MRI cartilage of the knee: segmentation, analysis, and visualization.

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Introduction.

A common manifestation of osteoarthritis (OA) of the knee is the morphological degeneration of articular cartilage. Magnetic resonance imaging (MRI) offers the potential to visualize and analyze quantitatively those changes in vivo. The common process follows the path of acquisition, segmentation, analysis, and visualization. The purpose of this study was to develop new techniques for the last three steps to quantitatively characterize the cartilage of the knee in 3D. The segmentation method was semi-automatic and based on Bezier splines and a Laplacian of Gaussian filter. Quantitative analysis in 3D of the segmented cartilage was then performed by the calculation of its thickness and volume. The thickness measurement technique presented in this abstract has subpixel accuracy, and it is automatic and based on the Euclidean distance transform (EDT) after shape-based interpolation has been performed on the segmented cartilage to get quasi-isotropic voxels. Visualization of quantitative data offers an additional tool to characterize the degeneration of articular cartilage of OA patients. In this work 1D and 3D techniques to visualize 3D thickness maps are also presented.

Materials and methods.

Sagittal 3D SPGR MR images of the knee were acquired at 1.5T (Signa scanner; GE Medical Systems, Milwaukee, WI) using a phased array surface coil. Images were acquired with the following parameters applying fat saturation: TI/TR/TE/º = 8/ 30 / 3.3 ms/ 30º, 60 slices, slice thickness = 2mm, matrix size = 512x512, with in-plane resolution of 0.235 mm. Images were coil corrected with an in-house algorithm and a graphical user interface (GUI) was developed which let the user place points interactively close to the cartilage contours to create Bezier splines (Fig. 1) . In order to enhance the cartilage edges the anisotropic diffusion algorithm (λ = 0.25, K = 80, 3 iterations) was applied [1] and edges were detected after filtering the image with a Laplacian of Gaussian (LOG) filter. The position of the control points of the Bezier splines was then automatically adjusted to overlap the closest edges on their local neighborhood (7x7 pixels) giving the opportunity to the user of manually adjust no satisfactory final positions to segment the cartilage (Fig. 1) . Splines were then copied to the next slice and adjusted automatically to the edges to reduce user interaction. After cartilage was segmented out of all slices of interest, shape-based interpolation was performed to get quasi-isotropic voxels before cartilage thickness and volume calculation. Discrete [2] and continuous [3] shape-based interpolation techniques were tested out. Due to the characteristic thin shape of cartilage, some segments were lost with the discrete morphological method even after centralization was performed as suggested in [4]. So a technique based on [3] was developed and employed to get a final through-plane resolution of 0.25 mm. This method consisted in the interpolation of shape based on splines, which required a one to one correspondence between control points of contours at different slices. Because the GUI let the user create Bezier splines with different number of control points, all contours were re-sampled and represented with the same number of points for analysis purposes. Then an artificial matching of points at different slices was performed based on their relative position to their respective end points. After shape was interpolated based on splines, minimum 3D Euclidean distances (EDT) between the Bezier splines defining the articular cartilage and the bone-cartilage interface were obtained. The articular cartilage contour was considered as reference because Lösch et al showed in [5] that this method was superior for the delineation of focal cartilage lesions, i.e. the EDT was applied to the bone-cartilage interface and the distances were read out at the articular cartilage contour. The last step of the analysis consisted in the cartilage volume measurement which was calculated based on the pixels enclosed by the splines in the whole interpolated volume. Because visualization of MR images is commonly perform in a slice by slice basis, besides a 3D quantitative visualization based on the *surface* function of MATLAB (The Mathworks, Inc. Natick, MA) where each cartilage point was represented in 3D with a different color with rotation and zoom options (Fig 1), a 1D visualization tool was developed to look at 3D information in slice by slice basis. In this method each point of the articular cartilage of the slice of interest was assigned a different color according to the results of the 3D EDT and a color bar with the thickness in mm was plotted for reference purposes (Fig 1).

Results and Discussion.

Degeneration of articular cartilage is a common manifestation of OA of the knee and MRI is able to depict and quantify this condition in vivo. In this work we have described a process to accomplish such a goal with subpixel accuracy. The implementation of a LOG filter for edge detection after smoothing the image with anisotropic diffusion had the objective of increasing reproducibility of the final analysis. Although shape–based interpolation based on the work presented in [3] performed better than the discrete morphological method, it also had some limitations. Interpolation between slices where the corresponding end points of the consecutive splines were far away from each other failed and yielded unrealistic results. This is an effect of the artificial point matching that can, and will be solved by an adaptive point matching, i.e. a matching technique that will depend on the distances of the corresponding spline end points and on the distance between the new interpolated slice and the two surrounding slices. Visualization of quantitative data is essential in the assessment of OA levels and we have presented visualization tools that are easy to implement and that allow the depiction of 3D cartilage thickness maps in 1D and 3D.

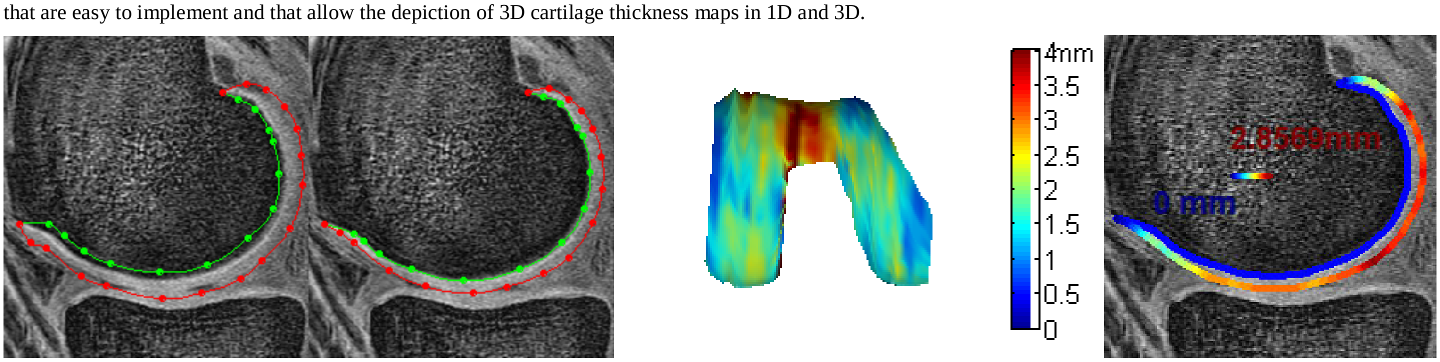

Fig. 1. Splines placed by the user; splines adjusted first by edge detection based on LOG and then by manual interaction; 3D and 1D thickness visualization.

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