Fast estimation of Colles’ fracture load of the distal radius by non-linear finite element analysis based on high resolution peripheral computed tomography

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Methods

Mechanical with microFE for a slightly improved accuracy. The computed fracture loads were strongly correlated with the experiments: $R^2=0.98$ for the hFE and $R^2=0.95$ for the microFE models. Computation of fracture load with hFE was around 3 times faster than

Background & Aim

High resolution peripheral quantitative computed tomography (HR-pQCT) provides in vivo assessment of local bone mineral density (BMD), trabecular morphology (e.g. fabric) and bone strength using linear microFE analysis. The second generation of HR-pQCT scanners (XtremeCT II, SCANCO Medical AG) enables in vivo reconstructions of the distal radius at even higher resolution, lower ionizing dose and reduced scan time compared to its predecessor. The aim of this work was to validate experimentally a fast patient-specific homogenized finite element (hFE) model of the human distal radius and to develop a fully automated diagnostic tool for the in vivo prediction of Colles’ fracture load based on the last generation HR-pQCT scanner.

BV/TV of the HR-pQCT images was calculated after segmenting the bone tissue and the Mean Intercept mgHA/ccm and the fabric orientation was evaluated using the Gradient Structure Tensor (GST). The BV/TV of the HR-pQCT based hFE model was used to evaluate fabric. A ball joint system was placed on the upper loading plate to maximize the initial contact surface between the loading plates and the cross sections of the bone as well as to increase the probability of inducing Colles’ fracture. Five pairs of lever arms with attached infrared light-emitting diodes (LEDs) measured the rotation of the loading plate. The bone sections were compressed until failure and then unloaded.

Workflow

Hundred thirty-three (133) cubic regions of interest with an edge length of 6 mm were extracted from the trabecular core of the 24 distal radius sections. Furthermore, to include cortical bone, fifty-four (54) cubic regions were selected from the periphery of the sections. All cubes (N=187) were used to calibrate the BV/TV values, whereas only the trabecular bone cubes (N=133) were used to fabricate the BV/TV of the HR-pQCT images was calculated by dividing the average BMD of each cube by 1200 mgHA/ccm and the fabric orientation was evaluated using the Gradient Structure Tensor (GST). The BV/TV and the µCT images were calculated after segmenting the bone tissue and the Mean Intercept Length method was used to evaluate fabric. Two samples were excluded from the validation study due to misalignment of the loading axis in one sample and loss of the HR-pQCT image in the second one. The computed fracture loads were strongly correlated with the experiments: $R^2=0.98$ for the hFE and $R^2=0.95$ for the microFE models. Computation of fracture load with hFE was around 3 times faster than with microFE for a slightly improved accuracy.

Results

Two samples were excluded from the validation study due to misalignment of the loading axis in one sample and loss of the HR-pQCT image in the second one. The computed fracture loads were strongly correlated with the experiments: $R^2=0.98$ for the hFE and $R^2=0.95$ for the microFE models. Computation of fracture load with hFE was around 3 times faster than with microFE for a slightly improved accuracy.

Conclusion

1. Both microFE and hFE modeling techniques achieved high accuracy in predicting radial fracture load
2. Motion artifacts are not accounted for in this study
3. The developed hFE method allows a fast and accurate estimation of radial fracture load in clinical studies with HR-pQCT. Reproducibility assessment is in progress.
4. Linear hFE simulations could provide a reasonable estimation of fracture load within a few minutes ($R^2=0.97$)
5. Evaluation of reproducibility is in progress

References