Predicting femoral bone strength after cephalomedullary nail removal with FE models using pre-operative CT scans

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Background:
Cephalomedullary nailing is frequently used to treat per- and subtrochanteric fractures of the proximal femur. After fracture healing, patients sometimes request nail removal due to persistent pain or irritation. However, removing the nail leaves a large void in the bone, which poses a considerable risk of re-fracture at the femoral neck. Pre-operative prediction of fracture risk would help to make an informed decision about nail removal and to estimate the required post-operative care. This study investigated whether patient-specific finite element (FE) models created from pre-operative CT scans can predict femoral bone strength after nail removal. Experimental data of femora after nail removal were used to evaluate the accuracy of the models.

Methods:
Ten femoral bones of human body donors who were treated with a cephalomedullary nail during their lifetime due to a per- or subtrochanteric fracture were obtained from the Medical Bio-/Implantbank Vienna. CT scans (0.4x0.4x0.6 mm^3 voxel size) were taken prior to nail removal using a dual energy protocol and an iterative metal artefact reduction algorithm. The bones were cut to 50 % length, embedded, and mounted to a material testing machine to simulate loading in stance. The load was increased monotonically until failure and the maximum force was recorded. The experiments were replicated using patient-specific nonlinear voxel-based FE models. The models were created by virtually removing the implant from the pre-operative CT image, aligning the bones in agreement with the experiment, coarsening the image to 3 mm voxel size and converting each voxel to a linear hexahedral element. Due to remaining metal artefacts from the distal locking screws, the FE models were cut to the proximal region above the distal locking screw. A density-dependent, isotropic, elastic-damage material was assigned to each element and the models were loaded until failure in analogy to the experiments. The maximum force predicted by the models was then compared to the experimentally measured maximum force using linear regression analysis.

Results:
Experimental femoral bone strength after nail removal ranged from 611 to 2851 N and FE-predicted strength ranged from 390 to 1873 N. FE model predictions and experimental measurements were well correlated (R^2=0.78, p<0.001), but the models underestimated the experimental measurements (experimental mean: 1837±598 N, FE mean: 1127±425 N).

Conclusions:
The FE models were able to predict the strength of femoral bones after cephalomedullary nail removal pre-operatively with good correlation to experimental measurements. This shows that voxel-based FE models can predict bone strength despite the presence of a metal implant in the CT scan and the highly irregular structure of the previously fractured and healed bones. Thus, FE models may be a useful tool to support clinical decisions on nail removal in the future.