A software framework for reconstructing the proximal femur from dual-energy x-ray absorptiometry and assessing the risk of fracture

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Objectives

In clinical routine, osteoporosis is diagnosed using the areal Bone Mineral Density (aBMD) computed from two-dimensional Dual-energy X-ray Absorptiometry (DXA) images. This measurement of the "projected density", however, is insufficient for an accurate quantification of the bone mineral spatial distribution. 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 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 diagnosis of osteoporosis and the assessment of the risk of fracture.
In this work we show how state-of-the-art techniques and methods for fracture risk assessment of the proximal femur using a 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 described in [1]. A statistical model is built from a database of QCT scans of proximal femora. The model incorporates statistical information about the shape variations as well as the variations of the spatial distribution of the bone. This statistical model is subsequently used to recover a 3D reconstruction from a 2D DXA image. To deal with the overlap of the pelvic region, the operator is asked to manually identify the border of the acetabulum in each of the DXA images as well as 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. In a 3D/2D intensity based-registration process, the statistical model parameters (pose, scale, shape and density model parameters) are optimized to maximize the similarity between the DXA images and the projection of the model. This results in a 3D subject-specific reconstruction of the femur represented by a surface mesh and a density volume. 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%.
A fracture risk estimation method was subsequently developed using a database of fracture patients and a control group [2]. A logistic regression analysis was performed to evaluate how the shape and density model parameters of the 3D reconstructions can discriminate between these two groups. This study showed that combining the 2D areal BMD values with the shape and density model parameters results in an improved discrimination in comparison with areal 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 for 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 integrated in the GIMIAS framework as a specific plugin, the OrthoPlugin. The building of the statistical model is done beforehand by researchers and directly integrated into 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 concerning usability aspects and clinical relevance in routine practices. From early feedback, we can see that the automation of the procedure, the visualization of the 3D shape and bone density volume and the speed of the reconstruction process (less than 10min) are greatly appreciated. Future work will focus in improving the pre-processing steps (automatic mask extraction) and the total processing time.

Conclusion

In this work the integration in an open source framework of a state-of-the-art method for reconstructing the proximal femur in 3D from DXA images and estimating the risk of fracture 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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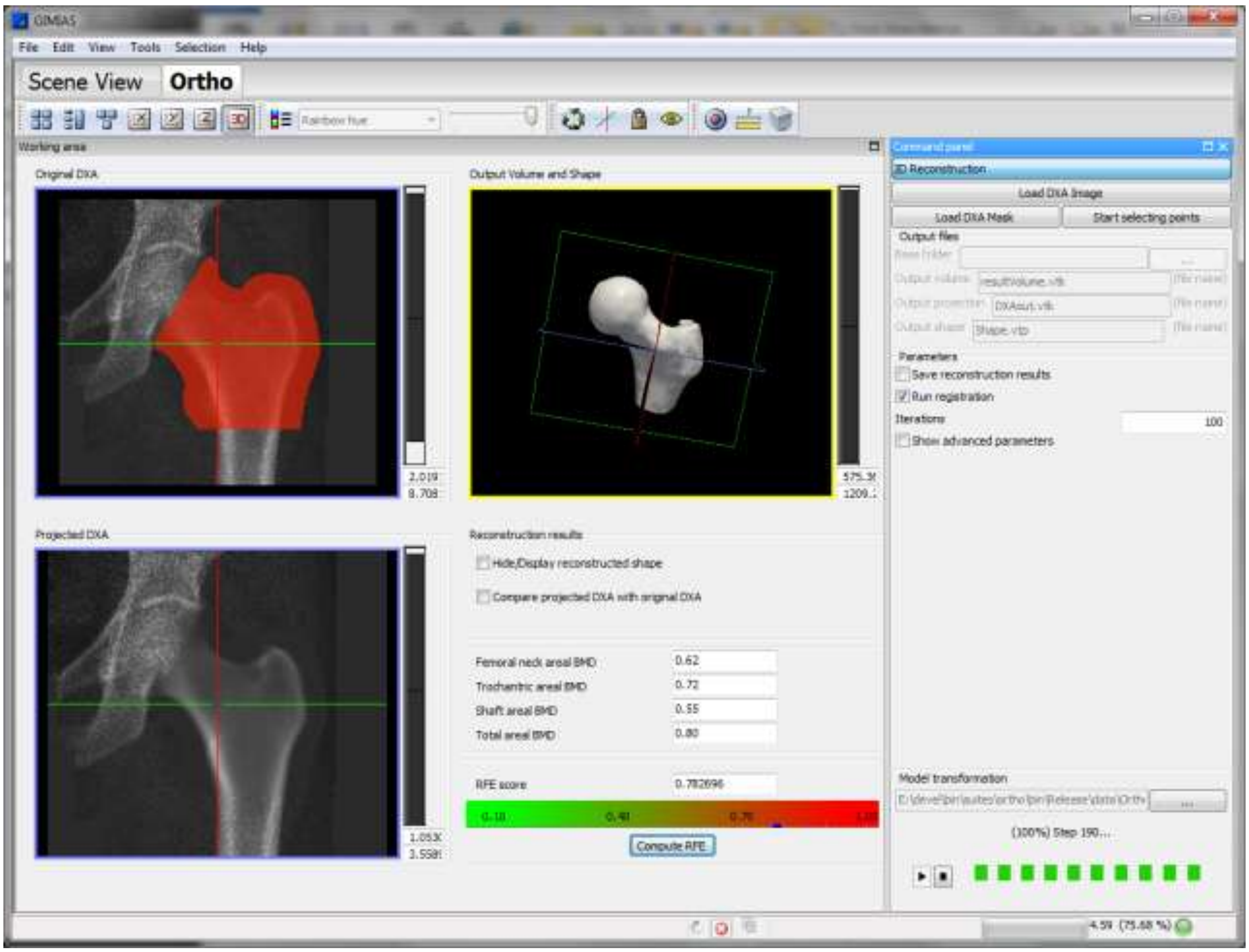

Figure 1: The GIMIAS OrthoPlugin display after 3D reconstruction