A methodology for anatomical 3D modelling of patient's bones from MRI

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Introduction

Periacetabular osteotomy is an accepted surgical procedure to reorient the acetabulum in patients with hip symptoms of mechanical overload, impingement or femoral head instability [1]. For both the diagnosis and the surgical planning, an accurate estimate of the range of motion of the hip is required. A current project of the CO-ME (Computer-aided and Image Guided Medical Interventions) Swiss NCCR (National Centre of Competence in Research) is to create for each patient a virtual hip derived from its static MRI data for anatomical and functional modelling of the lower limb. As a first step of this project, the present study describes a methodology for anatomical modelling of the hip derived from MRI. A Generic model is build and then used as discrete deformable models to reconstruct any individual models automatically.

Methods

<u>Image acquisition</u>

The pelvis and femur of healthy volunteers are imaged in three series using a Philips Intera 1.5T MRI system. A spin echo sequence is defined with TR=578ms, TE=18ms, Matrix/FOV=512x512/40cm and slice thickness=2mm to 10mm. Clinical acquisition time is approximately 40min (5min to set-up the patient, 5 min for the pilot scan and planning, 30 min for the pelvis, femur and knee sequences). This protocol attains excellent contrast between cortical bone and muscles, which is critical for segmentation.

<u>Generic model reconstruction</u>

Segmentation is performed using a discrete snake procedure [2] to extract the contours of bones on every slice. After rigid series registration, iso-surfaces are calculated to provide the anatomical shape. The segmentation is validated by visual inspection. We use four generic models (male and female pelvises and femurs).

<u>Individualized models reconstruction</u>

First, the generic model is elastically initialised with a landmark-based approach and Bookstein's Thin-Plate-Splines interpolation [5]. Then, the model is deformed automatically by minimisation of an energy function which is composed of an external energy term, measuring the matching between the model and image edges, and an internal energy term that maintains a smooth and connected model. External energy is calculated from the MRI oriented gradient images and model normals such as:

$E_{ext} = \sum_{nb\_points} \vec{\nabla}_i . \vec{n}_i$ where $\vec{\nabla}_i$ is the oriented gradient of the image trilinearly interpolated at the point i of the model and $\vec{n}_i$ is the model normal at i.

This energy is minimal when the model is aligned with the limit between cortical and trabecular bone. This is the region of highest contrast, allowing a more accurate and reliable matching. The internal energy derives from deformation spheres that constraint model deformation (see [3] for more details). In order to avoid convergence into local minima, we use a multi-resolution approach [4] and deformation spheres with decreasing radius (the model's deformability increases). The last step is a dilation process that pushes the model towards the limit between bone and surrounding soft-tissues (see Figure 1).

Results

It takes on average one hour for a model with 85,000 vertices to deform (Pentium4, 2GHz). The automatic method has been successfully tested and validated on eight different pelvis and femurs with the same parameters: deformability (radius from 2cm to 1cm), number of iterations (10000), number of landmarks (16) and number of resolutions (3). These parameters were found to produce the more robust results while minimizing manual tasks. We compared manual and automatic segmentation on the four different generic pelvises and femurs by doing cross tests. The average difference is less than 15% of the total number of voxels (see Figures 1 and 2).

Conclusion

We demonstrate a robust method to achieve a general, shape-independent reconstruction anatomical modelling of human bones from 3D MRI datasets that minimises manual tasks. As a potential application, orthopaedists can use these MRI derived models for both preoperative planning and postoperative guides. Joint functional based modelling, which requires precise anatomical models is under investigation within the framework of our project. This work is supported by CO-ME (Computer Aided and Image Guided Medical Interventions) project funded by Swiss National Research Foundation.

References

[1] JG. Hussell, JA. Rodriguez and R. Ganz. Technical complications of the Bernese periacetabular osteotomy. Clin Orthop, (363):81-92, 1999.

[2] M. Kass, A. Witkin, and D. Terzopoulos. Snakes: Active Contour Models. International Journal of Computer Vision, 1, 321-331, 1988.

[3] J. Lötjönen and T. Mäkelä. Segmentation of MR images using deformable models: Application to cardiac images. Int. J. of Bioelectromagnetism, 3(2), 37-45, 2001.

[4] J. Lötjönen, P-J. Reissman, I. E. Magnin and T. Katila, Model Extraction from Magnetic Resonance Volume Data Using the Deformable Pyramid. Medical Image Analysis, 3(4):387-406, 1999.

[5] K. Rohr, H. S. Stiehl, R. Sprengel, W. Beil, T. M. Buzug, J. Weese, M. H. Kuhn. Point-Based Elastic Registration of Medical Image Data Using Approximating Thin-Plate Splines. VBC, 297-306, 1996.

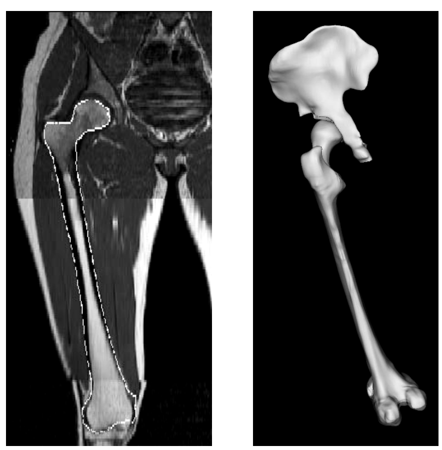

Figure 1: Automatic bone segmentation on a sample slice and corresponding 3D models

Figure 2: difference between manual and automatic segmentation on a sample slice (15%)