Active Contours and Statistical Shape Knowledge: An Automatic Solution for Segmentation of Articular Cartilage from MR Images which have a Partial Loss of Boundaries

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Introduction

Since the early 1990's, several studies have been published on the detection and quantification of lesions or slow progressive changes in articular cartilage from MR Images. A key factor on such studies is the influence of image artefacts on the image segmentation techniques used to extract the cartilage from the rest of the articular joint structures. Different segmentation techniques have been implemented (e.g. Region Growing [1], Canny filter Edge Detection [2], Active Shape Models [3], B-Spline Snakes [4]) to reduce the effects of artefacts such as noise, Gibbs ringing, etc. However, volume averaging and the consequently partial loss of boundaries of cartilage surfaces in direct contact (Fig. 1) has been targeted by manual corrections or simply avoided.

We present here a recently developed technique, Diffusion Snakes (DS) [5], which can automatically segment articular cartilage from MRI data sets. Based on the integration of Active Contours and Statistical Shape Knowledge, the DS technique can produce reliable segmentations, even in regions where the boundaries of the cartilage has been partially blurred or removed by the volume averaging effect.

Figure 1: Partial loss of patellar and femoral cartilage boundaries at the patello-femoral joint (axial slice).

Methods

Nine left patellae and two entire left knees from fresh, cadaveric porcine samples were scanned. Images of the patellae were acquired using a Magnex 4.7 T, 16 cm bore magnet (Magnex Scientific, Oxford, UK) linked to a Bruker Pharmascan console operating with Paravision 2.1.1 software (Bruker Medizin Technik, Karlsruhe, Germany); a self-shielded 90 mm gradient set (max gradient 293 mT/m) was used with a 54 mm diameter sine spaced probe. A conventional 3D Gradient Echo fat suppressed protocol was used (TR 60 ms; TE 3.6 ms; flip angle 50°; fat suppression pulse bandwidth 1400 Hz; FOV 60.3 mm x 40.2 mm x 40.2 mm; isotropic res. 328 μm). Images of the entire knees were acquired using an Oxford Instruments 2 T, 100 cm bore magnet linked to a Bruker Medspec AvanceTM S200 console operating with the same Paravision software; a home-built 24 cm gradient set (max gradient 41 mT/m) was used with a 17 cm diameter sine spaced probe. The same 3D Gradient Echo fat suppressed protocol was used with a new set of parameters (TR 50 ms; TE 8.3 ms; flip angle 40°; fat suppression pulse bandwidth 400 Hz; FOV 18 cm x 9 cm x 9 cm; isotropic res. 352 μm).

All the data from the isolated patellae and one of the entire knee data set were used for training purposes; this involved manual land-marking of the patellar cartilage on the middle axial slice with 59 control points as in [3], and loading those landmarks into a training software to obtain the statistical shape characteristics of the cartilage as described in [5]. To assess the reliability of the DS segmentation for extremely blurred cartilage boundaries from MR Images, cartilage regions were corrupted by introducing noise. The pixel intensities of the region corresponding to the entire patello-femoral joint (cartilages and their internal boundaries) were replaced by new intensity values calculated as the weighted sum $(1-\alpha)I + \alpha N(\mu,\sigma)$, were I is the original image; $N(\mu,\sigma)$ is Gaussian noise, with μ and σ being respectively the estimated mean and standard deviation of the cartilage intensity on the original image; and α a corruption constant that had five values 0, 20, 40, 60 and 80 %; this ensured that the resulting corrupted images kept intact all the information from outside the cartilage regions, including the cartilage outer boundaries (Fig. 2). The DS algorithm was evaluated over these five images using two quantitative criteria: computing the segmented area and estimating the mean and standard deviation of the distance between corresponding points on the segmented contour from the original image (α =0%) and the corrupted images (α =20, 40, 60, 80 %). All the training, segmentation and evaluation algorithms were implemented in Matlab (R13, The MathWorks Inc., Natick, 2003).

Figure 2: MR Image with a corrupted patello-femoral joint using weighted noise (α = 80 %).

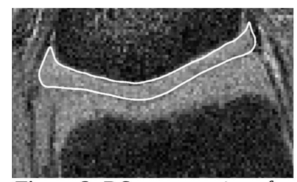

Figure 3: DS segmentation of the patellar cartilage from the reference MR image (α = 0 %).

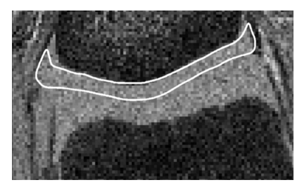

Figure 4: DS segmentation of the patellar cartilage from a corrupted image using weighted noise (α =80 %).

Results

As it can be seen in Fig. 3, DS provide accurate segmentation of the patellar cartilage, even in those regions where the boundaries had been partially blurred or removed by the volume averaging effect in MR Images. The training procedure of DS allows it to recover the blurred boundaries and therefore, to provide segmentations with less than 3% of error in the computed segmented areas and erroneous displacements that are statistically within 1 pixel (Fig. 4 and Table 1).

Conclusion

Although the DS algorithm was trained mostly with MR images from isolated patellae, this is not a requirement. Importantly, the fact that different samples were used for the training procedure (patellae with and without the remainder joint structures), obtained from different magnets, with different image resolutions, SNR and contrasts, demonstrates that the segmentation algorithm is robust, even in the presence of such changes. The integration of a training procedure based of statistical shape knowledge, and the consequent robustness to partial loss of boundaries, is the main characteristic of DS that enable it to produce reliable segmentations of articular cartilage from MR Images.

Table 1: Evaluation of the segmented areas and contour displacements (mean and standard deviation)

noise	area (pixel)	mean dist. (pixel)	std dist. (pixel)
0%	497	-	-
20%	505	0.52	0.20
40%	497	0.58	0.21
60%	489	0.69	0.24
80%	482	0.69	0.30

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