Automated Segmentation of Left Ventricle in Cine Cardiac MR Images: Experience From a Large Study

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Introduction: To quantitatively analyze global and regional cardiac function from MR, clinical parameters such as ejection fraction (EF) and left ventricular mass are required. These depend upon accurate delineation of endocardial and epicardial contours of the left ventricle (LV). Accurate LV segmentation is acknowledged as a difficult problem because of: 1) the lack of edge information; 2) the shape variability of the endocardial and epicardial contours across slices, phases and subjects. A novel method for the robust, accurate and fully automatic LV segmentation from short axis (SA) cine MR images is presented in this study.

Materials and Methods: Short-axis imaging data (N=147, 40 ischemic heart failure, 33 non-ischemic heart failure, 35 LV hypertrophy and 39 healthy subjects) were acquired on a 1.5T scanner (GE CV/i Excite) with SSFP cine MRI. The segmentation algorithm consists of three stages for each data set. First, the LV center is localized on a mid-ventricular slice in the end-diastolic phase (starting image) by a roundness metric (Fig.1). Second, the endocardial contour is detected by determining an optimal threshold[1] and creating a binary blood pool image; then the endocardial contour is smoothed by applying a fast Fourier transform and filtering (Fig.2). Third, the epicardial contour is detected by mapping the pixels from Cartesian to polar coordinates, then region growing is used to calculate the contour. The contour is then smoothed by the fast Fourier transform approach (Fig.3). In order to quantitatively evaluate the automatically detected endocardial and epicardial contours of the end diastole (ED) and end systole (ES) phases of all slices, five quantitative measures were assessed. *LV located* is the percentage of patients where the centroid of the blood pool is correctly calculated. *Detected* is the percentage of the automatic contours that could be calculated compared with the manual contours. *Good* is the percentage of the detected contours that had average perpendicular distance less than a threshold of 4mm. *Average perpendicular distance* (APD) is the distance from the automated contour to the corresponding manually drawn expert contour, averaged over all contour points. *Dice metric* (DM)[2] is the fractional contour overlap, with higher DM indicating better match between automatic and manual segmentations.

Results: The LV was correctly localized in 91.2% (134/147) studies, with an average computation time of 0.096 s per subject. The LV located percentage, detected percentage, good percentage, APD and DM averaged over slices and ES and ED phases for each pathology group are shown in Table 1. The APD and DM presented in Table 1 only include studies where APD < 4mm. The average computation time of the segmentations was 0.8 s per image for these 147 exams.

Discussion and Conclusions: A limitation of the proposed method is that it cannot segment the LV from the right ventricle if the slice includes the atria. The segmentations of the hypertrophy group have a lower success rate due to the concomitant hypertrophy of the papillary muscles that obscures the endocardial border. Future research will extend the algorithm to handle these cases. In summary, the proposed fully automated segmentation technique is fast, effective and robust and should be of benefit for quantification of cine cardiac MR in clinical practice.

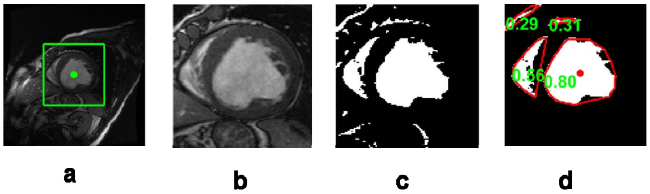

Fig. 1. LV location procedure. a. Target image with rectangular ROI (green box) and image center(green point), b. ROI image, c. Binary image, d. Surviving objects' convex hulls (red) and the corresponding roundness metric(green). The detected LV blood pool centroid is labeled as a red point.

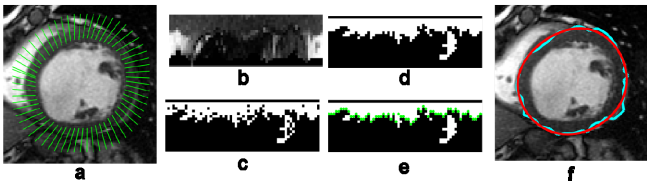

Fig. 3. LV epicardial contour detection procedure. a. Scan lines for mapping the pixels from Cartesian to polar coordinates. b. Result of image transform. c. Region growing binary image. d. Image after filling holes. e. Edge points (green). f. Epicardial contour before (cyan) and after FFT smoothing (red).

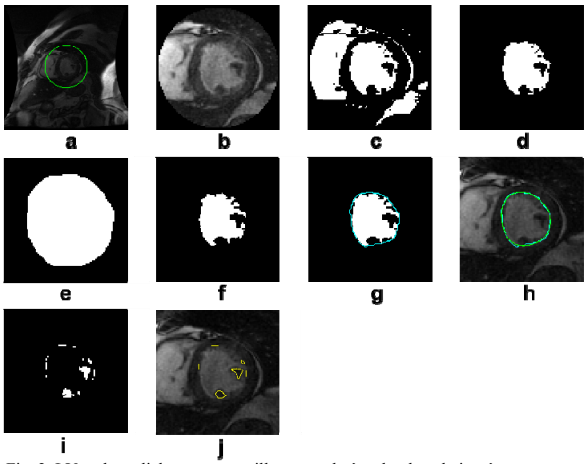

Fig. 2. LV endocardial contour, papillary muscles' and trabeculations' contours detection procedure. a. Image with circle ROI, b. ROI image, c. Binary image, d. Coarse LV blood pool, e. Dilated mask, f. Refined LV blood pool, g. Convex hull of the LV blood pool (cyan), h. Smoothed endocardial contour (green), i. Papillary muscles and trabeculations' mask, j. Papillary muscles and trabeculations' contours (yellow).

Table 1. Segmentation results categorized by pathology group

Patient Group	LV located (%)	Detected (%)		Good (%)		APD (mm)		DM	
		endo	epi	endo	epi	endo	epi	endo	epi
Ischemic heart failure	100 (40/40)	99.1	98.9	84.8	84.9	1.94	1.71	0.92	0.95
Non-ischemic heart failure	90.9 (30/33)	98.1	98.6	74.3	73.3	2.19	1.88	0.91	0.94
Hypertrophy	74.3 (26/35)	94.8	97.5	55.3	59.0	2.70	2.29	0.86	0.93
Healthy	97.4 (38/39)	96.5	97.0	69.9	73.8	1.91	1.71	0.90	0.94
Mean	91.2 (134/147)	97.1	98.0	71.1	72.8	2.19	1.90	0.90	0.94
Std	11.6	1.9	0.9	12.2	10.6	0.36	0.27	0.03	0.01

endo: endocardial, epi: epicardial

[1] Otsu, N., IEEE Trans Systems, Man, and Cybernetics, 9(1), 62-66(1979).
[2] Lynch M., et al., IEEE Trans Med Imaging. 27(2), 195-203(2008).