Automated Segmentation of the Left Ventricle using Myocardial Effusion Threshold Reduction and Intravoxel Computation (METRIC)

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INTRODUCTION: An automated partial voxel left ventricular segmentation algorithm is presented. The algorithm, termed LV-METRIC (Left Ventricular Myocardial Effusion Threshold Reduction with Intravoxel Computation), measures the blood volume of the LV from cardiac cine MRI images, for all phases and slices. Papillary muscle and trabecular muscles are accounted for through partial voxel interpolation. Minimal interaction is required in some basal slices for which the valve plane must be defined.

ALGORITHM: 1) A Hough transform is performed on the subtraction of images from phases 1 and 10 of a mid-ventricular slice (1-4). **2)** Edge-based region-growth is performed to discover the mean and standard deviation (μ_b / σ_b) of full-blood voxels. **3)** A planar surface is fit to full-blood voxels to compensate for coil sensitivity variations. **4)** Successive lower-bound threshold based region-growth processes are run for an iteratively decreasing threshold to estimate the myocardial mean. Eventually, region-growth breaks through the myocardium, "effusing" into surrounding structures. This effusion threshold is strongly related to the mean (μ_m). **5)** The total blood volume is determined by the summation of the histogram multiplied by a linear weighting function between ($\mu_b - 2\sigma_b$) and ($\mu_m + 2\sigma_b$). **6)** The seed point for the next slice or phase is determined by applying an energy function based on distance from the center of the window and the intensity difference from the previous slice's blood mean is applied to each pixel in the window.

MATERIALS AND METHODS: The study included 38 randomly selected patients (15 male, mean age 52.4 years ± 15.1 standard deviation), including 20 referred for clinical cardiac MRI and 18 with normal systolic function (based on a-priori MT). The most common clinical indications for referral were assessment of presence or pattern of myocardial scar. This retrospective study was HIPAA compliant and approved by our IRB. No informed consent was required. Scans were performed using a GE Signa 1.5T scanner, imaging parameters TR 3.3-4.5ms, TE 1.1-2.0ms, flip angle 55-60, matrix size 192x192 – 256x256, image dimensions 256x256, receiver bandwidth 125 kHz, FOV 290-400 x 240-360, slice thickness and slice gap 6-8mm & 2-4mm, respectively (total 10mm). The LV in each patient was imaged in 6-10 slices, 20-28 cardiac phases.

Two LV-METRIC volume measurements were compared to expert manual tracing (MT) measurements in order to assess the influence of partial voxels in volume calculation. In the first measurement, LV-METRIC linearly interpolated the blood content of voxels. In the second, no linear interpolation was performed: all partial-blood voxels are considered full-blood. Manual tracing excluded papillary muscles from the blood volume, and basal slices were defined as the most basal slice containing at least 50% myocardium, according to established criteria (2,3). Basal slice selection did not vary between MT and LV-METRIC. Student's t-test was used to determine statistical significance between measures.

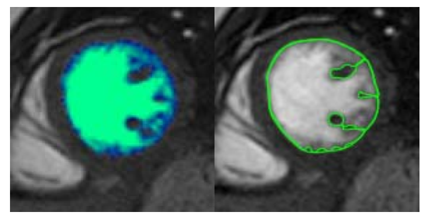

Figure 1: Example LV-METRIC and Manual Tracing segmentations, respectively. Partial voxel content is linearly interpolated from least to most as blue to green.

RESULTS: The absolute and relative differences between MT and LV-METRIC with linear interpolation of partial-blood voxels are shown in Table 1. All differences were statistically significant. The differences between MT and LV-METRIC without linear interpolation of partial-blood voxels (all partial-blood voxels measured as full-blood voxels) are also shown in Table 1. No statistically significant differences were observed. Example segmentation images are shown in Figure 1.

DISCUSSION: While LV-METRIC volumes were smaller than manual tracing (MT) volumes, the LV-METRIC measurements that counted partial-blood voxels as full-blood voxels were similar to MT. Therefore, the difference between MT and LV-METRIC was likely due to partial voxel effects. In current breath hold 2D acquisition of cine SSFP images, the voxel size is limited to 1.4x1.4x10 mm^3. Consequentially, voxels with mixed myocardium and blood are invariably present, which leads to volume overestimation. Further validation using phantoms and high resolution scans as comparison standards must be performed to conclusively show the accuracy of partial voxel measurements.

	End Diastolic Volume (MT minus Automated)		End Systolic Volume (MT minus Automated)		Ejection Fraction (MT minus Automated)		Linear Regression Correlation‡	
	Absolute	**Relative**	**Absolute**	**Relative**	**Absolute**	**Relative**	**Volume**	**EF**
LV-METRIC* (PV Interpolation)	23.1 ± 10.2 (mL)	16 ± 4.8 (%)	11.6 ± 7.2 (mL)	20.7 ± 7.2 (%)	-1.9 ± 2.5 (%)	-3.0 ± 4.2 (%)	y = 0.86x – 2.94 R^2 = 0.990	y = 1.02x + 0.39 R^2 = 0.972
LV-METRIC (no PV Interpolation)**	0.8 ± 5.1 (mL)	0 ± 0.03 (%)	-1.9 ± 6.1 (mL)	0 ± 0.1 (%)	1.5 ± 3.3 (%)	0 ± 0.1 (%)	y = 0.978x – 2.9 R^2 = 0.992	y = 1.01x – 1.9 R^2 = 0.95

Table 1: Comparison of Automated Measurements to Manual Tracing. All subtraction values shown are the average and standard deviation of paired differences (manual tracing minus each given automated method).

* All differences are statistically significant ($p < 0.05$).

** No differences, except ejection fraction, are statistically significant ($p > 0.05$).

‡ x = MT. y = LV-METRIC.

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