Introduction: The lifetime risk of suffering a hip fracture for women over the age of 65 with osteoporosis is 35% to 40%[1]. Hip fractures are associated with significant morbidity, mortality, and costs, and as an aging US population pushes the number of hip fractures upward the impact of these injuries will increase dramatically[2]. In large clinical trials anti-resorptive agents decrease hip fracture rates a maximum of 50% while parathyroid hormone, despite stimulating bone formation, is even less effective in decreasing hip fracture rates[3,4]. Considering that women with osteoporosis face a 15-20% lifetime risk of hip fracture even when appropriately treated, and that the number of hip fractures is increasing dramatically, treatments which further reduce the risk of hip fracture could have significant clinical benefit[2,5]. Interventions that completely prevent fracture in osteoporotic bone have yet to be developed. Given the imperfect success of medical therapies in preventing hip fractures and the significance of these injuries, we believe there is a role for additional therapeutic interventions that reduce the incidence of hip fractures. PMMA is used clinically to stabilize regions of bone loss, to increase strength in therapeutic interventions that reduce the risk of hip fractures. PMMA is used clinically to stabilize regions of bone loss, to increase strength in osteoporotic bone, and to stabilize vertebral compression fracture. In the current study we test the ability of PMMA to increase proximal femur strength.

Materials and Methods: MTF provided cadaver femurs. We used the iDXA system (GE Lunar) to determine bone density. Proximal femurs were wrapped in saline-soaked towels and frozen until 24 hours prior to use, then warmed to room temperature. We constructed a mechanical testing apparatus attached to the platform of a standard testing system (MTS, Minneapolis, MN) through linear bearings. This device was instrumented with two load cells to measure forces applied to the femoral head and greater trochanter, and a third load cell to measure the three force and three moment components in the distal femoral shaft. For testing, femurs were internally rotated 15° from vertical and the femoral shaft elevated 10° from horizontal, and a vertical force was applied to the femoral head at a velocity of 100 mm/s. In this configuration the force applied to the femur approximates the direction and velocity of forces on the hip during falls resulting in fracture[6]. We tested 47 proximal femurs: 10 normal, 13 osteopenic, 12 osteoporotic, and 12 (contralateral) osteoporotic femurs augmented with intramedullary PMMA. Taken together the five force components and three moment components completely describe the loads imposed on the femur during strength testing. In this abstract we present load data for force at the greater trochanter during bone loading and fracture. To augment the proximal femur with PMMA we first broached the lateral cortex distal to the greater trochanter with a 5/16-drill bit, then washed the proximal intramedullary canal with pressurized saline. PMMA (Dough-type, Zimmer, Warsaw, IN) was mixed under vacuum and inserted with a Stryker cement gun (Stryker, Kalamazoo MI). Cement filling of the proximal intramedullary canal was evaluated on anterior-posterior and lateral radiographs. We imaged the anterior surface of the proximal femur during strength testing with a Fastcam high-speed video camera. Recordings were obtained at a speed of 6,000 frames per second and a resolution of 1024 x 512 pixels. Force and moment data were recorded simultaneously and correlated with the image frames.

Results: Femurs were categorized as normal, osteopenic, or osteoporotic based on WHO criteria. BMD values ranged from 0.936 to 1.11 g/cm2 for normal bones (T-score -0.4 to 1.1), 0.733 to 0.798 g/cm2 for osteopenic bones (T-score -2.1 to -1.5), and 0.319 to 0.656 g/cm2 for osteoporotic bones (T-score -5.5 to -2.7).

Discussion: Although current literature establishes that hip fractures have significant adverse impacts and that current medical-based therapies fail to prevent more than 50% of these fractures, there are few alternative strategies to reduce hip fracture incidence. Our studies show that PMMA injection increases the strength of osteoporotic femurs to equal that of osteopenic bones, suggesting the potential to reduce hip fracture risk in clinical situations. Failure at the bone-cement interface in the femoral head appeared as a proximate cause of failure, implying that techniques or materials that strengthen this interface would lead to increased strength of the reinforced femur. Additionally, use of PMMA to strengthen the proximal femur will require monitoring to determine the extent and effect of the associated temperature increase.

The simultaneous acquisition of video images and load data gives a new depiction of fracture progression, and correlation of these data sets will be a powerful tool for numerical modeling of the fracture process and improved understanding of fracture initiation and progression. Combined with force, moment, and strain measurements, video data will allow us to define metrics for ranking various femoral reinforcement designs, and will facilitate the development of strategies to maximize strength in bones at risk for fracture.


Acknowledgements: The Musculoskeletal Transplant Foundation (MTF) is gratefully acknowledged for donation of cadaver femurs. Force (Newton) at failure in 47 cadaver femurs

Table 1 shows the force applied to the greater trochanter at the time of failure. All femurs initiated fracture within 60 ms, and the fracture event resolved completely within 20 ms of crack initiation. The average strengths for normal and osteoporotic femurs in our study are comparable to values in the literature[6]. Analysis of video recordings showed initial cortex distortion, followed by crack initiation and cortex failure.

The strength of PMMA reinforced femurs was 34% to 290% greater than the contralateral osteoporotic femurs, with an average strength difference of 91%. The average strength for reinforced osteoporotic femurs was comparable to that of osteopenic femurs in our studies and in the literature[6]. We found a negative correlation between the strength of osteoporotic femurs and the strength of the contralateral femur after PMMA reinforcement (Pearson –0.82).

The femur-PMMA constructs were carefully examined after testing. Two modes of failure were identified: In seven femurs failure was initiated by a crack along the medial cortex in the neck or in the vicinity of the lesser trochanter, associated with crack propagation in the PMMA. In five cases failure occurred at the interface between cement in the proximal femoral neck and cancellous bone in the femoral head. These latter five femurs were significantly weaker than femurs that failed with femoral neck or intertrochanteric fractures (3,452 N vs. 4,716 N, p< 0.01).

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Osteopenic</th>
<th>Osteoporotic</th>
<th>Osteoporotic + PMMA</th>
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<tr>
<td>Mean</td>
<td>4,996</td>
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<tr>
<td>Std Dev</td>
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<td>668</td>
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<td>N</td>
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Mechanical strength in osteoporotic femurs augmented with PMMA
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