Contribution of Endocardial Trabeculae and Papillary Muscles to Left Ventricular Volumes

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Abstract: At present the estimation of left ventricular (LV) volumes and ejection fraction (EF) from cine MR images requires manual tracings of the LV cavity. This manual process introduces considerable latitude for the observer to include varying amounts of endocardial trabeculae (T) and papillary muscles (P) as part of the LV cavity both at end-diastole (ED) as well as end-systole (ES). Two experienced observers delineated the LV cavity that included the LV blood pool, P, and T, and one observer drew an additional contour that circumscribed P separately at ED and ES. An automatic algorithm estimated the LV blood volume (A_B). From these measures, we quantitatively evaluated the relative contributions of tissues T and P to LV volumes at ED and ES, and to EF, using Bland Altman analyses.

Introduction: Estimation of left ventricular (LV) volumes and ejection fraction (EF) requires an operator to manually delineate the endocardial boundary. The operator makes decisions about the extent to which endocardial trabeculae (T) and papillary muscles (P) are to be included as a part of the end-diastolic volume (EDV) as well as the end-systolic volume (ESV). For example, sub-endocardial trabeculae are fine structures that are part of the endocardium, and the relatively modest spatial resolution of MR acquisition makes it difficult to distinguish them from the LV myocardium. While the papillary muscles are easy to circumscribe when they are isolated from the LV myocardium in end-diastole (ED), they are difficult to delineate in end-systole (ES). This results in considerable variability in the inclusion or exclusion of tissues P, and T in ED versus ES. The purpose of this paper is twofold: (i) to estimate the relative contribution of tissues P, and T to EDV, ESV, and EF, and (ii) to study the effect of inclusion of tissues P, and T to EDV but their exclusion from ESV on EF.

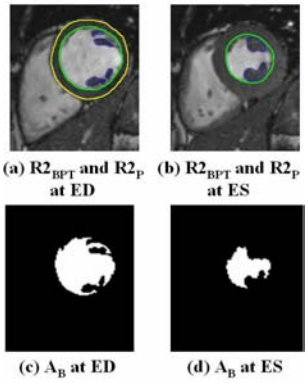


Figure 1: Manual contours and automatic blood segmentation

Materials and Methods: The studies were performed on 21(13m/8f) healthy volunteers, with a mean age of 34 years (range 22-54 years), and 43 years (10m/3f) clinical patients, with a mean age of 55 (range 17-78 years), all of whom were evaluated for LV dysfunction.

MR Sequences: All subjects were imaged on a 1.5T, Philips Gyroscan NT-Intera, using a 5-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 the following order: a vertical long-axis (VLA) view, a 4-chamber (4CH) view, and 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).

Manual Contours: Two experienced observers manually analyzed the short-axis images on a post-processing workstation (Easy Vision, Rel. 5.0, Philips Medical Systems). In each subject, the first observer (R1) determined the ED and ES phase and annotated the basal, mid-cavity and apical slices. Both the observers (R1 and R2) drew endocardial contours circumscribing tissues P and T at ED and ES. We refer to these contours as $R1_{BPT}$ and $R2_{BPT}$ to identify that these contours included the contributions from tissues B, P and T and are drawn by observer R1 and R2 respectively. Second observer (R2) drew a second set of contours delineating tissue type P ($R2_P$). An automatic segmentation algorithm estimated the blood volumes (A_B). The same naming convention is used to describe different combinations, e.g., $R2A_{BP}$ stands for the cumulative volume that includes blood volume from automatic segmentation algorithm (A_B), and tissue type P segmented by R2 (A_B+$R2_P$).

		$R2_{BPT}/R1_{BPT}$		$R2_{BPT}/R2_{BT}$		$R2_{BPT}/R2A_{BP}$		$R2_{BPT}/A_B$	
		Bias	2SD	Bias	2SD	Bias	2SD	Bias	2SD
ED	Basal (%)	-0.77	16.71	0.51	2.06	9.96	17.51	10.47	18.32
	Mid-cavity (%)	2.74	5.75	5	4.42	19.2	20.27	24.19	23.25
	Apical (%)	9.94	19.2	0.78	2.68	25.32	38.03	26.1	39.95
ES	Basal (%)	-6.31	6.68	0.61	2.52	17.9	16.39	18.51	17.93
	Mid-cavity (%)	6.65	22.61	14.23	2.34	32.68	33.97	46.9	34.65
	Apical (%)	11.81	15.75	2.87	13.55	53.2	31.88	56.07	35.51
	EDV (%)	3.15	33.87	2.76	8.44	17.65	72.25	20.41	76.45
	ESV (%)	3.43	12.97	7.78	7.62	31.67	24.61	39.45	28.1
	EF (%)	-0.07	3.93	-2.26	2.4	-7.39	7.78	-10.41	8.8

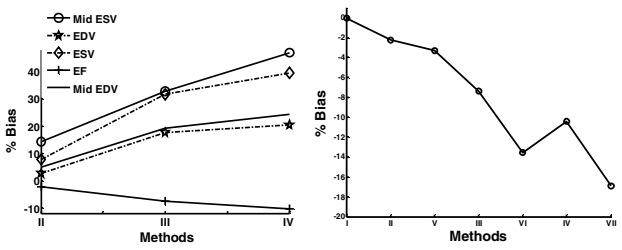
Table 1: Bland-Altman comparisons between manual methods I to IV.

Results: A total of 1078 slices (343 from 21 volunteers and 735 slices from 43 patients) were analyzed manually by two experts R1 and R2 and by automatic LV blood segmentation algorithm. Some representative images are shown in Fig. 1. The following BA comparisons were made. When tissues P and T were included in both ED and ES, there was minimal inter-observer variability ($R2_{BPT}$ v/s $R1_{BPT}$) for EDV, ESV, and EF (Table 1). With respect to $R2_{BPT}$ at ED and ES (Method I), when tissues P (Method II), T (Method III), and P+T (Method IV) were sequentially excluded both in ED, and ES, the percentage underestimation of ESV was twice as much as that in EDV, and there was a overestimation of EF (Figure 2a, Comparisons 2-4). When tissues P, T, and P+T were sequentially excluded in both ED and ES (Method II - IV), and were compared against corresponding volumes where P (Method V), T (Method VI), and P+T (Method VII) were excluded only in ES (Comparisons 5-7), there was an underestimation only in ESV, and further overestimation of EF, as expected (Table 2, Figure 2b).

Discussion: The pair wise comparisons provide the following insights. First, when compared with Method I, the exclusion of tissue types P, T, and P+T (Methods II-IV) underestimated ESV (8, 32, and 40 %) more significantly than EDV (3, 18, and 20 %), respectively. This underestimation of ESV was primarily due to the presence of tissue types P and T in mid ventricular sections (14, 33, and 47 % compared to mid-ventricular sections in Method I), and the corresponding underestimations were roughly half of that at EDV. The underestimation in mid-cavity ES can be attributed to the overestimation of EF (2, 7, and 10%) as depicted in Fig. 2a. Secondly, some of the current literature indicates inconsistency in treating tissues P and T across phases ED and ES [1]. Most of these methods tend to be somewhere between Methods V and VI. The bias values for Comparisons 5-7 between Methods V, VI, and VII with Method I show overestimation of EF (3, 13, and 16% respectively). These results suggest that consistent treatment of tissue types in both diastole and systole can reduce the extent of overestimation (Fig. 2b).

Method		Ejection Fraction	
ED	ES	Bias (%)	2SD (%)
$R2_{BPT}$	$R1_{BPT}$	-0.07	3.93
$R2_{BPT}$	$R2_{BT}$	-3.33	2.71
$R2_{BPT}$	$R2A_{BP}$	-13.55	7.14
$R2_{BPT}$	A_B	-16.88	7.78

Table 2: BA comparisons of EF between methods I, V, VI, VII.



(a) (b)

Figure 2: (a) Relative underestimation of EDV, mid-cavity ESV, and ESV, and (b) resultant overestimation of EF due to inconsistent inclusions of P and T.

Conclusion: The results from this study indicate that the papillary muscles (P) and sub-endocardial trabeculae (T) affect EF calculations by about 2%, and 7% respectively. The cumulative effect of tissues P and T on EF is around 10%. These effects are significantly higher if the tissues are treated unequally in diastole and systole.

References: 1. Sievers et al., Impact of papillary muscles in ventricular volume and ejection fraction assessment by cardiovascular magnetic resonance, JCMR, Vol 6, No.1, pp 9-16, 2004.