3D PERSONALIZED RECONSTRUCTION OF PROXIMAL FEMUR FROM BI-PLANAR DXA IMAGES

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INTRODUCTION

Osteporosis is a major public health problem (Melton LJ III, 1993). The current definition of this disease is based on bone mineral density (BMD g/cm²) measured by Dual energy X-ray Absorptiometry (DXA). BMD has proven to be an important factor for hip fracture risk in clinical studies (Greenspan SL. et al, 1994; Cummings SR. et al, 1993), but not the only one. Other structural factors such as bone micro and macro-architecture independently affect bone resistance (Genant HK. et al, 1996).

Bone macro-architecture has already been evaluated using 2 dimensional images, either on X-ray films or on DXA scans (Glüer C. et al, 1994; Faulkner K. et al, 1993). Several geometric parameters have been evaluated as hip axis length (HAL), femoral neck axis length (FNAL), femoral neck diameter, femoral shaft width, neck-shaft angle, cortical wall thickness of the femoral neck and diaphysis,… Many of these 2D structural parameters predict fracture and some independently of BMD results (Glüer C. et al; 1994; Faulkner K. et al, 1993; Gnudi S. et al, 1999) but their 3D evaluation would be more precise.

Recent advances in stereoradiographic reconstruction technique allow obtaining 3D bone structure geometry from 2D-contours identified on bi-planar radiographs (Laporte S. et al, 2003). This 3D reconstruction method called Non Stereo-Corresponding Contour algorithm, i.e. NSCC, has already been applied on the distal femur, using conventional X-rays, with accuracy close to that obtained using 3D CT-scan reconstruction. This algorithm is based on the deformation of a 3D model relatively to identified 2D radiographic contours.

The aims of this study are, 1) to apply and validate this 3D reconstruction method on proximal femur, and 2) to perform this method for 3D reconstruction from bi-planar images provided by a DXA device. (Delphi W, Hologic Inc., USA).

METHODS

28 excised non-pathologic human proximal femurs were considered (23 female, 5 male) from 54 to 103 years old subjects (mean age 84 ± 13 years) provided by the Institut d'Anatomie René Descartes (Paris, France).

3D CT-Scan reconstructions: The 28 proximal femurs were investigated using a multislice CT-scan device (Somatom Plus 4, Volume Zoom, SIEMENS, Germany) at the radiology department of Lariboisière hospital (Paris, France). Proximal femurs were scanned in water to avoid image reconstruction artefacts. Examination consisted of a scout view, selection of the examination volume, image acquisition and reconstruction. Image acquisition parameters were 140 kVp, 300 mAs, pitch 0.75. Axial image of 1.25 mm thickness were reconstructed each 0.7 mm, with a 'bone' filter and a 130 mm field of view. CT-scan images obtained had a pixel resolution of approximately 0.25 mm.

The three-dimensional reconstructions were obtained using the SliceOmatic® software. An automatic segmentation of grey level and a manual correction of potential segmentation errors were performed to identify all bone voxels in each slice. Finally, the CT-scan slices were piled and 3D femur reconstructions, containing up to approximately 10000 points, were obtained. Thus, a three-dimensional reconstruction reference was obtained for each proximal femur. The accuracy of this technique was evaluated to be ± 1mm (Landry et al, 1997).

Moreover, the generic proximal femur mesh (12239 nodes), representing the structure shape used in NSCC was obtained with a similar CT-scan protocol applied on an another proximal femur (female, 89 years).

9 anatomic areas enable to generate 3D contours were defined from this generic object (Figure 1): femoral head, superior and inferior femoral neck, greater trochanter, lesser trochanter, medial, lateral, anterior and posterior parts (halves) of the femoral diaphysis . For each of these areas, 3D contours were associated.

3D DXA reconstructions

DXA acquisitions of the whole sample were performed at the rheumatology department of Cochin hospital (Paris, France)

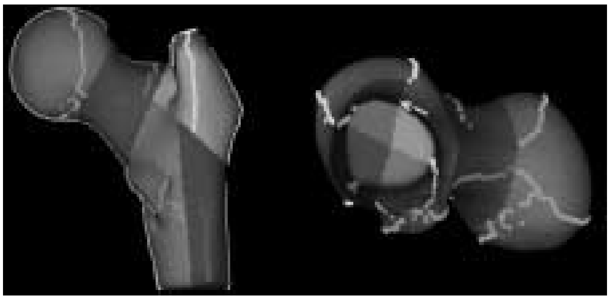

Figure 1: Representation of the anatomic areas defined on the 3D generic model (left : postero-anterior view - right: view from below). On this figure, 3D model contours are generated as if they were projected on frontal and lateral views.

First of all, a DXA spatial calibration environment was performed before proximal femur acquisitions. This step is necessary to apply the 3D NSCC reconstruction method. The calibrating object, required to calculate a set of geometrical parameters of the DXA environment, was a box composed of four Plexiglas plates containing 80 calibrating metallic spherical beads (0.7 mm in diameter) of known 3D co-ordinates, previously measured by means of a 3D measuring device with an accuracy of ± 0.01 mm. A calibration algorithm based on the DLT (Selvik G. et al, 1976; Dansereau J. et Stokes IAF., 1988) and modified to fit to the specificity of the system (linear scanning) was applied to obtain the 3D parameters of the DXA device. As the DXA device used did not have a C-arm for lateral incidence, the consecutive frontal and lateral acquisitions of the calibrating box were performed thank to a device allowing a 90° rotation around an axis parallel to the scanning direction.

Secondly, each proximal femur was fixed by the femoral shaft on the device previously described with paying attention to the femoral neck axis parallel to the examination table. Then, a linear scanning of each specimen was performed in two orthogonal incidences (frontal and lateral views). Soft tissues X-ray attenuation was simulated by immersing specimens in a 14 cm depth water bath.

From both DXA images, 2D contours (corresponding to the anatomic areas defined on the generic object) were identified semi-automatically by mean of active contours (Kauffmann C. et al., 1998) (Figure 2).

- 7 contours on the frontal view corresponding to femoral head, inferior femoral neck, superior femoral neck, medial diaphysis, external diaphysis, greater trochanter and lesser trochanter.

- 6 contours on the lateral view corresponding to femoral head, femoral neck, anterior diaphysis, posterior diaphysis, greater trochanter and lesser trochanter.

Figure 2: Contour identifications on lateral and frontal DXA images.

Finally, the NSCC algorithm performs an elastic deformation of the generic object to fit its 3D retro-projected contours with identified contours.

Once the 3D DXA personalized model is reconstructed, an iterative control is performed by visualising the retro-projection of the 3D model on the real femoral contours seen on both DXA images. If the retro-projected contours are close to the real DXA image contours, the 3D model is accepted. If not, identified contours are modified in order to match the retro-projected model contours with the image contours. In case of mismatching between the contours, the 3D model was not accepted and the case was considered as a failure of the method.

Comparison protocol: The accuracy of 3D DXA reconstructions was evaluated in comparison with the CT-scan ones. This comparison consists in superimposing the two models using geometrical transformations (rotation, translation) and a least square matching method (Figure 3).

Results were expressed as point to surface distances: That means that after superimposition, each point of the model (obtained from stereoradiography) is projected on the reference surface (obtained from CT-scan) in order to calculate the point to surface distance (Mitton D., 2000, Mitulescu A. , 2001). Average, 2RMS and maximal point to surface distance values were calculated. 2RMS distances represent the maximal error for 95% of all points, while the maximum distance values represent the isolated extreme values obtained for the entire sample.

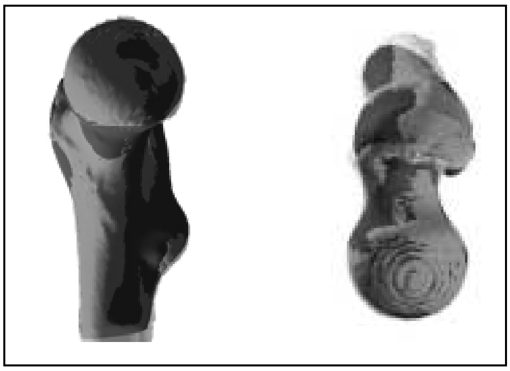

Figure 3: Superimposition of 3D DXA (mauve) and CT-Scan (yellow) reconstructions

RESULTS AND DISCUSSION

The NSCC method succeeded for 25 of the 28 proximal femurs. For 3 specimens, the retro-projected contours of the 3D model did not fit sufficiently with the DXA image contours and so the proposed reconstructions were not accepted.

These 3 failures showed sensitivity of the method to the proximal femur orientation during scanning. For these 3 cases, the specimens were not fixed in real frontal and lateral orientations. Thus, considering a view with a bad lateral orientation of the femoral shaft, the 3D contour of the medial diaphysis area could not generate a 2D contour on the projection plane. So, the association between the contour identified on the DXA “lateral” image and the retro-projected 3D contour could not be possible.

Quantitative comparisons between the CT-scan reference reconstructions and the 3D DXA reconstructions yielded 0.8 mm, 2.1 mm respectively for average and 2RMS errors. Local maximal value reached 7.8 mm on areas as the greater or lesser trochanter, probably due to important anatomical variability at these muscular insertion areas.

This study yields 3D DXA proximal femur reconstructions close to CT-scan ones. This method could allow to calculate 3D structural geometric parameters (femoral neck axis length, femoral neck diameter, femoral head diameter…), which are correlated with mechanical hip strength. Moreover, these parameters could be predictive for a potential osteoporotic hip fracture (Faulkner K. et al, 1993; Glüer C. et al, 1994).

SUMMARY

28 excised non-pathologic human proximal femurs were considered in order to apply and validate a 3D reconstruction method using bi-planar DXA images. This study shows the feasibility and the accuracy (mean distance error = 0.8 mm, 2RMS = 2.1 mm) of NSCC reconstruction technique applied to the proximal femur. Association of 3D

structural parameters with classical densitometric DXA analysis of the proximal femur could provide a new tool to predict in a better way the osteoporotic hip fracture risk

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