Semi-automated Knee Joint Segmentation from Magnetic Resonance Images based on a Subchondral Bone Approach

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Abstract: The aim of this paper is to present the development of a semi-automatic segmentation method for human knee cartilage and bones from magnetic resonance images (MRI). This segmentation process belongs to a higher aim that consists of a 3D simulation of knee joint to find how stresses are distributed in contact regions between cartilages and to quantify them as well as the contact region size. Imaging acquisition was performed in a 3T scanner with high spatial resolution (voxel size 0.293 x 0.293 x 1 mm). This method consists of a 2D segmentation of each sagittal plane and a reconstruction of the volumetric image with the segmented masks.

Keywords: MRI Segmentation, computer vision, cartilage, active contours, region growing.

Introduction

According to recent studies 27 million adults in the U.S. (more than 10% of its adult population) had clinical Osteoarthritis (OA) in 2005, and in 2009 OA was the fourth most common cause of hospitalization [1]. These studies can be extrapolated to other countries and reveal the importance of the OA as a disease. Several studies relate OA with cartilage volume loss [2], which can be displayed accurately from MRI [3] and with mechanical processes [4]. Knowing how stresses are distributed in articular cartilage would help to quantify degeneration processes due to them so it is needed to build an articular cartilage FE model to quantify the stresses. For the first step of this purpose, a segmentation tool has been designed and is presented in this paper.

There are several segmentation methods of articular cartilage [5-7], but, to date, most of them require the active presence of an operator. The segmentation procedure presented in this paper combines the use of Active Contour and Region Growing methods. The first of these methods is the segmentation method itself and the second one is used to MRI preprocessing. The operator's role includes initialization and checking of the segmentation process.

The strength of this method is that not only it allows the segmentation of knee bones and cartilages using a single interface, but it also includes a postprocessing option to match common edges of cartilage and bone. The aim of the segmentation procedure is to segment bone structures and eliminate the associated information of the MRI to improve the cartilage segmentation convergence due to the intensity gradient increase after segmenting and removing bone structures. Postprocessing is a requirement for the finite element (FE) model in order to avoid discontinuities in the load and stress transfer.

Distinguishing between bone or cartilage segmentation requires the study of the Active Contour parameters behaviour to increase the efficiency of the process. Depending on what is being segmented, different parameters are used in the Active Contours method implementation.

The purpose of the semi-automatic segmentation method designed is to obtain 3D knee bone and/or cartilage masks from MRI and process them for volumetric quantification or FE analysis.

This paper is organized as follows. In Section II, first, the raw material of the segmentation is reviewed, that is, DICOM images from magnetic resonance (MR). A general review of the segmentation process designed is also included. Then, special attention is paid to how segmentation methods are implemented. The postprocessing of the segmented masks is also conceptually summarized. In section III, tibial and femoral cartilage and bone segmentation results are presented. In Section IV, results are discussed using qualitative criterion. Finally, some conclusions of the designed segmentation process are drawn.

Materials and methods

The semi automated segmentation was developed in Matlab® and it implements Active Contour Model by Kass et al [8] and seeded Region Growing by Adams et al [9].

The starting point of the segmentation is the DICOM images extracted from MR acquisition. The images series used were acquired in a 3T Achieva TX (Philips

Healthcare, Best, The Netherlands) magnet using an echo time (TE) of 4.429 ms and repetition time (TR) of 20 ms in combination with a flip angle (α) of 15º. The sequence used was a 3D with water excitation technique (Proset®) in order to increase cartilage-bone contrast. The acquisition volume was divided into 63 axial partitions, each one with an in-plane matrix size of 512 x 512 pixels. The size of each voxel is (0.293 x 0.293 x 1) mm. In Figure 1 a DICOM image sample of the set used for knee cartilage and bone segmentation is shown.

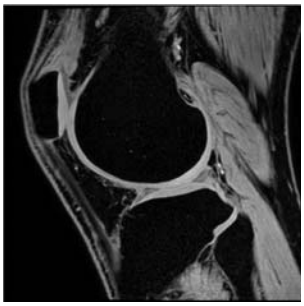

Figure 1: Sagittal acquisition image sample

The semi-automatic segmentation method is summarized in a block diagram (Figure 2) for the sake of clarity.

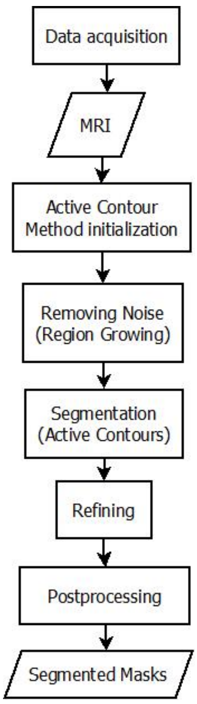

Figure 2: Segmentation process

Active Contours were implemented using *interate* [10] Matlab® function which is based in Kass et al. algorithm [8]. Different Active Contours parameters were used in bone and cartilage segmentation due to their image features (intensity, gradients to be found), summarized in Table 1. An advantage of the designed method is that it uses bone segmentation to improve convergence of the cartilage segmentation by removing bone segmented masks to the MRI to increase edge gradient in cartilage, see Figure 3.

Table 1: Active Contours segmentation parameters.

Parameter	Cartilage	Bone
α	0	0,05
β	0,9	0,9
γ	5	3
κ	0,05	0,09
ω_{line}	0	0
ω_{edge}	2	2,5
ω_{term}	2	1

The active contours parameters were heuristically obtained.

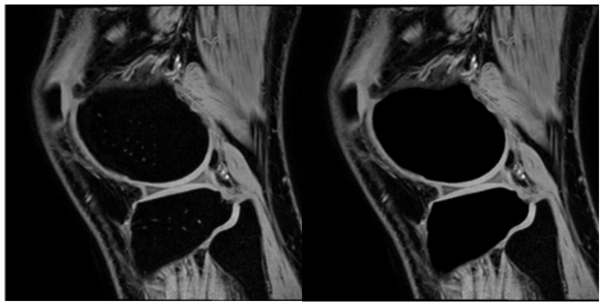

Figure 3: Removing bone structures from MR to improve cartilage segmentation convergence (Left, before. Right, after).

The Seeded Region Growing method developed by Adams et al [9] was implemented by the Matlab® function *regionGrowing.m* [11].
A fine segmentation correction was applied in order to match common edges of cartilage and bone. The method consists of cartilage limits detection, connecting them to the centroid of the bone's mask and substracting them to match edges in each slice as it is shown in
Figure 4.

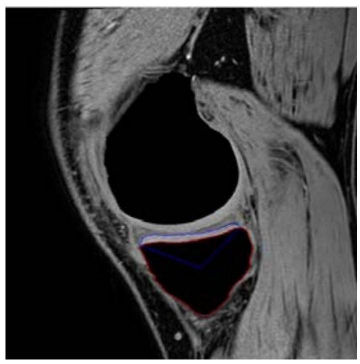

Figure 4: Masks fine segmentation processing.

Results

The edges of the segmented masks can be appreciated in Figure 5. The method permitted the effective segmentation of knee bone and cartilage structures from different patients. The method semi-automatically detects and generates the contours of cartilage (red) and bone (green).

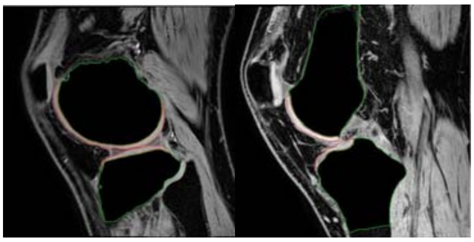

Figure 5: Segmentation results for bone and cartilage

Furthermore, volume reconstruction from segmentation results can be obtained in order to graphically depict appropriateness of segmentation.

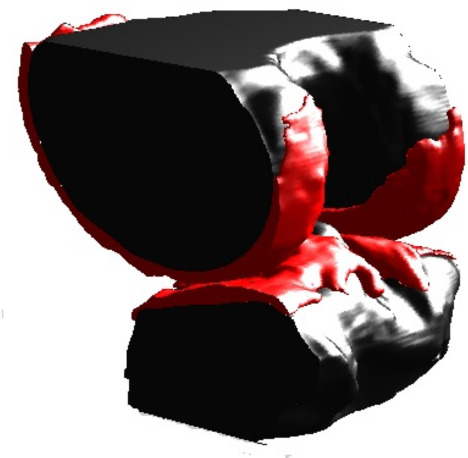

Figure 6: 3D segmented volume reconstruction of the knee joint.

Discussion

Because of the lack of ground-truth to compare with, results are assessed qualitatively using the following criteria:

- Level of accuracy on edge detection.
- Matching common edges between cartilage and bone.

The accuracy of the segmentation method and the fine edge matching algorithm between bone and tissue cartilage can be appreciated in figure 7.

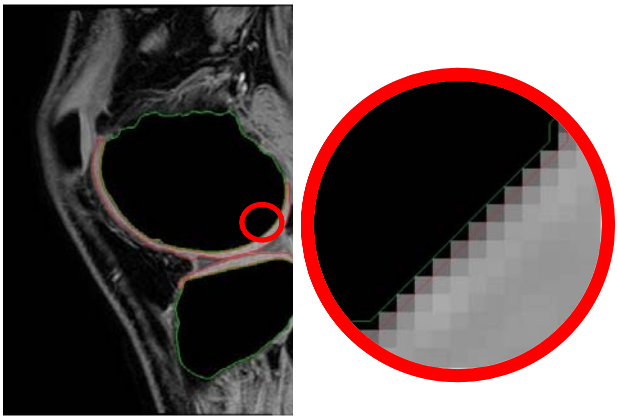

Figure 7: Common edges detail

These segmentation results of the contour details were as accurate as required for FE contact modelling. The main advantage of the method is that improves edge cartilage detection by removing knee bone structures. As a future work, it is proposed to optimise Active Contour parameters by comparing the method to the ground truth and using the designed method and increase automation of the process.

To conclude, the method developed allows for a fast an efficient way of extracting the bone and cartilage knee geometries with minimal user interaction. This method will have a direct application in the development of patient-specific biomechanical simulations of knee joint.

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