INTRODUCTION: Pathological fracture of the proximal femur due to metastatic tumors is a common and serious consequence of cancer of the breast, prostate, lung, thyroid, and kidney. Current methods for identifying patients at risk of fracture and, therefore, in need of prophylactic surgical fixation have been shown to be inadequate. 1 CT scan-based nonlinear finite element (FE) modeling is a precise tool for estimating proximal femoral fracture load for bones without metastatic tumors. 2 This technique may be useful for assessing the risk of pathological fracture of the proximal femur for bones with metastatic tumors. However, the relationships between CT scan data and material properties that are used for generating these models may be different for bone with metastatic lesions than for normal bone, and may therefore affect the accuracy of these models. In this study, we examined whether CT scan-based FE models can be used to predict fracture loads for proximal femora with metastatic lesions.

METHODS: Human femora from one female age 52 years (Subject A) and one male age 74 years (Subject B) were obtained fresh frozen. Cause of death for both subjects was metastatic lung cancer. Multiple blastic lesions were present in all proximal femora. The right proximal femur from Subject A and both proximal femora from Subject B were studied. FE modeling and mechanical testing to failure were performed under single-limb stance-type loading with displacement applied to the femoral head at 20° to the shaft within the coronal plane.

The femur from Subject A was evaluated previously as part of a study to validate nonlinear FE models for prediction of fracture load. 2 This previous study included 17 femora without metastatic lesions from donors age 54 to 92 years. The femora from Subject B were evaluated using analogous procedures, as described below. FE modeling and mechanical testing data for the three femora with metastatic lesions were compared with data for the 17 femora without metastatic lesions.

The femora were immersed in water and CT scanned along with a calibration phantom. The femur from Subject A and the 17 control femora were scanned on a GE 9800 Research Scanner with a K2HPO4 calibration phantom at the following settings: 80 kVp; 280 mAs; 3-mm slices; 320×320 matrix; 1.08-mm pixels; standard reconstruction. The femora from Subject B were scanned on a GE HiSpeed Advantage CT scanner with a calcium hydroxyapatite phantom (Image Analysis, Inc., Columbia, KY) at 80 kVp; 280 mAs; 3-mm slices; 512×512 matrix; 0.674-mm pixels; standard reconstruction.

A three-dimensional nonlinear FE model of each femur was generated from the CT scan data using 3-mm linear cube-shaped elements. Ash density, elastic modulus, and material strength of each element were computed from the calibrated CT scan data as described previously. 1 To account for the use of a solid calibration phantom instead of a liquid phantom, a conversion relation was applied to the calibrated CT scan data. Elements on the loaded surface of the femoral head were assigned an elastic modulus of 20 GPa and a strength of 0.2 GPa to prevent severe element distortion. Post-failure properties were computed from each element’s ash density using correlations for tibial trabecular bone, as described previously. 2 Post-failure behavior was represented by an initial perfectly plastic phase at the yield stress, followed by a strain softening phase and, ultimately, a perfectly plastic phase. The modeled boundary conditions represented the conditions of mechanical testing. Displacement was incrementally applied to the femoral head and the models were restrained distally. The FE analysis, which computed the femoral head reaction force at each displacement increment, was performed with ABAQUS version 5.4 using the distortion energy failure theory, geometric nonlinearity, and automatic time stepping options. FE-predicted fracture load (FMEAN) was defined as the maximum total reaction force at the femoral head.

The femora were mechanically tested to failure at 0.5 mm/s. Measured fracture load (FMET) was defined as the maximum load achieved during mechanical testing to failure. Displacement was incrementally applied to the femoral head at 20° to the shaft within the coronal plane.

The linear relationship between FMET and FMEAN for the 17 proximal femora without metastatic lesions was computed. The 95% confidence interval for the population was examined to determine whether the FMET versus FMEAN results for the bones with tumors were from the same population (that is, followed the same linear relationship) as those for bones without tumors.

RESULTS: The data for all three femora with blastic lesions fell outside the 95% confidence interval for the population of femora without tumors (Fig. 1). Thus, the relationship between measured and predicted fracture load for bones without metastatic lesions was not applicable to the bones with blastic metastatic lesions (p < 0.05). Furthermore, the difference between FMEAN and the fracture load that would be predicted by the regression line ranged from 1.7 to 2.8 kN (21% to 45% of FMET), which is equivalent to 2.4 to 4.0 times the standard error of the estimate for this regression equation.

DISCUSSION: We have shown that these CT scan-based FE models do not predict fracture loads for proximal femora with blastic lesions with the same accuracy as for femora without metastatic lesions. These findings are consistent with the results of Hipp et al. 3 whose data indicated that the presence of blastic lesions in bone might alter the relationship between bone density and mechanical properties.

Concern about pathological fracture usually focuses on bones with lytic lesions, rather than blastic lesions, because of the direct weakening effect of the former. However, blastic and lytic lesions can be present in the same bone, and the risk of pathological fracture of these bones can be significant. Based on the results of this study, the presence of blastic lesions in these bones can cause FE models to provide inaccurate results. Thus, CT scan-based modeling techniques may need to be modified for use with bones with metastatic lesions.


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