A software framework for 3D reconstruction and fracture risk assessment of the proximal femur from dual-energy x-ray absorptiometry

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Objectives

In clinical routine, osteoporosis diagnosis is performed using the areal Bone Mineral Density (aBMD) computed from two-dimensional Dual-energy X-ray Absorptiometry (DXA) images. This measurement of the "projected density" gives a global marker of osteoporosis but is insufficient for an accurate quantification of non-uniform mineral deficiencies. Quantitative Computed Tomography (QCT) is one possible modality for retrieving shape and bone mineral density measurements in 3D, leading to a better characterization of the local bone quality and the fracture risk. However, due to high financial costs and a high radiation dose for the patient, this modality is rarely used in clinical routine for the follow-up of osteoporosis.
In this work we show how state-of-the-art techniques and methods for fracture risk assessment of the proximal femur using 3D analysis from single-view DXA images were brought to the research and clinical end-user, through the use of an existing open source framework for fast prototyping of clinical applications.

Materials and methods

The chosen 3D reconstruction method is the one described in [1]. It uses a statistical model built from a database of QCT scans of proximal femora. Using 3D-3D intensity-based registration methods, a point-to-point correspondence is established between all the femoral shapes and a voxel-to-voxel correspondence is found between the QCT volumes. Principal component analysis is then used to extract the principal modes of variation in terms of shape and BMD distribution. This statistical model is subsequently used to recover a 3D reconstruction from a 2D DXA image. To deal with the overlap between the pelvis and the femur, the operator is asked to manually identify the border of the acetabulum in each of the DXA images and the part of the femur below the lesser trochanter in the frontal DXA image. These points are used to create a binary mask defining the region of interest that will be used in the reconstruction process. Then, in a 3D/2D intensity based-registration process, the statistical model parameters (pose, scale, shape parameters and BMD parameters) are optimized to maximize the similarity between the DXA images and a Digitally Reconstructed Radiograph generated form the projection of the model. This results in a 3D subject-specific reconstruction of the femur represented by a surface mesh and a volume of voxels for the BMD distribution. This method was evaluated using a database of 30 patients with a mean shape accuracy of 1.1mm and errors in terms of BMD distribution of 4.9%.
Then a fracture risk estimation method was developed using a database of groups of patients with and without femoral fracture [2]. A logistic regression analysis was undertaken to evaluate how the shape and density parameters of the 3D reconstruction can discriminate between these two groups. This study showed that combining the areal 2D BMD values with the shape and density model parameters results in an improved discrimination in comparison with areal 2D BMD values alone.
The integration of the method was done in the GIMIAS (Graphical Interface for Medical Image Analysis and Simulation, http://www.gimias.org) framework [3]. Distributed as open source (BSD like license), this

framework allows easy prototyping of medical software by means of state of the art and innovative algorithms in the field of biomedical imaging technologies. The GIMIAS platform provides a complete and extensible set of C++ API libraries covering most aspects of biomedical imaging processing and analysis (from image acquisition to image rendering, via image filtering, characterization and analysis, up to user interface interaction). It encapsulates well known libraries that are standard de facto in this field and specialized algorithms that have been developed on top of them. The platform has been built with the idea of integrating tools, data and models from the VPH community in a common framework, as described in the VPH Vision and Strategy (see [4]). It provides a high level of abstraction that permits an easy management of each tool and facilitates the integration of data obtained from different sources. In this sense, GIMIAS not only permits to easily build an entire and specific medical application, but also to keep this application up to date or extend it, which is a crucial feature in a dynamic and multi-objective environment like clinical research.

Results

The registration algorithms were implemented using standard design patterns provided by the open source ITK library (Kitware, Clifton Park, NY), thus allowing for further reuse in frameworks based on it. They were then wrapped in a GIMIAS plugin. The building of the statistical model is done beforehand by researchers and directly integrated in the software. The clinical users can run the typical workflow which consists in (1) load the input DXA stored using the DICOM format from a local storage, a PACS or an XNAT server, (2) manually create the mask image or load it from file, (3) launch the reconstruction algorithm and finally (4) assess the fracture risk. The user interface is presented in Figure 1.

The software was installed on different machines at CETIR Grup Mèdic (Barcelona, Spain) where clinicians use it in clinical routine, by loading DXA images and calculating the fracture risk. The feedback provided by the clinical use of the software will be used to improve the software prototype, mainly for what concerns usability aspects and clinical relevance in routine practices. From early feedbacks, we can see that the automation of the procedure, the visualization of the 3D shape and bone density and the speed of the reconstruction process (less than 10min) are appreciated. Future work will focus in improving the pre-processing steps (mask creation) and the total process time.

Conclusion

In this work the integration in an open source framework of a state-of-the-art method for reconstructing in 3D the proximal femur DXA images and estimating the femur fracture risk was presented. The open source nature of the GIMIAS framework not only facilitates the understanding of its architecture thanks to the source code access but also benefits the research community via the improvements made to the framework. These improvements are either generic (for example better generic data display) or relate to the specificity of the plugin domain (for example a specific fracture risk display).

This work would not have been feasible in a similar time frame if such a framework had not existed. This proves the value of the development of open source tools that support integrative research and provides an ICT framework for VPH research as stressed by the VPH Vision and Strategy. This vision needs to be strengthened and continued in order for similar initiatives such as the one presented to be possible.

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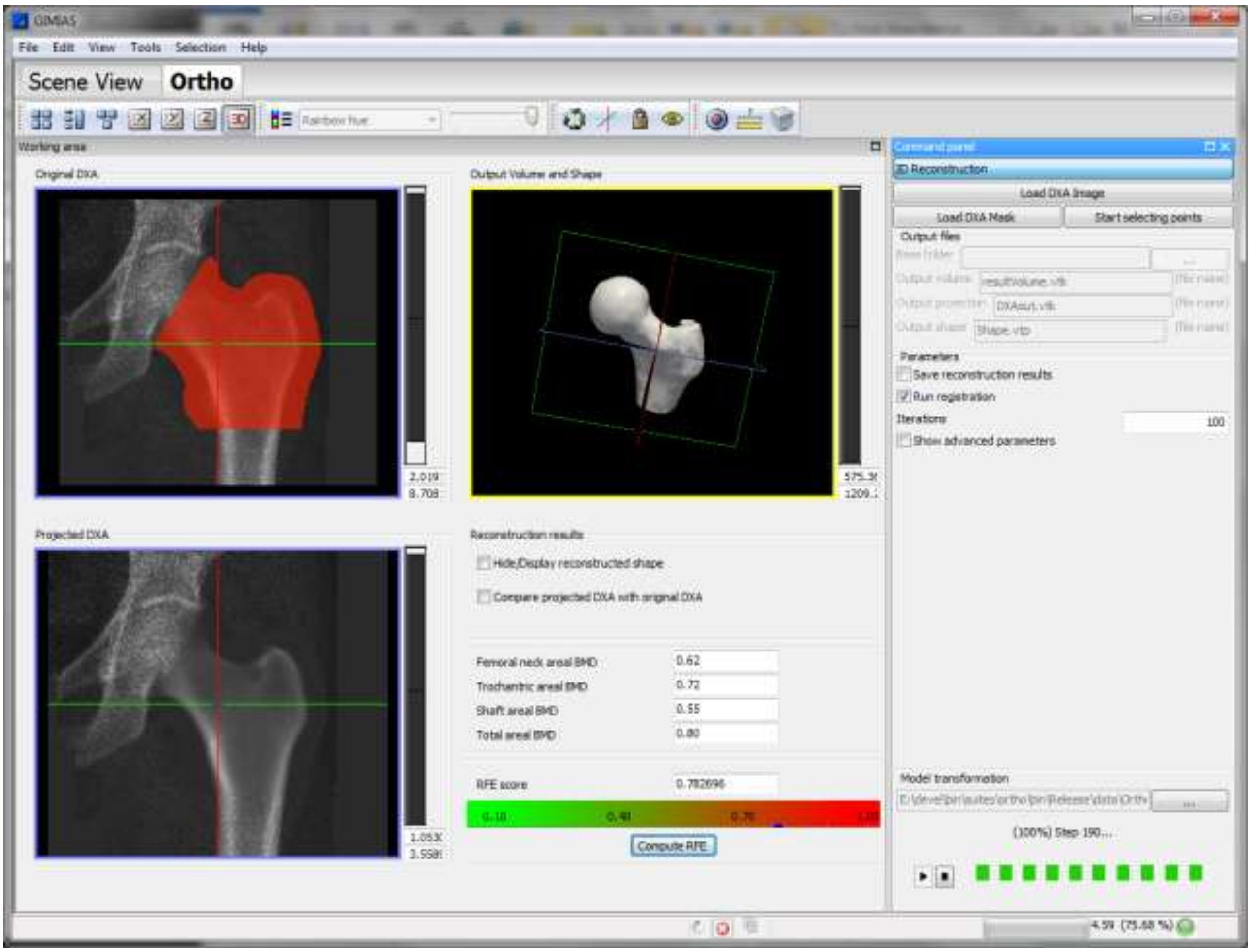

Figure 1: The GIMIAS OrthoPlugin display after 3D reconstruction