INTRODUCTION
Distal radius (Colles’) fractures are a common injury in older women, and generally result from a fall onto an outstretched hand. While not life-threatening, these fractures cause significant impairment. Because Colles’ fractures usually occur during impact from a standing height or lower and are considered low energy fractures, diminished bone quality (i.e. osteopenia or osteoporosis) has been implicated as a risk factor for sustaining these and future hip fractures [1-3]. Whether and where a fracture of the radius occurs after a fall depends on the magnitude and direction of the impact force and upon the strength of the bone itself. Despite the fact that most cadaver studies have loaded the wrist axially, experimental results indicate that the loading direction varies during impact from a fall [4]. Clinical interventions for osteoporosis have recently focused on improving bone density through pharmaceutical means such as anti-resorptive therapy [5]. However, such improvements may be less important in preventing fractures than other mechanical factors such as loading direction. We used a previously validated finite element model of the radius, scaphoid, and lunate [6], to address the question of how fracture strength is influenced by loading direction.

METHODS
The finite element model has previously been described in detail [6]. Briefly, the right wrist of a 53 year old female volunteer was imaged with computed tomography. Geometrical and density data for the radius, scaphoid, and lunate were extracted using custom-written software (Matlab 7.01) and a finite element model was built using ANSYS 10.0. Bone material properties were assigned based on Hounsfield data. A 2.5 mm-thick layer of cartilage was created on the distal articular surface of the radius. The ligaments that directly attach to the radius, scaphoid, and lunate were included in the model as non-linear springs (Figure 1).

A crack large enough to propagate was assumed to have developed if a contiguous volume of greater than 350 mm³ reached the failure criterion [9]. Failure for each element was calculated at each load increment using the Mohr-Coulomb failure criterion of \( \sigma_t/\sigma_y - 1 \geq 1 \) [10] where \( \sigma_t \) and \( \sigma_y \) are the tensile and compressive yield stresses of the material, respectively.

RESULTS AND DISCUSSION
Loading direction had a strong influence on predicted fracture strength. For the baseline BMD model, an axial load caused fracture at 2752 N. In contrast, the most off-axis load applied to the same model predicted failure at 1448 N. Not surprisingly, the intermediate loading direction predicted an intermediate failure load of 2185 N.

Changes in BMD had a much smaller effect compared to changes in loading direction (Figure 2). All models showed a similar trend as the load on the radius increased: the largest contiguous failed volume remained small and relatively constant until a critical point was reached. At that point the volume of failed elements rapidly increased. Thus, the predicted fracture load was relatively insensitive to the volume cut-off point of 350 mm³.

Although changes in BMD significantly influence predicted fracture load and although clinical evidence suggests that antiresorptive therapy is successful in reducing fractures in severely osteoporotic individuals, the direction of load applied to the radius appears to have a much stronger influence on the bone’s fracture strength. Because the majority of falls onto the hands probably result in off-axis peak loads [11], it is possible that previous studies utilizing axial loads may have overestimated the amount of force required to initiate a fracture of the distal radius.

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REFERENCES