INTRODUCTION. Density measurements are often used clinically to diagnose osteoporosis, estimate hip fracture risk and track a patient’s response to therapy. Experimental studies have demonstrated correlations between BMD, bone strength and fracture risk. In this study we sought to determine whether regional densitometric measurements would explain different ex-vivo fracture types and fracture loads in a heterogeneous population of cadaveric female femurs.

METHODS. Twenty left cadaveric female femurs (ages 32 – 95) were acquired from a local tissue bank in accordance with federal, state and local regulations and statutes. Plane radiographs were taken to screen for metastatic cancer or undiagnosed fractures. Femurs underwent densitometry using a Hologic QDR-2000 Plus bone densitometer. All femurs were placed on a 1½" thick acrylic plate to simulate an equivalent soft-tissue thickness. Femurs were scanned in pencil-beam mode to measure total and regional bone mineral density (BMD) and bone mineral content (BMC).

All proximal femurs were separated from the shaft and embedded in an aluminum channel using orthodontic acrylic. A physical impression of the greater trochanter was made using Bondo® Body Filler to protect the greater trochanter from local crushing during testing. Each femur was placed in a simulated fall configuration with 10° of rotation in the coronal plane and 15° of internal rotation. Fracture testing was conducted on an Instron 8511 test machine. A 110 Newton preload was applied at 2mm/second to assure proper sample seating. Testing was conducted at 100mm/sec until fracture. Post-fracture radiographs were independently evaluated by three graders for classification into four categories: femoral neck, intertrochanteric, greater trochanteric or fracture not evident. All scores were averaged to determine occurrence in fracture pattern.

Linear regressions were completed on DXA and fracture load measurements to elucidate primary relationships (r²-values). Stepwise multiple linear regressions were completed on the entire cohort and two general fracture categories to determine adjusted r²-values.

RESULTS. There was a wide distribution of bone densities for the sample cohort, BMDtotal = 0.50 – 1.32 g/cc. Both density and fracture load demonstrated age related decreases (Figure 1 and 2, respectively). Simulated fall testing produced primarily osteoporotic-like fracture patterns (Femoral region and the greater trochanter (30% and 20%, respectively). There was no statistical difference in fracture load between the fracture type groups. Fracture testing was conducted on an Instron 8511 test machine. A 110 Newton preload was applied at 2mm/second to assure proper sample seating. Testing was conducted at 100mm/sec until fracture. Post-fracture radiographs were independently evaluated by three graders for classification into four categories: femoral neck, intertrochanteric, greater trochanteric or fracture not evident. All scores were averaged to determine occurrence in fracture pattern.

DISCUSSION. Our simulated fall testing produced osteoporosis-like fractures in over 75% of our samples. This cohort also demonstrated age related decreases in fracture load and BMD/BMC as expected. BMD measurements explained up to 85% of the variability of fracture load data in the entire cohort. We expected that the amount of bone within a specific region would be better correlated with fragility for that specific region. However, this was not the case. Fracture load in the trochanteric fracture group was well correlated with bone mass at all sites. Clearly, the fragility of the femoral neck fracture group was not driven as strongly by the amount of bone present in any of the regions compared to trochanteric fractures which were well correlated with bone mass at all sites.

These data suggest that trochanteric fractures are more strongly related to bone mass than femoral neck fractures. Therefore, BMD-based fracture risk estimations and risk reduction due to therapy may be better suited for individuals prone to trochanteric fractures. Clearly, femoral neck fractures are more complex involving other factors such as anatomy and microstructure. It remains unclear where measurements should be made to predict femoral neck fractures or estimate femoral neck fracture risk. It is likely that these will require more complex models and potentially new in-vivo diagnostics.