**Introduction:** The risk of hip fracture associated with osteoporosis may be reduced with preventive treatments including reinforcement of weak bones with PMMA. The finite element (FE) method was used to evaluate various reinforcement implant designs. The simulation used the third generation standardized femur (1). To understand the effects of the implant on increasing osteoporotic bone strength, the standardized femur model was modified. The trabecular elastic modulus was reduced to simulate osteoporosis (2). The femurs were oriented and loaded to simulate falling on the hip. The simulations compared the stress levels on osteoporotic bones implanted with PMMA only and with metal reinforced PMMA designs. In the current study, we showed that the integration of metal reinforcement with PMMA further enhanced the strength of the implanted femur.

**Materials and Methods:** FE simulations were performed on bone models with PMMA and PMMA reinforced cylindrical implants integrated in the neck region. All simulations used ANSYS Workbench 11. Normal, osteoporotic, and implanted osteoporotic femurs were modeled to simulate falling on the hip. To more closely mimic the anatomical femur, the cortical shell and trabecular bone were both modeled. The trabecular bone was modified from the standardized femur to create a hollow femoral shaft. The PMMA implant (I1) was modeled as a 2 cm diameter, 8.5 cm long cylinder. Five PMMA reinforcement implant designs were evaluated: a central hollow tube (I2), a central hollow tube with four outer tubes (I3), a hollow double helix (I4), 10 slender fibers (I5), and 15 slender fibers oriented in two concentric rows (I6) (Fig. 1A). Material properties are shown in Table 1. Boundary conditions were applied to the model to simulate falling on the hip (Fig. 1B). A frictionless support was applied to the femoral head and a 4 kN force was applied to the greater trochanter. The distal shaft was constrained allowing only a rotation perpendicular to the femoral shaft. The femur was meshed with tetrahedral elements and the implant meshed with hexahedral elements. Meshes with around 900,000 elements were used.

![Figure 1: (A) FE model geometry of reinforcement implants; (B) Boundary conditions applied to simulate falling on the hip; (C) Maximum von Mises stress plot of external and internal implant stresses (MPa).](image)

**Results:** Maximum von Mises stresses in the femur were recorded in the subcapital, intertrochanteric, and mid-neck regions for all models (Fig. 1C). The stresses in the neck region of the osteoporotic model increased two-fold over the normal model (Table 2). When the PMMA only implant was inserted into the osteoporotic model, stresses in the cortical neck region decreased by 15%, showing the implant was effective in reducing stresses under the same loading condition. Adding metal reinforcement to the PMMA further decreased the cortical stresses for all implant designs. Most notably, I6, the double rowed slender fiber reinforcement, showed 26% decrease in bone stress. Implant designs with parallel fibers offset from the center are more effective in reducing bone stresses than a single tube close to the center or helical designs. This reduction in stress levels is equivalent to a similar increase in the strength of the implanted bones.

**Discussion:** The FE method was used to evaluate different implant designs. The implants were simulated using both PMMA and composite designs incorporating PMMA and 316L stainless steel components in various configurations. The osteoporotic model showed a two-fold increase in von Mises stress above that of normal bone. All of the implant designs were effective in reducing the stress levels compared to those of osteoporotic bone models. The implant with 15 parallel fibers was most effective. The present study showed that the combination of PMMA and metal reinforcements can result in an implant design that can strengthen the osteoporotic bone more than PMMA alone.