Automatic Computation of Ejection Fraction using Temporal Intensity Information

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Abstract: The current clinical practice of manually tracing the endocardium and blood pool to compute the left ventricular (LV) ejection fraction (EF) from cine-magnetic resonance images (cine-MRI) is labor intensive, time consuming, and operator dependent. We automatically estimated the EF using temporal intensity information in conjunction with geometrically smooth parametric curves in 23 subjects (16 normal volunteers, and 7 patients). This entirely data-driven, two-step approach first classifies partial volumed pixels as blood or muscle using periodic intensity variation intrinsic to the cardiac cine-MR and then incorporates smoothness of the LV shape through convex, closed, and piecewise parametric curve to delineate endocardial boundary. The results show that the mean bias values determined by Bland-Altman (BA) analysis between automated and experts' manual volumetric computations at end-diastolic (ED, <2ml) and end-systolic (ES, <4ml) phases and hence for EF (<2%) are in close agreement with typical inter- and intra-observer variability[1].

Introduction: A reliable automatic method to segment the LV cavity in short-axis cine-MR would eliminate the cumbersome practice of manual segmentation by experts and would reduce intra- and inter-observer variability. Recent efforts for automatic delineation of the LV endocardial contour, circumscribing the papillary muscles and trabeculae, involve energy minimization between the image-derived features and the statistical LV shape. We propose a data driven, 2D slice-by-slice approach incorporating temporal intensity information intrinsic to cardiac cine images. The purpose of this paper is to describe our segmentation approach and to investigate its clinical feasibility.

Materials and Methods: The studies were performed on 16 (8m/8f) normal volunteers with a mean age of 37 (27-54) years, and on 7 (6m/1f) clinical patients with a mean age of 56 (31-80) years, all of whom were evaluated for LV dysfunction.

MR Sequence: All subjects were imaged on a 1.5T, Philips Gyroscan NT-Intera, using a 32-element phased-array surface coil. Vector-cardiographic (VCG) gated cine SSFP images (TR/TE/flip: 3.2 msec/1.6 msec/60 deg; temporal resolution: 40 msec; acquired spatial resolution: 1.25 x 1.25 x 8 mm^3) were acquired in a series of 10 to 13 contiguous short-axis (SA) slices covering the entire LV from apex to base (the level of the mitral valve annulus). Each cine slice was acquired during suspended respiration (10-12 heartbeats).

Algorithm: The algorithm involved the following steps: A) Defining the intensity threshold between myocardium and blood by analyzing the intensity-time profiles of individual pixels from SA multi-phase images, 1) the mean intensity of the intensity-time profile is set to zero, 2) the pixels are defined as transitory (blood-muscle-blood) pixels if they experience only two zero crossovers over the cardiac cycle with the first one from positive to negative value, 3) the lower intensity time segments of the transient pixels are classified as partial volumed (blood-muscle) pixels, 4) the intensity statistics (half max full width) of the partial volumed pixels is used to determine the higher threshold for the myocardial intensity (Fig. 1(b)), 5) the LV blood pool is identified from the thresholded images using progressive 3D geometric continuity constraints[1]; B) Defining the endocardial contour as the closed convex curve which has piecewise second order geometric continuity, 6) a convex hull is fitted to the LV blood pool, 7) salient points of the convex hull are determined based on the curvature (Fig. 1(c)), 8) piecewise Bezier curve of second order geometric continuity is fitted though the salient points of the convex hull to delineate the endocardial contour (Fig. 1(d)).

Results: A total of 404 slices (293 slices from 16 volunteers and 111 slices from 7 patients) were analyzed using our algorithm (A) and manually by a clinical expert (R). The manual contours for slice with LV outflow tract were used for accurate volumetric and LVEF measurement. Mean LVEF was 58% (49-70) in volunteers and 53% (40-65) in clinical patients. Some representative images describing the segmentation process and BA comparisons of EDV, ESV, and EF are shown in Fig. 1.

(a) Temporal Intensity

(b) Pixel Intensity Profile

(c) Salient LV Points

(d) ES LV Contour

(e) EDV BA Analysis

(f) ESV BA Analysis

(g) EF BA Analysis

(h) EF Linear Regression Analysis

Discussion: The results show that the mean bias computed using BA analysis between expert manual contours and automated contours for EF (2%), EDV (2ml), and ESV (4ml) to be in close agreement. In the ED phase the limits of agreement were small (<4% EDV) and comparable to the typical inter- and intra-observer variability (<5% EDV)[1]. However, in the ES phase the limits of agreement were twice (<14% ESV) that of the typical inter- and intra-observer variability (<8% ESV) but were still less than 12ml.

Conclusion: Our clinical evaluation in 23 subjects using BA analysis of automated contours with expert manual contours show that the data-driven, slice-by-slice segmentation approach utilizing temporal intensity information can estimate the EDV, ESV, and EF accurately.

Reference: 1. J. Magn. Reson. Imaging 2008; 28:39–50.