ABSTRACT
Bone mechanical properties of the human distal radius can be estimated by means of finite element analysis (FEA) based on computed tomography (CT) scans. Clinically this is conventionally performed by means of quantitative CT (QCT) scans with a resolution varying between 300 and 1500 μm, which is insufficient to capture the bone at the micro-level. High resolution peripheral QCT (HR-pQCT) is feasible to capture the bone’s microarchitecture, though QCT scans can be advantageous over HR-pQCT scans in terms of availability, utility and time. The first generation HR-pQCT scanner allows scans with an isotropic resolution of 82 μm (XCTI), where the second generation scanner can mimic the first generation protocol at 82 μm resolution (XCTII-LR) and allows scans with an improved isotropic resolution of 61 μm (XCTII). Both HR-pQCT generation scans and QCT scans are feasible for FEA of the human distal radius. However, studies comparing the FEA outcomes based on the different imaging modalities are scarce. The first part of the project focuses on the comparison between the first generation HR-pQCT scans and QCT resolution scans. In recent research it was found that HR-pQCT in combination with µFEA is a promising tool to assess longitudinal changes in bone mechanical properties during fracture healing in the distal radius. It is unknown whether these changes can be detected as well when using images with lower resolutions, comparable to more widely available QCT scans. The aim is to investigate whether this is the case.

Postmenopausal women with a stable distal radius fracture (n=18) were scanned by an HR-pQCT system at 4 visits during a 12 week follow-up period. HR-pQCT scans (resolution 82 μm) were downscaled, mimicking QCT resolutions. Stiffness in compression, torsion and bending were assessed by µFEA based on HR-pQCT scans using a standard and Shefelbine approach and by FEA based on downscaled scans using a grey-level dependent approach. µFEA outcomes and FEA outcomes based on the downscaled images were compared by means of linear regression and Bland-Altman plots. A linear mixed-effect model was used to identify significant changes in stiffness from baseline. When similar significant longitudinal changes were found for µFEA and downscaled FEA, the resolution was considered sufficient to assess bone stiffness in the fracture healing process.

All correlations were significant (p<0.05), however R2 decreased when a larger downscaling factor was applied. R2 for scaled FEA outcomes with µFEA Shefelbine outcomes were higher than for scaled FEA outcomes with µFEA standard outcomes. Scaled approaches generally overestimated stiffness compared to µFEA approaches. The limits of agreement widened when a larger downsampling factor was applied and were more narrow for the µFEA Shefelbine comparison. µFEA outcomes all showed significant changes from baseline at 12 weeks post-fracture (p<0.05). The largest downscaled voxel size with significant longitudinal changes in stiffness was 328x328x656 μm for the torsional and bending stiffness (p<0.05 and p<0.1, respectively).

Concluding, FEA based on scans with clinically feasible voxel sizes could lead to similar conclusions for torsional and bending stiffness as µFEA based on HR-pQCT images during the fracture healing process.

The second part concerns the comparison of µFEA outcomes based on different scan protocols using both generation HR-pQCT systems. Although the second generation scanner allows imaging of the bone at a higher resolution, it is unknown whether bone mechanical properties derived from both generation scanners can be compared directly. For research using both generation scanners or in case the transition is made from the first to the second generation scanner, it is useful to know whether this is the case. In addition, the XCTII patient evaluation protocol applies a dual threshold, unlike the XCTI or the XCTII-LR protocol. The dual threshold might affect the µFEA outcomes as the trabecular and cortical part of the bone may be disconnected. The aim is to compare µFEA outcomes based on first generation HR-pQCT scans to µFEA outcomes based on the second generation HR-pQCT scans and additionally investigate the effect of the novel dual threshold protocol on those outcomes.
Human cadaveric embalmed radii (n=10) were scanned using the first generation scanner at the XCTI protocol (resolution 82 μm) and the second generation scanner at both the XCTII-LR (resolution 82 μm) and the XCTII protocol (resolution 61 μm). μFEA based on XCTI, XCTII-LR, XCTII and XCTII using a one threshold protocol (XCTII-1th) was performed. μFEA outcomes were compression stiffness and failure load. μFEA outcomes were compared by linear regression, assessment of Bland-Altman plots and a paired student’s t-test. Correlations for both XCTII-LR and XCTII with XCTI were high (R2>0.95). XCTII-LR and XCTII both significantly underestimated compression stiffness (23.7% and 29.2%, respectively) and failure load (12.7% and 20.0%, respectively) compared to XCTI (p<0.05). A proportional bias was present for the XCTII-LR and XCTI comparison: underestimation increased in the higher range values. XCTII-1th significantly overestimated compression stiffness (4.1%) and failure load (4.3%) compared to XCTII (p<0.05), however the correlations were high (R2>0.99). Concluding, μFEA outcomes based on the different imaging modalities are not directly comparable, but can be when the appropriate corrective factors are applied. The dual threshold protocol of the second generation scanner does not have a relevant effect on the μFEA outcomes.