurable by dual-energy x-ray absorptiometry (DXA).

Monotonic strength of the proximal femur has been attributed to the distribution of trabecular and cortical bone as reflected in a global measurement of BMD (R²=0.78-92) (3,5). Previous studies have not predicted a relationship between BMD and fatigue fracture of whole bone specimens. We chose to compare cyclic loading to DXA measurements of the proximal femur. In addition, monotonic fracture data of contra-lateral hip specimens was available.

METHODS

Eighteen pairs of cadaveric proximal femora were obtained, equally distributed among males and females. Weight at death, age, gender, and cause of death were recorded. The mean ages and mean weight for the specimens were 79±7.01 years and 729±160 N, respectively. BMD data were obtained from all specimens using the QDR 2000+ DXA scan. Quantitative analysis was performed above the lesser trochanter in the neck region. From a previous study (5), contra-lateral hip data of ultimate load in a fall scenario of the hip was obtained.

Each femur was sawed perpendicularly to the shaft and 9cm below the lesser trochanter. The shafts were cleaned and then embedded in poly-methyl methacrylate (PMMA) in a cylinder up to 3cm below the lesser trochanter. In addition, the top half of PMMA was tapered to make a curve, conical fit to the shaft, reducing the stress concentration about the shaft/acrylic interface. The embedded femora were harnessed to an angle-block for testing, resting on a plate with translational and rotational freedom, horizontally. The angle block had a horizontal offset of 21° medial in the medial/lateral plane, and 6° anterior in the anterior/posterior plane corresponding to FEA data from Cheal, et al (6). The apparatus was mounted in an Instron material testing machine, and loads were applied to the femora via a tapered plexiglass cup with a notch towards the trochanteric region. Water-based lubricant assisted motion at the head/cup interface.

Each specimen was sinusoidally loaded at 1 Hz under load control from a 100 N preload to 4.6 times BW (4,6). The femora were wrapped in gauze and subjected to a saline drip to maintain moisture during testing. All tests were ceased at the failure of the bone or around the 150,000 cycle mark, to prevent significant bone degradation at room temperature. Fractured specimens were radiographed and fracture type was classified by an experienced orthopedist. The data from the cyclic tests and contra-lateral, monotonic tests were compared.

RESULTS

In the cyclic testing of 18 cadaveric hip specimens, 15 produced a fatigue fracture. All 15 specimens failed with subcapital fractures of the femoral head or per nipercapicular fractures to the femoral neck, both clinically observed fracture patterns. Specimens which did not fail were not included in the regression analysis. Only 13 of these failed specimens had contra-lateral data of ultimate load. No correlation was found between BMD and cycles to failure. Fracture load, i.e. the cyclic load divided by monotonic load, compared to cycles to failure yielded an R² value of 0.71 (Fig. left). To compare BMD to cycles to failure, an index was created as a correction factor for BMD, specifically, BMD was multiplied by the fractional load. This index versus cycles to failure yielded an R² value of 0.40 (Fig. right).

DISCUSSION

This study was performed to characterize the fatigue life of the proximal femur and compare it to BMD. We believe this is the first study to relate BMD and fatigue loading for the whole proximal femur. Fractal load corresponding to cycles to failure indicates that the loading strategy, including choice of body weight factor and loading angle, were appropriate. One limitation of this study is in the contra-lateral data. These were obtained from monotonic fractures induced during simulated falls by compression of the trochanteric region, whereas our fatigue tests were based on loading during heel-strike. Also, BMD does not yield information about microstructure, which may be crucial to cyclic tests such as this. Still, our results suggest a relationship between fatigue life and densitometric properties of the proximal femur. The measurement of BMD is possible in many clinical settings and may be useful in predicting spontaneous fractures of the hip due to fatigue. Since monotonic data have been obtained with a positive correlation of failure stress to bone density, specifically, of the corresponding contra-lateral side to our specimens (5), we here extended this correlation to fatigue loading conditions.

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REFERENCES