Gradient-Field-Based MRI Knee Cartilage Segmentation Algorithm with Self Correction

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Introduction

Knee osteoarthritis (OA) is a chronic disorder characterized by degeneration of the joint cartilage, which in severe cases causes the bones to rub against each other and consequently stiffness, pain, and loss of movement in the joint. Magnetic resonance imaging in comparison to plain radiography provides a unique tool for evaluating changes in cartilage morphology and biochemical composition. However, in order to perform such quantification, knee cartilage has to be segmented. Although many different approaches have been reported in the literature, knee cartilage segmentation is still under constant research and improvement. In this work a new semi-automatic cartilage segmentation technique is presented. The main characteristic of the technique is that it has a self correction component that drastically reduces the user interaction.

Methodology

A semi-automatic algorithm was developed based on Bezier splines that move towards the cartilage edges by the influence of external forces resulting from gradient fields. A self correction algorithm was also implemented based on local changes in cartilage thickness between slices. The cartilage segmentation was performed using two different splines, one for the bone-cartilage interface (cAB), and other for the articular surface (AC).

The cAB was initially extracted by Canny edge detection (Fig. 1a), and it was delimited by two clicks given by the user, which was the only requested user interaction (Fig. 1b) Exploiting the physical characteristic of the cartilage, on which the cAB and AC are close to each other and have similar lengths, the cAB previously extracted was used as initialization for the AC spline. In order to fit the cAB spline into the AC, 2D median filtering and confidence levels [1] were used to enhance the gradient of pixel intensities. The first order gradient was obtained to move the control points of the spline defining the cAB to the center of the cartilage, and the second order gradient was used to adjust their positions in the AC after control point shifting. A combination of gradients and local thickness changes were used for self correction, since as is shown in Fig.2 for 4 subjects, the mean cartilage thickness does not change dramatically between consecutive slices. Cartilage thickness in 2D was calculated for each control point and compared to the thickness of the closest point (not necessarily a control point) in the spline of the closest segmented slice. If a large change existed in the thickness value, the control point was moved from the cAB to a distance equal to the corresponding thickness value in the reference slice and then readjusted based on gradients of pixel intensities. These gradients were the result of filtering the image with a 2D median filter in order to minimally distort the edge positions. The user had the opportunity of adjusting the segmentations at any time.

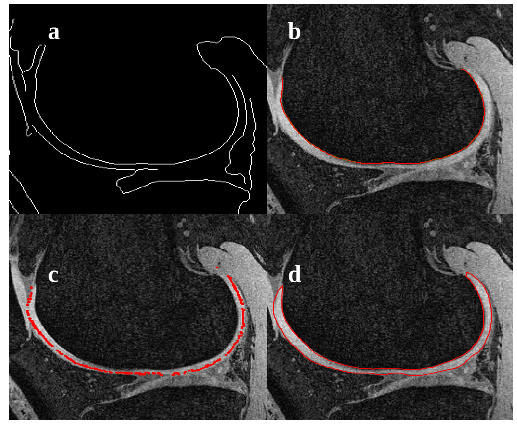

Fig. 1. a) Canny Edge Detector Output, b) Correlation with image, c) Movement with 1st order gradient and shifting, d) Corrections with reference.

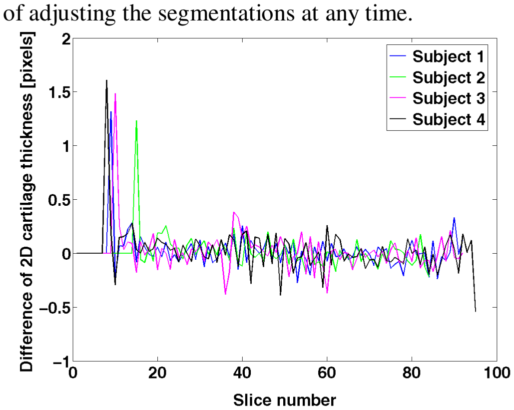

Fig. 2. Difference of 2D thickness values between consecutive slices.

TABLE 1 THICKNESS AND VOLUME CV		
Compartment	Thickness CV [%]	Volume CV [%]
Patella	1.48	2.55
Condyle	1.35	2.55
Lateral Tibia	1.10	1.73
Medial Tibia	0.97	1.99
All	0.57	1.69

The algorithm was implemented in MATLAB (The Mathworks, Inc. Natick, MA), and tested on MR images of 10 human knees with different grades of OA based on the Kellgren-Lawrence (KL) score (n=6, KL=1-2; n=3, KL=3; n=1, KL=4). The set of images was acquired on the sagittal plane with a fat suppressed (fs) spoiled gradient-recalled echo (SPGR) pulse sequence and parallel imaging (ASSET) with an acceleration factor R = 2, and in plane resolution of 0.312 mm x 0.312 mm with slice thickness of 1mm.

Cartilage was segmented twice and 3D cartilage thickness and volume were computed in order to assess the reproducibility of the proposed technique.

Results and discussion

A semi-automatic knee cartilage segmentation technique with reduced user interaction and high precision was developed, making segmentation time shorter than manual. The self correction algorithm based on contiguous local cartilage thickness values showed robustness as demonstrated by the global coefficients of variation (CV) [2], which were 0.57% for global cartilage thickness and 1.69% for global cartilage volume. The results by anatomical compartment are shown in Table 1. As observed, the largest CVs by compartment correspond to the patella and the femoral condyles, where sometimes even in manual segmentation it is hard to tell the position of the edge due to cartilage-cartilage and cartilage-muscle low contrast boundaries. However, results are well in agreement to those previously published in the literature for manual cartilage segmentation, and even better especially for cartilage volume. Current work is focused in testing the accuracy of the technique based on images of porcine knees.

References

[1] Shen D., et al. *IEEE Trans. on Medical Imaging.* 20(4): 257-270. [2] Glüer C.-C. et al. *Osteoporosis International*. 5(262-270).