Predicting physiological hip joint loads with inverse bone remodeling using clinically available QCT images
Supplemental Material

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1. Sample Information

Table 1: Sex, age, and side information for the used sample set. Both sides were used for five of the 15 donors.

Sample ID	Donor ID	Sex	Age (years)	Side
#1	1	female	80	left
#2				right
#3	2	female	83	left
#4	3	female	88	left
#5				right
#6	4	male	80	right
#7	5	female	82	left
#8	6	female	92	left
#9	7	female	72	left
#10	8	female	85	left
#11				right
#12	9	female	84	left
#13				right
#14	10	female	82	right
#15	11	female	69	right
#16	12	male	71	left
#17				right
#18	13	female	94	left
#19	14	female	92	left
#20	15	male	94	right

2. Cartilage Thickness Sensitivity Study

To test the influence of the cartilage layer thickness on the results of inverse bone remodelling (IBR), the cartilage layer radius offset was varied for the "hFE QCT" model.

The radius of the cartilage layer, defined from the center of the head, was set to be 2.2 mm in addition to the head radius for the baseline models. The radius was then varied by -0.1 mm, +0.1 mm, +0.2 mm, +0.3 mm, +0.4 mm, +0.5 mm, +1.0 mm, +2.0 mm, and +5.0 mm from the baseline. This resulted in an average cartilage layer thickness of 1.8 mm for the models with 2.1 mm radius offset (variation -0.1 mm) and 6.9 mm for the models with 7.2 mm radius offset (variation +5.0 mm). A smaller cartilage layer than 2.1 mm radius offset was not possible for all the hFE QCT models, as in certain instances, nodes from the cortical surface were otherwise protruding the cartilage layer.

The applied unit load cases were scaled based on the area of the load patches to stay at a magnitude of 1 kN.

Figure 1 shows the resulting distribution of predicted loads. Either a slight increase in loads (F_2, F_3, F_{10}) or a slight decrease (F_1, F_4, F_6, F_9) was observed when the radius offset was increased. The difference was only marginal for radius offsets between 2.1 mm and 3.2 mm. The largest change was observed for unphysiological radius offset sizes, i.e., 7.2 mm radius offset.

The same sensitivity study was performed for the model "hFE ORTHO", "hFE INHOM", and "hFE XCT2" and yielded similar results.
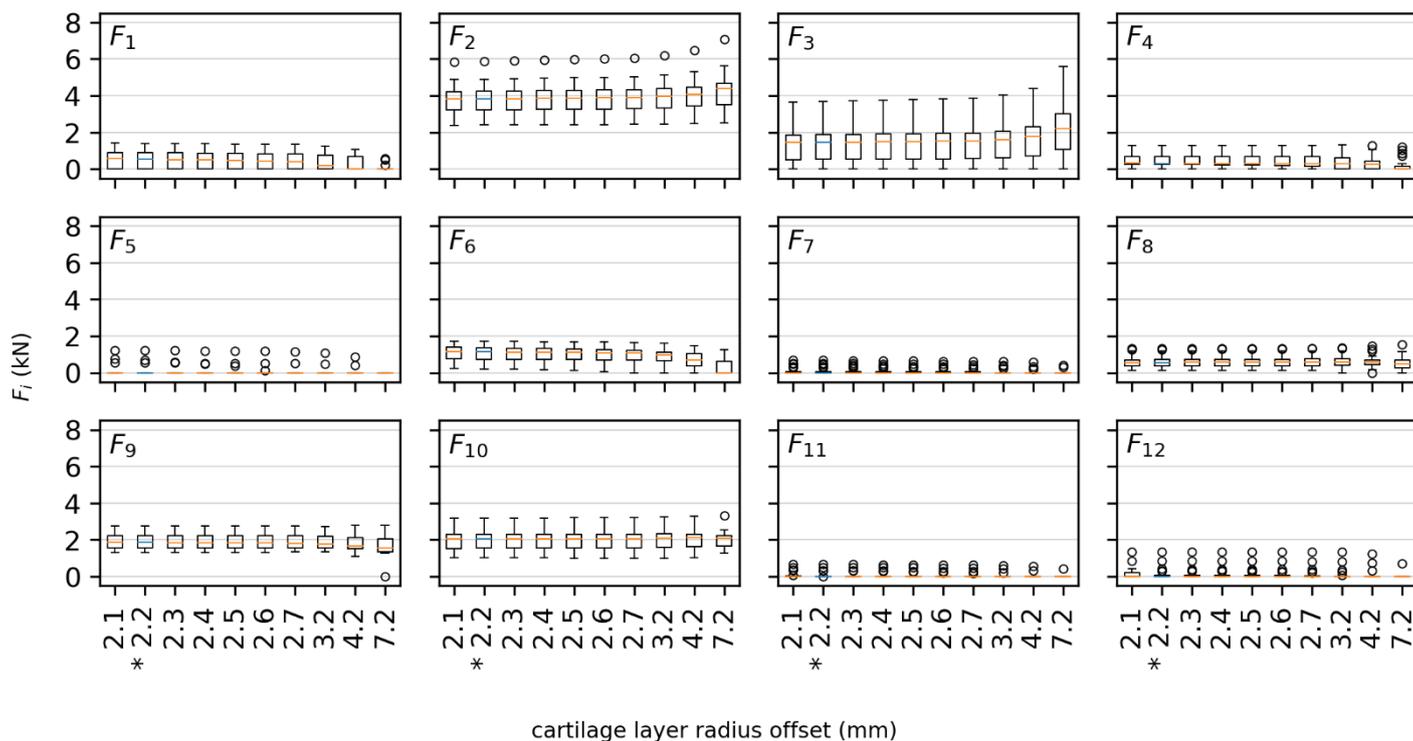

Figure 1: Influence of cartilage layer radius offset on IBR results. The baseline model is marked with an asterisk (*).

3. Predicted Loads for each Sample

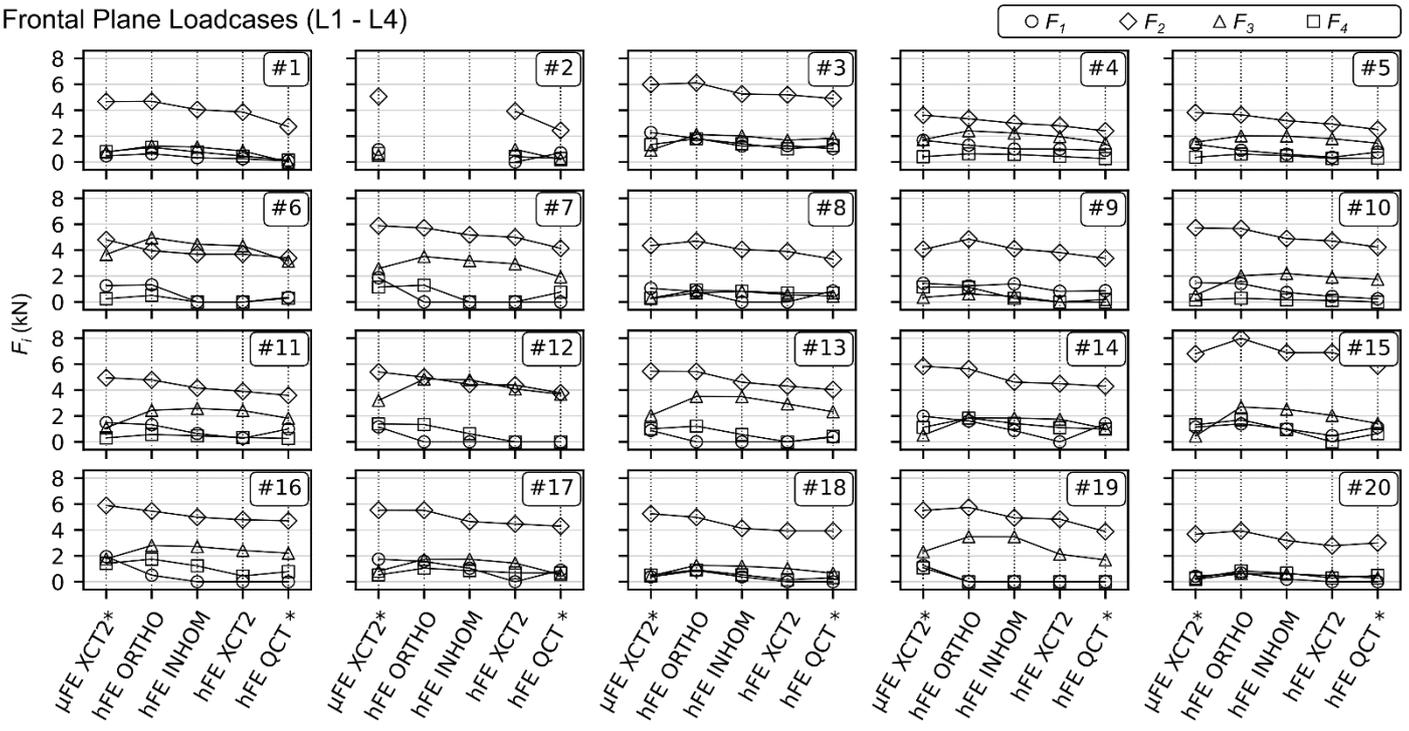### Frontal Plane Loadcases (L1 - L4)

Figure 2: Predicted load case magnitudes for all models and samples for the frontal plane load cases (L1 to L4). The number in the top right corner is the sample ID (Table 1). Meshing failed for sample #2 for hFE ORTHO and hFE INHOM models; thus, no results are available for these two models.
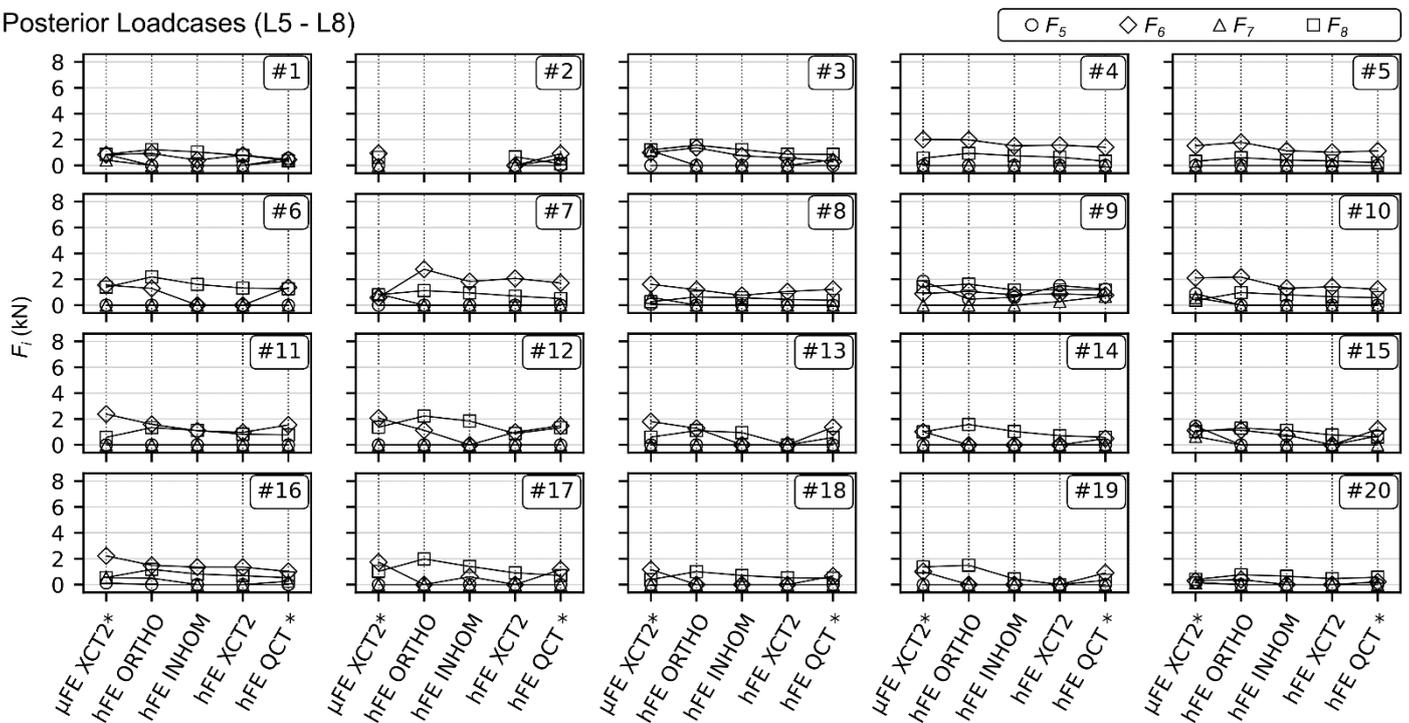
Posterior Loadcases (L5 - L8)

Figure 3: Predicted load case magnitudes for all models and samples for the posterior load cases (L5 to L8).
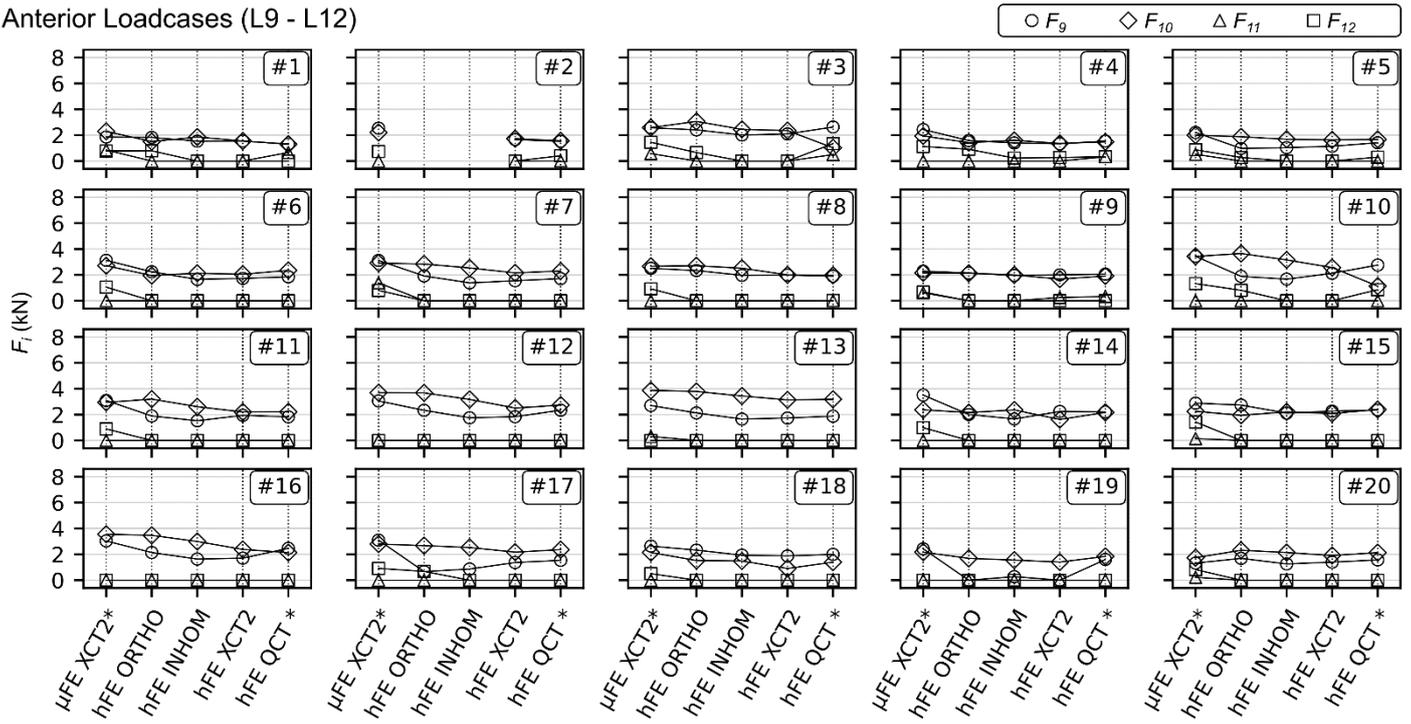
Figure 4: Predicted load case magnitudes for all models and samples for the anterior load cases (L9 to L12).

4. Artificial Resampling of QCT Images

The 0.3 mm voxel size QCT images were artificially coarsened up to 1.5 mm voxel size (Using SimpleITK and Gaussian Interpolation). FE models were created in the same way as the "hFE QCT" models. To avoid artifacts during the material mapping, the VOI size D_{VOI} was increased to 7.5 mm and the grid spacing δ_{grid} to 3.5 mm. This step has to be performed to maintain a sufficient number of voxels per VOI. However, as steep density gradients are smeared using a larger VOI, the same VOI size was also applied for the 0.3 mm voxel size baseline model, to achieve comparability between the models.

The results of IBR without peak calibration (Figure 5) show that especially the peak load (α_2) is affected only slightly; other load cases are affected more by the coarsening. Overall, the behaviour is only slightly sensitive to the resolution of the images.
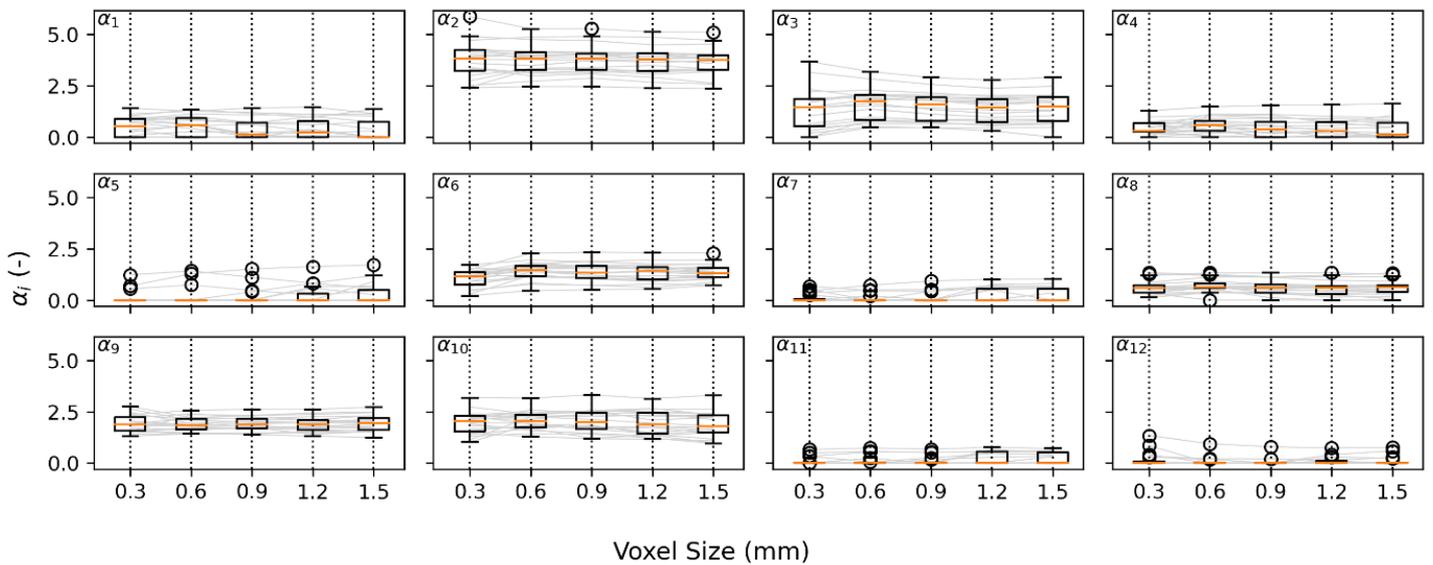

Figure 5: Load scaling factors without peak calibration for different artificially resampled image resolutions. Gray lines show individual images.

5. Influence of Background-Grid Parameters on BMD-BV/TV Calibration

To evaluate the influence of choosing different background-grid parameters D_{VOI} (Diameter of Volume of Interest (VOI)) and δ_{grid} (Background-grid distance), the following study was performed: The BMD from a single QCT image (Sample #7) and BV/TV from the matching XCT2 image was evaluated on a finite element mesh using different parameters.

First, δ_{grid} was kept constant at 1.6 mm and different D_{VOI} were applied (Figure 6). Due to the fixed grid distance, the minimal VOI size was 3.2 mm. Second, D_{VOI} was kept constant at 3.6mm and δ_{grid} was varied (Figure 7). Due to the fixed VOI size, the maximal grid distance was 1.75 mm.
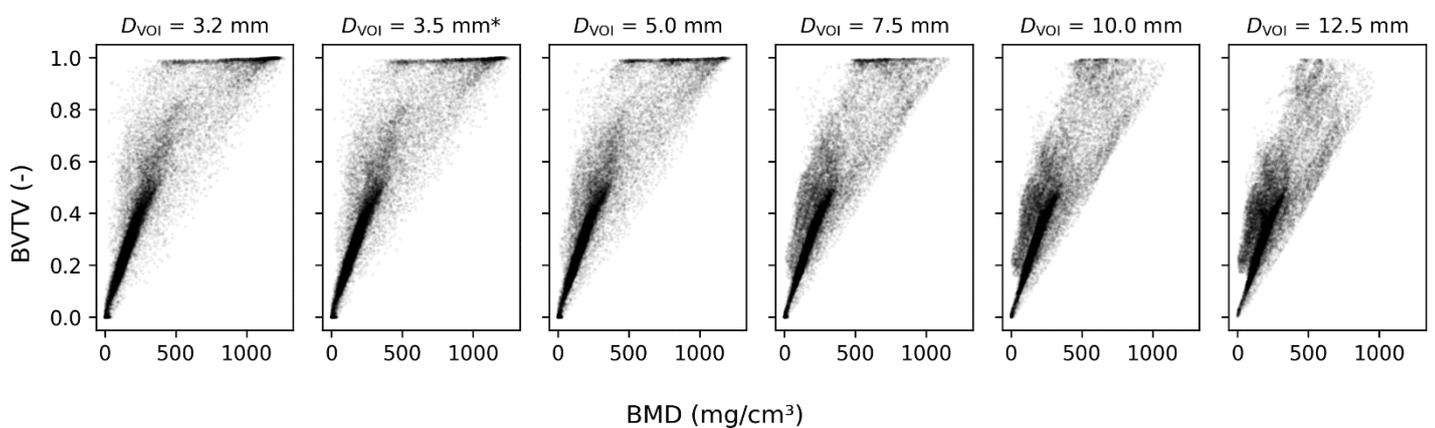

Figure 6: Results for constant grid spacing δ_{grid}=1.6 mm for single image. Model with asterisk (*) marks the value that was finally used.
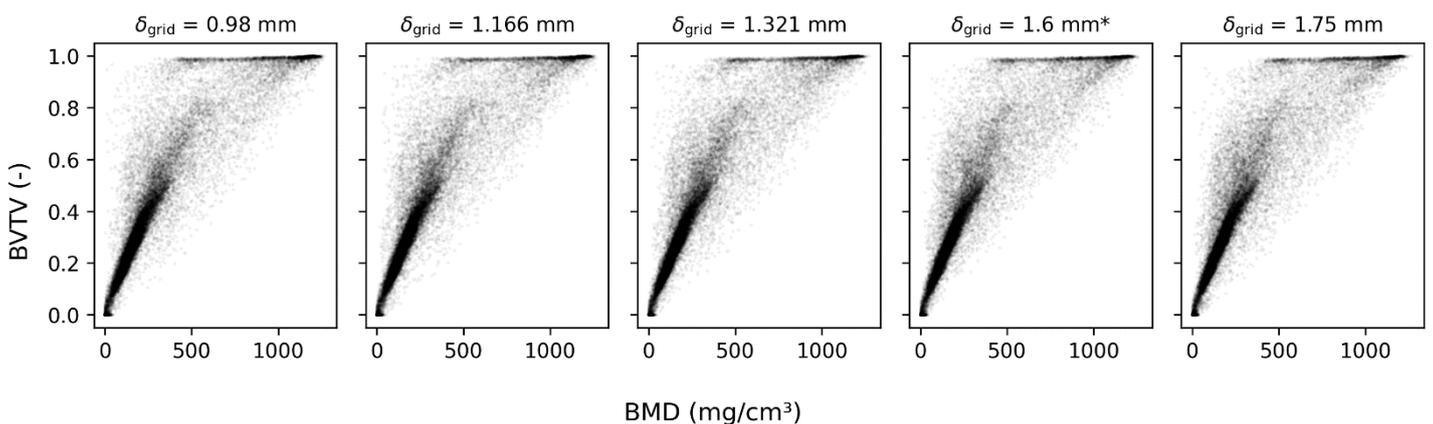

Figure 7: Results for constant VOI size D_{VOI} = 3.6 mm for a single image. Model with asterisk (*) marks the value that was finally used.