Adaptive Registration of Varying Contrast-Weighted Images for Improved Tissue Characterization (ARCTIC): Application to T_1 mapping

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Target Audience

Scientists and clinicians who are interested in myocardial tissue characterization.

Purpose/Introduction

Myocardial T1 mapping is an emerging technique for the assessment of diffuse interstitial fibrosis. Multiple images are commonly acquired with various T_1-weigthing (T_1w) using a breath-hold ECG-triggered single shot sequence. Pixel-wise T_1 estimation is then performed by fitting T_1-weighted images to the T_1 recovery curve. Despite breath-hold instructions, motion is observed in ~50% of patients due to diaphragmatic drift and the patient's limited breath-holding capability[1]. Registration of each T_1w image can be performed to reduce motion artifacts in T_1 maps but remains challenging due to the high intensity variations among T_1w images[1]. In this study, we propose a novel image-based approach for Adaptive Registration of varying Contrast-weighted Images for Improved Tissue Characterization (ARCTIC) and evaluate its performance for myocardial T_1 mapping applications.

Materials and Methods

Theory: Figure 1 shows the general scheme of the proposed ARCTIC approach. Each T_1w image is individually registered to a common reference T_1w image. The reference image is arbitrary chosen as the 4th image of the series. In the proposed approach, a region of interest (ROI) is first manually drawn around the left ventricle of the reference image (LV-ROI). All subsequent steps are performed automatically. The global affine motion of the left ventricle is first estimated using a region-matching algorithm[2]. Feature points obtained by regular sampling of the LV-ROI contour are then automatically tracked using a region-matching approach restrained to a small ROI centered on each of these points. A simple 2D translational model is estimated for each feature point to maintain the robustness of the estimation. Global affine motion estimate is then refined using a novel local non-rigid motion estimation approach based on an extended optical flow formulation where both motion field and intensity variations are simultaneously estimated[3]. In addition, the displacement of the feature points is used as an additional constraint of the minimization process[2], which results in the following minimization problem:

$$E = \iint_{x,y} \left(\left\| I_x u + I_y v + I_t - c \right\|_2^2 + \alpha^2 \left(\left\| \nabla u \right\|_2^2 + \left\| \nabla v \right\|_2^2 \right) + \beta^2 \left\| \nabla c \right\|_2^2 + \lambda^2 \sum_{i=1}^{N} \left(F(d_i) \left[(u - u_i)^2 + (v - v_i)^2 \right] \right) \right) dxdy$$

where I(x,y,t) is the image series, (u,v) is the motion field, I_x,I_y,I_t are the spatio-temporal gradient of I, (u_i, v_i) is the displacement of the i[th] feature point, F(d_i) is the distance between the pixel of coordinates (x,y) and the i[th] feature point, and α,β,λ are weighting parameters.

Experimental Evaluation: Twenty patients (57±14 y, 12 m) referred for clinical CMR exams were scanned before and after administration of contrast agent. T_1 mapping was performed in 1-3 slices with a 5-(3)-3 scheme for pre-contrast and 4-(1)-3-(1)-2 scheme for early and late post-contrast scans. 85 total T_1 maps were acquired. All T_1 maps were reconstructed with and without motion correction using a 3-point fit model.

Data Analysis: Each T_1w image series was visually assessed for the presence of motion and was subsequently classified as "no motion" or "with motion". To quantify the registration step, the myocardium was manually segmented in all T_1w images and the DICE coefficients were computed between each registered T_1w image and the reference image (1: ideal alignment, 0: none). Overall T_1 map quality and motion artifacts were assessed by a blinded reader using a 4-point scale (0: non diagnostic/severe motion artifact, 4: excellent/no motion artifact).

Results

57% of the T_1w image series were visually identified as "with motion". Figure 2 shows example of an uncorrected/motion corrected pre-contrast image series. Improved alignment of the myocardium across all T_1w images was achieved using the ARCTIC approach. Overall, DICE coefficients were slightly improved in "no motion" series (0.90±0.02 vs. 0.91±0.02, p<0.002) and greatly improved in "with motion" series (0.80±0.14 vs. 0.89±0.03, p<0.001). Figure 3 shows T_1 maps reconstructed with and without motion correction for pre-contrast and post-contrast imaging. Moderate to severe motion artifacts were observed in all uncorrected T_1 maps and was successfully suppressed using the ARCTIC approach. No statistical difference was found in term of overall T_1 map quality before and after correction in "no motion" series After motion correction, improved overall T_1 map quality (2.86±1.04 to 3.49±0.77, p<0.001) and reduced motion artifacts (2.51±0.84 to 3.61±0.64, p<0.001) were obtained in "with motion" series.

Conclusions

A novel approach has been developed for the correction of respiratory-induced motion occurring during breath-hold T_1 mapping sequences. The method provides excellent motion correction for both pre- and post-contrast T_1 mapping, and significantly improves the quality of T_1 maps.

Acknowledgements

The authors acknowledge grant support from NIH R01EB008743-01A2.

References

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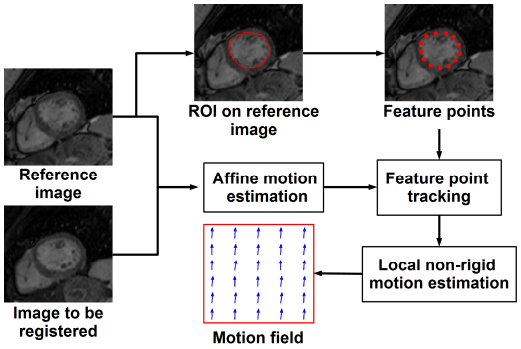

Figure 1. General scheme of the ARCTIC approach.

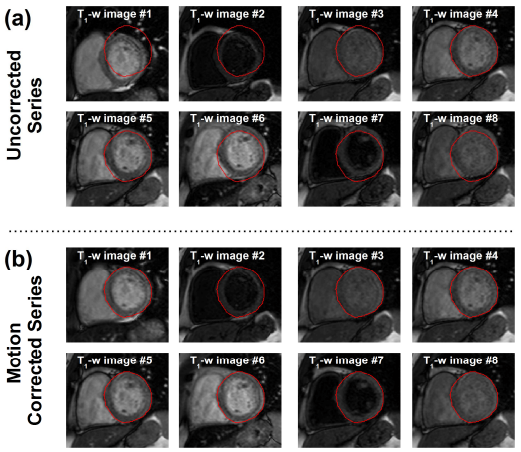

Figure 2. Example of uncorrected (a) and motion corrected (b) image series. The epicardial contour of the reference image (red curve) is reported in all images. Substantial drifting motion in uncorrected images was suppressed with the ARCTIC approach.

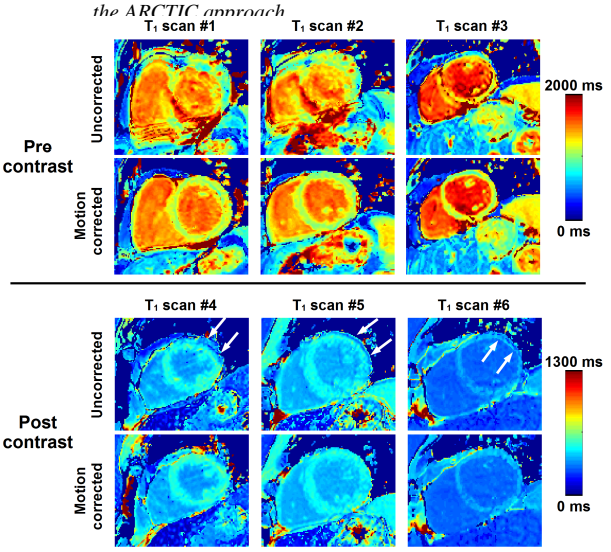

Figure 3. Uncorrected and motion corrected T_1 maps. Motion artifacts in uncorrected T_1 maps were suppressed using the ARCTIC approach.