ESTIMATION OF FEMORAL TRABECULAR BONE FABRIC FROM QCT IMAGES DEPENDS ON THE SIZE OF THE REGION OF INTEREST

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Introduction
Quantitative computed tomography (QCT)-based patient specific finite element (FE) models have proven to be a useful tool in evaluating bone strength. The accuracy in this prediction seems to depend on the loading scenario [Dall’Ara, 2013], but may be improved by including directional anisotropy [Lenaerts, 2009]. The mean intercept length (MIL) method is the gold standard when assessing anisotropy from segmented high-resolution images, but this method cannot be applied to QCT images of trabecular bone. The gradient structure tensor (GST) is a viable method for evaluating anisotropy of trabecular bone from QCT [Wolfram, 2009], but the accuracy has yet to be clearly delineated. The goal of this study was to develop a reliable method for evaluating femoral trabecular bone anisotropy from QCT images using the GST.

Methods
Twelve human proximal femora were scanned using QCT and high resolution peripheral QCT (HR-pQCT) scanners. Two registered data sets were created at two different isotropic voxel sizes (0.33 and 0.082mm). Thousands of cubical regions of interests (ROIs) of different sizes (5, 7.5, 10, 15mm) were cropped in the trabecular region of the QCT datasets and a GST fabric tensor \( \mathbf{G} \) was computed (Fig 1., left). Cubes were cropped at the same location from the HR-pQCT dataset to obtain the normalized MIL fabric tensor \( \mathbf{M} \) (Fig 1., right).

A power transformation was proposed to relate the MIL tensor \( \mathbf{M} \) with the GST tensor \( \mathbf{G} \):

\[
\mathbf{M} \leftrightarrow \mathbf{G} = \left( \frac{\mathbf{G}^n}{\text{tr}(\mathbf{G}^n)} \right)^{\frac{1}{n}}
\]

(1)

As a good correspondence between the main eigenvectors of \( \mathbf{M} \) and \( \mathbf{G} \) was found for high degrees of transverse anisotropy (DTI), a threshold \( DTI_{\text{thres}} \) was defined with the eigenvalues \( \text{GST} \)\( \mathbf{m} \) such that 95% of all ROIs had an angular difference of 30° or less:

\[
DTI_{\text{thres}} = \frac{2(\text{GST} \mathbf{m}_1)}{\text{GST} \mathbf{m}_2 + \text{GST} \mathbf{m}_3}
\]

(2)

Results
For ROIs above \( DTI_{\text{thres}} \) significant power relationships were obtained between the GST and MIL DTI for all sizes (\( R^2 > 0.72 \)). The \( DTI_{\text{thres}} \) and the coefficient \( n \) are plotted for a range of ROI sizes (Fig. 2). Results define the \( DTI_{\text{thres}} \) and \( n \) required for GST-based anisotropy predictions for a given ROI size.

Discussion
Regions with a high DTI also exhibit a high BV/TV, predominantly contributing to the femoral stiffness and strength. This method may be used to improve QCT-based FE models for the prediction of femoral strength.

References
Dall’Ara et al, Bone, 52:27-38, 2013
Lenaerts et al, Phil.Trans, 367:2079-93, 2009
Wolfram et al, JBiomech, 42:1390-1396, 2009