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Generation of 3D shape, density, cortical thickness and finite element mesh of proximal femur from a DXA image

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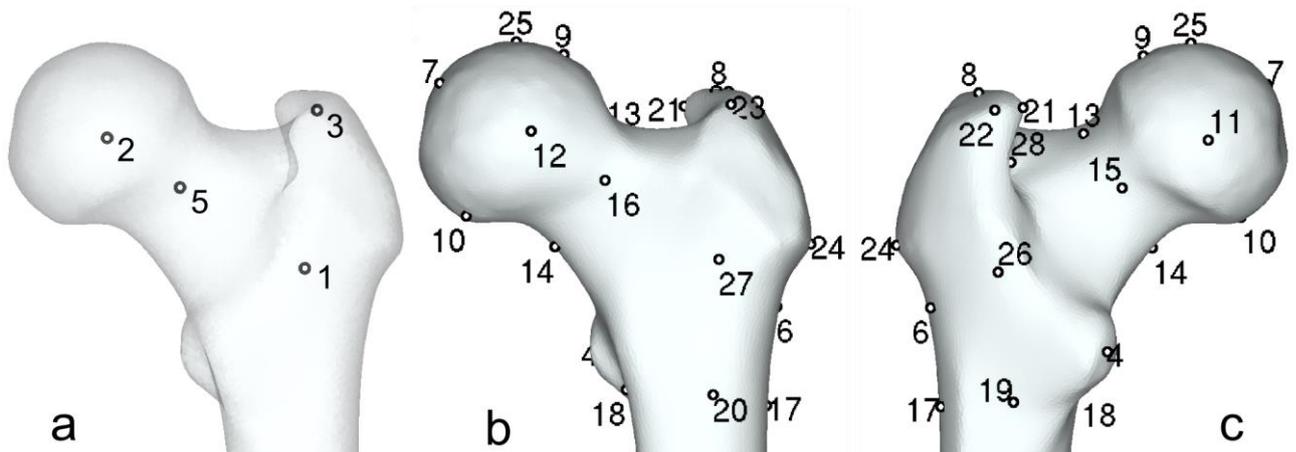http://dx.doi.org/10.1016/j.media.2015.06.001

Landmarks on femur

Supplementary figure S1: Landmarks on the femur: a) Landmarks inside femur, b) landmarks on the anterior surface, c) landmarks on the posterior surface.

Landmarks were set on the femur with an automatic code, which was developed in our earlier study using Matlab (Väänänen et al., 2012). Each landmark position is defined as follows:

1. Cutting point of the shaft and neck axes.
2. Centre of the femoral head, i.e., centre of the largest ball that could be fitted inside the head.
3. Centre of the major trochanter tip. The location was defined based on the superior–inferior (S-I), anterior– posterior (A-P) and medial–lateral (M-L) axes. S-I axis: midpoint between the neck valley and the most superior point of the major trochanter. A-P and M-L axes: slices from tip to S-I axis location were summed, this combined 2D image was converted to a binary image, and its centroid was calculated.
4. Tip of the minor trochanter, i.e., the furthest point from the shaft axis at the area of minor trochanter.
5. Centre of the neck, i.e., centre of the slice with the smallest area perpendicular to the neck axis (identified iteratively).
6. Intersection of the neck axis and femur surface at trochanteric area.
7. Intersection of the neck axis and surface at the area of the femoral head.
8. Intersection of the shaft axis and femur surface at trochanteric area.
9–12. Landmarks located at the surface of the femoral head perpendicularly to the neck and shaft axes from the centre of the head (second landmark). Locations were superior, inferior, posterior and anterior from the centre of the head, respectively.
13–16. Landmarks located at the surface of the femoral neck perpendicularly to the neck and shaft axes at the location of the neck centre (landmark 5). Locations were superior, inferior, posterior and anterior from centre of neck, respectively.
17–20. Landmarks located at the surface of the femoral shaft perpendicularly to the shaft axis 21mm below the tip of the minor trochanter (landmark 4). Locations were lateral, medial, posterior and anterior from the shaft axis, respectively.

21. Medial tip of the superior part of major trochanter. Defined by the shortest distance to the major trochanter from the posterior–superior side of the femoral head.
22. Posterior–superior point of the major trochanter. Defined by the shortest distance to the surface of the major trochanter from point (P-A, M-L, S-I) (half of the length of the neck axis from the most posterior point of the femur, coordinate 2 of landmark 8, coordinate 3 of landmark 8 subtracted by third of the length of the neck axis).
23. Medial-superior point of the major trochanter. Defined by the shortest distance to the surface of the major trochanter from point (P-A, M-L, S-I) (one-third of the length of the neck axis from the most medial point of the femur, coordinate 2 of landmark 8, coordinate 3 of landmark 8 subtracted by half of the length of the neck axis).
24. The most lateral point of the major trochanter.
25. The most superior point of the head.
26. Posterior surface of the femur from landmark 1.
27. Anterior surface from landmark 1.
28. The medial-superior aspect, at the junction between the major trochanter and the femoral neck.

The automatic code sets the landmarks by following similar rules. Some specifications: Landmark 2 (centre of the femoral head) was the first located landmark. It was located by calculating distance transformation for the segmented femoral CT image (function bwdist in Matlab). The landmark was located on the voxel where the Euclidean distance to femoral surface was the largest.

The neck axis was then determined based on the centre of the femoral head (landmark 2) and by finding the centres of the slices at the neck region. A line was fitted along these points. The neck axis was aligned horizontally and the centre points of the neck were located again. This was iterated until the search converged.

The shaft axis was determined based on the landmark 3 (centre of the major trochanter tip, located similarly as defined above) and the centre of the shaft below minor trochanter. The shaft centre was located from the axial slice where the bone intersection was round and the cortex started to thicken on all sides, *i.e.*, below minor trochanter.

The algorithm automatically located the remaining landmarks similarly as they were defined in our previous paper and above (Väänänen et al., 2012).

Landmarks on pelvis
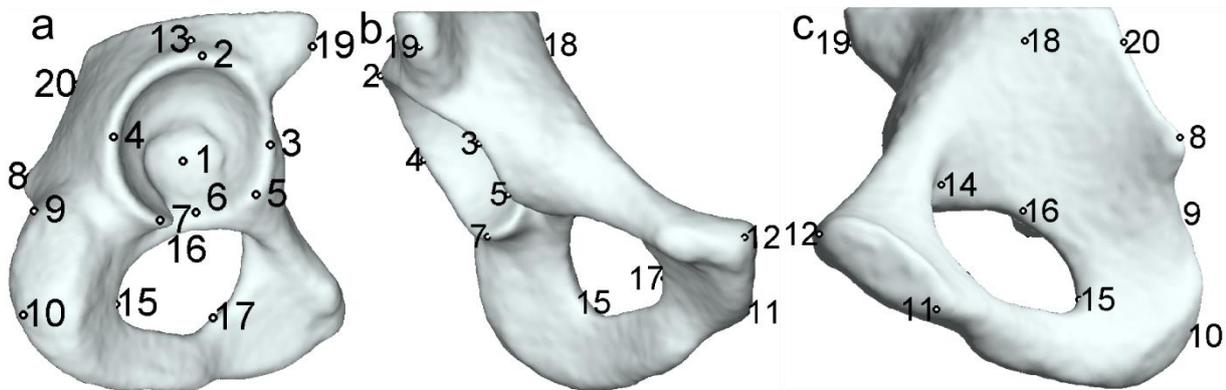
Supplementary figure S2: Landmarks on the pelvis

Landmarks 1-12 and 14-17 on the pelvis were set manually around the acetabulum using a custom-made GUI tool in Matlab. The GUI guided the user through the landmark positioning. Then, landmarks 13 and 18-20 were set automatically on the axial plane 5 mm above landmark 2. Landmark 19 and 20 were located on the extreme ends of the surface, and landmarks 13 and 18 on the intersection of the axial plane and a second plane which went through landmarks 1, 2 and 6.

Supplementary results
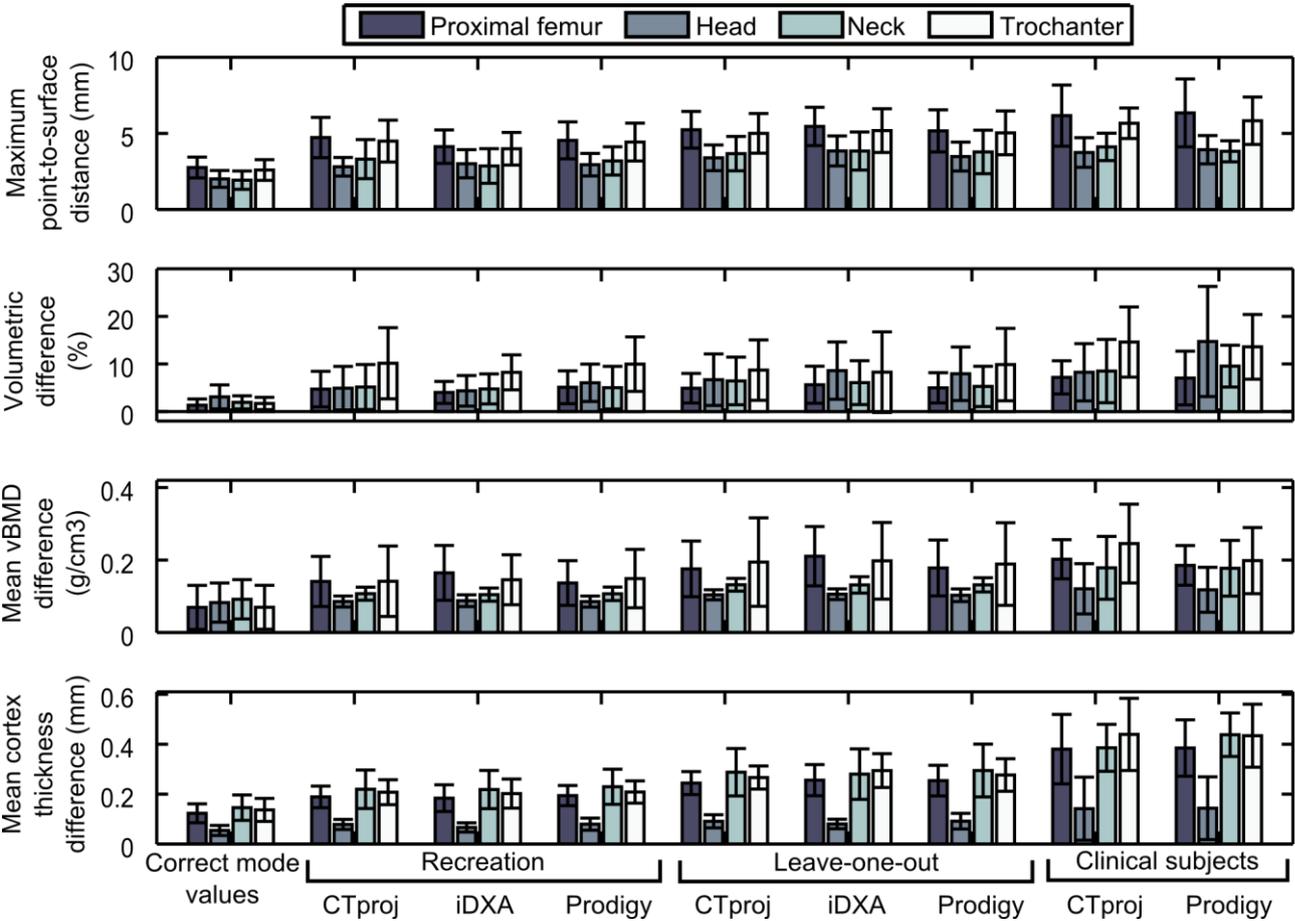
Supplementary figure S3. Accumulation of the error during reconstruction measured with different parameters

References

Väänänen, S.P., Jurvelin, J.S., Isaksson, H., 2012. Estimation of 3-D shape, internal density and mechanics of proximal femur by combining bone mineral density images with shape and density templates. Biomech. Model. Mechanobiol. 11, 791–800.