INTRODUCTION
Distal forearm fracture is one of the most frequently observed osteoporotic fractures resulting from low energy falls. Wrist fractures have been shown to be predictors of future hip and spine fractures [1,2]. Therefore, fracture evaluation at the distal radius has high potential for identifying individuals under osteoporotic fracture risk.

Recently, high resolution peripheral computed tomography (HR-pQCT) has been introduced as a potential noninvasive, in vivo bone imaging technique that can provide detailed three-dimensional geometry and architecture information at peripheral sites including the distal radius. These images have been combined with finite element modeling to determine bone stiffness that can help assess, noninvasively, the mechanical competency of the bone [3-5].

In this study, a new finite element modeling approach is proposed that combines HR-pQCT imaging with nonlinear fracture mechanics-based modeling to determine the distal radius fracture load. This approach is expected to provide additional insight into the evaluation of fracture risk by including explicit representation of the crack formation process.

METHODS
HR-pQCT images from five female subjects (63 to 81 years of age), obtained as a part of another study, were processed to create the whole bone section (including both the trabecular and the cortical bone compartments) (Fig. 1a) as well as only the cortical bone compartment (Fig. 1b). These images were meshed with tetrahedral elements using an image processing software (ScanIP, Simpleware) and were imported into a finite element program (ABAQUS) (Fig. 1c, 1d). A crack plane was inserted at the midpoint of all models that corresponds to the average location of the distal forearm fractures (Fig 1e, 1f). The crack plane in each model is tiled with cohesive elements. Cohesive finite elements are based on a traction-crack opening displacement relationship and form a crack when there is no transfer of traction between the opening surfaces (Fig. 2a, 2b).

The load was applied at the distal end of the bone based on the loading configurations used in experiments [6] and was incrementally increased to determine the fracture load until the cohesive elements form a crack. The bone sections were fixed in all directions at the proximal end. The models were assigned isotropic properties [5] and the fracture properties for the cohesive elements were taken from the literature [7].

RESULTS
The simulation results showed that the whole bone provided higher fracture loads compared to just cortical bone (Table 1) with load ratios varying between 0.50 to 0.79. The load ratios were highly correlated with the ratio of cortical to whole bone volume (Fig. 3a) as well as the ratio of cortical crack area to whole bone crack area (Fig. 3b).

DISCUSSION
The current study focused on the application of a new nonlinear fracture mechanics-based finite element modeling approach to HR-pQCT images to improve noninvasive fracture risk assessment of distal radius. The proposed approach differs from the existing finite element models in the literature by explicitly modeling the crack formation process.

The results showed that the load sharing between the cortical and trabecular compartments of the bone was highly correlated with the proportion of the cortical area at the crack plane as well as the overall proportion of the cortical volume in the whole section. Cortical area at the crack plane provided a good estimate of the fracture load for both the whole bone and cortical bone models.

In summary, the results of this study demonstrated a promising approach combining HR-pQCT imaging and cohesive finite element modeling which has the potential to improve fracture risk assessment techniques by explicitly representing the crack formation process.

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REFERENCES