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Original Article

Heart-Model-Based Automated Method for Left Ventricular Measurements in Cardiac MR: Comparison with Manual and Semi-automated Methods

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Purpose : To assess the effect of applying an automated heart model based measurements of left ventricle (LV) and compare with manual and semi-automated measurements at Cardiovascular MR Imaging.

Materials and Methods: Sixty-two patients who underwent cardiac 1.5T MR imaging were included. Steady state free precession cine images of 20 phases per cardiac cycle were obtained in short axis views and both 2-chamber and 4-chamber views. Epicardial and endocardial contours were drawn in manual, automated, and semi-automated ways. Based on these acquired contour sets, the end-diastolic (ED) and end-systolic (ES) volumes, ejection fraction (EF), systolic volume (SV) and LV mass were calculated and compared.

Results: In EDV and ESV, the differences among three measurement methods were not statistically significant (P = .399 and .145, respectively). However, in EF, SV, and LV mass, the differences were statistically significant (P=.001, <001, <001, respectively) and the measured value from automated method tend to be consistently higher than the values from other two methods.

Conclusion: An automatic heart model-based method grossly overestimate EF, SV and LV mass compared with manual or semi-automated methods. Even though the method saves a considerable amount of efforts, further manual adjustment should be considered in critical clinical cases.

Index words : Magnetic resonance imaging (MRI) · Heart · Volumetery

INTRODUCTION

The accurate measurement of left ventricular (LV) volume and LV mass is important for risk stratification and clinical management, because these parameters are powerful predictors of prognosis related with a variety of cardiovascular disease (1–3).

Cardiac magnetic resonance (CMR) imaging performed using the cine gradient-echo and steady state free precession (SSFP) is the reference standard in the assessment of the LV volume and mass (4–6). With the use of these techniques, an acquisition of the delineations of endocardial border throughout the entire cardiac cycle was facilitated (7). Thus, the measurement by the summation-of-disk section method has been the established reference standard for assessing LV volume and mass. However, short axis (SAX) stacks, considered to be the standard procedure for quantifying LV volume and function, and as such for validation (5), are inevitably leading to problems that underestimated the longitudinal component of cardiac contraction. On the other hand, long axis (LAX) stacks, which have been proposed as an alternatives (8), may be more reliable and

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reproducible in normal ventricles (9), but more susceptible to the errors in asymmetric diseased ventricles.

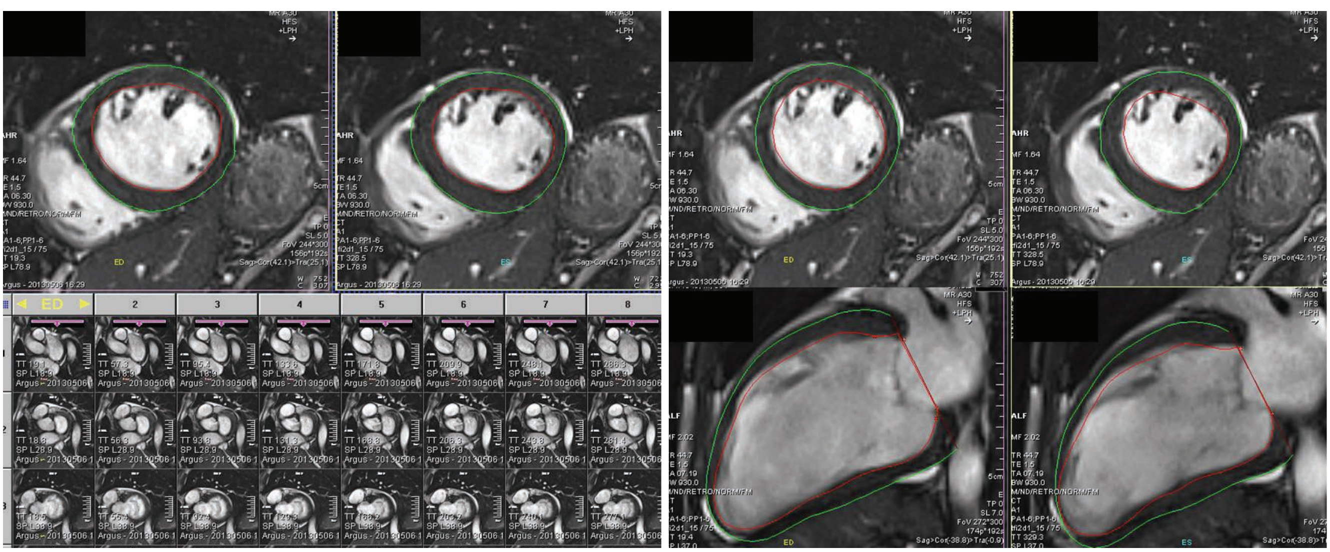
Under the circumstances that there is no accepted gold standard for exact LV volume and mass measurements, one of the plausible ways could be the combination of two approaches, i.e., SAX and LAX stack. The automated tool (Argus 4D VF®, Siemens Healthcare, Erlangen, Germany), which is based on a heart-model-based algorithm, tried to combine both methods by employing end-diastole and end-systole long-axis planes into its SAX based LV volume and mass calculation.

Therefore, the aim of this study is to assess the effect of applying an automated heart model based measurements of LV, which contains more components of LAX, and compare the result with conventional manual 2D SAX stack based measurements at Cardiovascular MR Imaging.

MATERIALS AND METHODS

Patient Population

This retrospective study was approved by the institutional review board of our hospital, and the requirement for informed consent was waived. 62 patients who underwent cardiac 1.5T MR imaging between



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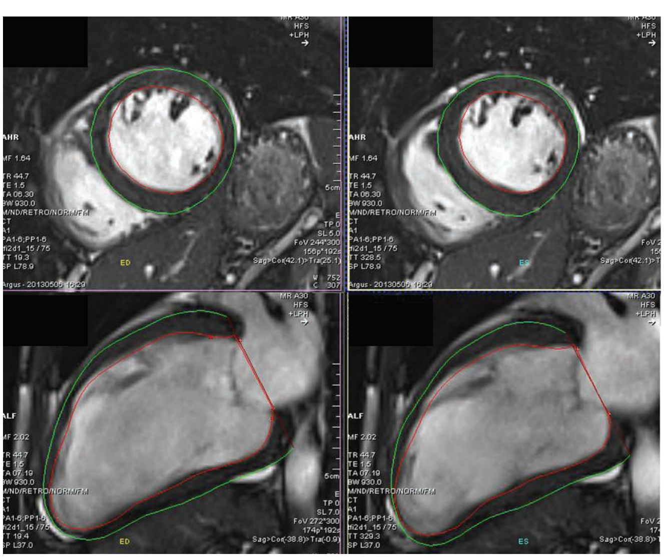

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Fig. 1. Sample illustration of contour sets of a 68-year-old male patient who had ischemic heart disease. Each contour sets were generated by manual (**a**), automated (**b**), and semi automated methods by Argus 4D.
Note that the automated methods have the tendency to draw endocardial border to exclude more portion of papillary muscle in the LV cavity than other two methods do.

March 2011 and July 2011 were included in this study. 51 patients were male and 11 female, with a mean age of 49 years (range 7–77 years, standard deviation 19.9 years). 21 of them had ischemic heart disease, 7 had valvular heart diseases, 14 had cardiomyopathy, 13 had congenital heart diseases, and the remaining 7 had no significant structural heart disease.

All CMR investigations were performed in a 1.5T unit (Sonata, Siemens Healthcare, Erlangen, Germany), using a standardized clinical protocol. Cine images were obtained in 2-chamber, 4-chamber, RV outflow tract and short-axis planes with a temporal resolution that was sufficient to accommodate 20 true phases per cardiac cycle.

Left Ventricular Parameter Measurements

Left ventricular parameters were measured from a stack of short-axis and long-axis cine images with commercially available software (Argus 4D VF®, Siemens Healthcare, Erlangen, Germany). They were analyzed to calculate LV volume and mass using a manual contour tracing technique, automated heart-model-based technique, and semi-automated technique.

First, in the manual measurements, the source cine images of SAX stack were manually segmented and contoured in every phase of the cardiac cycle (10), while, in the automated measurements, the basal border of the LV cavity was automatically adapted in every phase of the cardiac cycle, after mitral valve insertion points on long-axis planes were identified in end-diastole and end-systole phase. LV parameters were calculated based on these 2 LAX views and borders generated on SAX stack. Finally, in the semi-automated measurements, the aforementioned sets of contours, which were generated in the automated measurements, were adjusted manually to represent proper blood pool of LV in SAX stack in every phase of a cardiac cycle.

The end diastolic volume (EDV), end systolic volume (ESV), ejection fraction (EF), systolic volume (SV) and end-diastolic LV mass among three measurement methods were compared.

Statistical Analysis

One-way analysis of variance (ANOVA) test was

Table 1. One-way Analysis of Variance Regarding to Given Cardiac Parameters

Parameters	Mean	Standard Errors	Post Hoc Multiple Comparison	P value
EF (%)				
Manual(M)	55.00	1.61	M,S/A	.001
Automated(A)	62.87	1.41		
Semi-automated(S)	55.94	1.81		
EDV (mL)				
Manual	160.45	5.62		.399
Automated	169.21	6.34		
Semi-automated	171.28	5.97		
ESV (mL)				
Manual	75.24	4.92		.145
Automated	65.49	4.59		
Semi-automated	79.22	5.62		
SV (mL)				
Manual	85.17	2.76	M,S/A	<.001
Automated	103.73	3.41		
Semi-automated	92.06	3.13		
LV Mass (ED) (g)				
Manual	129.06	5.17	M/S/A	<.001
Automated	151.73	6.18		
Semi-automated	118.04	5.20		

Note.— EF = Ejection Fraction, EDV = End-diastolic volume, ESV = End-systolic volume, SV = Stroke volume, LV = Left ventricle

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used for the comparison of the measurements data and Kruskal-Wallis test was used for posthoc analysis among three methods. P < .05 was considered to be a significant difference. Statistical analysis was performed using commercial software (SPSS for Windows, version 18.0, SPSS, Chicago, IL).

RESULTS

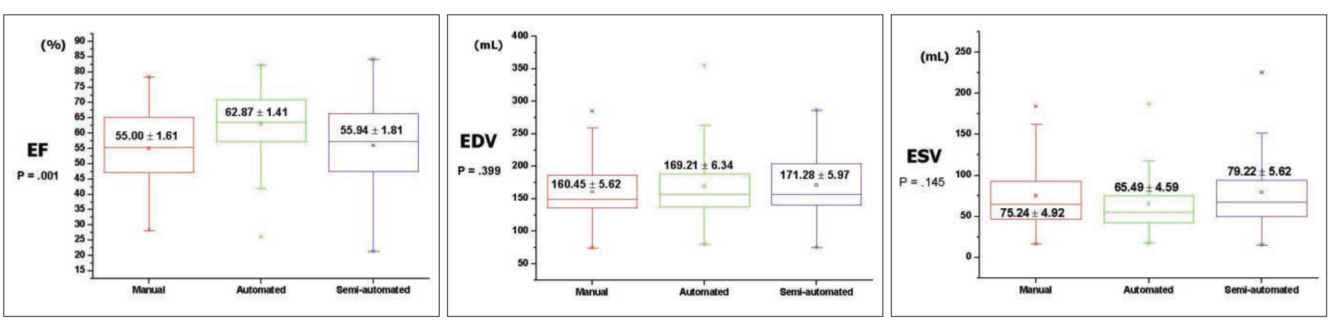
Left Ventricular Parameter Measurements

All loaded images of SAX stack and 2 LAX were sufficient for tracing of the endocardial and epicardial contours with three different methods (example see Fig. 1). Left ventricular parameters were calculated for each contour set.

Statistical Analysis

In EDV and ESV, the differences among three measurement methods were not statistically significant. (P = .399 and .145, respectively). On the other hand, as for the EF, SV, and LV mass measurements, the differences were statically significant (P=.001, <.001, <.001, respectively) and the measured value from semi-automated method tend to be consistently larger than those from the other methods (Table 1).

In EF, the mean value measured from the automated method (62.87 ± 1.41) turned out to be larger value than one from the manual method (55.00 ± 1.61). After the generated contour sets in automated methods were manually adjusted in each phase, the mean EF value was decreased. Therefore, the value from semi-automated measurements (55.94 ± 1.81), was lower than that from the automated method. As a result, the mean measured value from the automated method was significantly higher than those from other two methods (P = .001), while, the values from manual and semi-automated methods were not significantly different in post hoc multiple comparisons. Similarly, in SV, the mean value from the automated one (103.73 ± 3.41) was higher than one from the manual method (85.17 ± 2.76). The value from semi-automated method was lowered (92 ± 3.13) after the adjustment, and the mean measured value from the automated method was significantly higher than those from other two methods (P < .001), while the difference between manual and semi-automated one was not statistically significant. Finally, in LV mass, the mean value from the automated one (151.73 ± 6.18) was higher than one from the manual method (129.06 ± 5.17). The value from semi-automated one was decreased again (118.04 ± 5.20), therefore, the mean



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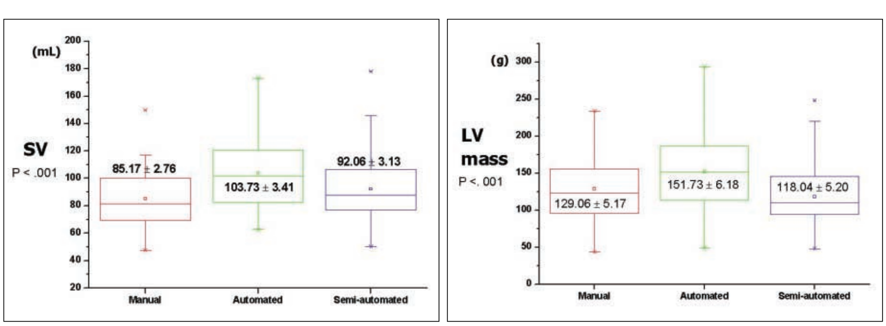

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Fig. 2. Graphical presentation of LV parameter values of (**a**) Ejection fraction, (**b**) End-diastolic volume, (**c**) End-systolic volume, (**d**) Stroke volume, and (**e**) Left ventricular mass, using manual, automated and semi-automated methods, respectively.
Note that the automated methods consistently overestimated EF, SV and LV mass compared with the other two methods.

measured value from the automated method was significantly larger than those from other two methods (P <.001). Unlike to EF and SV, the difference between manual and semi-automated was statistically significant in post hoc multiple comparison, and the mean value from semi-automated method was lower than one from the manual measurement. Graphical presentations of the result were illustrated in Fig 2.

DISCUSSION

Because the most validation studies in CMR have been performed based on SAX measurements (11, 12), the correct selection of the basal slice is of importance for accuracy of volume data, which were often became the source of the problem leading to low reproducibility (13). Furthermore, the measurement sorely based on the SAX stacks without the incorporation of LAX components, could be inevitably underestimate the longitudinal part of heart contraction. Argus 4D tried to visit these issues by incorporating end-diastole and end-systole LAX view and by enabling the user to identify the mitral valve insertion point. The primary finding of our study results is two-fold: in comparison with conventional 2-D disc summation method, automated heart-model-based method grossly overestimated EF, SV and LV mass with statistical significance. The other point is that, in semi-automated measurement, which is based on the manual adjusted contour sets of automatically generated ones, the differences with conventional 2-D method were decreased so that the statistical significance went away although the overall tendencies of exaggeration were preserved (Fig. 2).

A first and straightforward explanation lies in the discrepancy to define mitral valve plane and subsequent inclusion of additional ventricular or myocardial volume in the automated method. As mentioned earlier, the choice of the most basal slice in the 2D disc-summation technique is somewhat arbitrary, which is defined as the closest slice to mitral valve, surrounded by at least 50% of myocardium. In the automated method, the most basal contour can be oriented along the anatomic mitral valve plane with long and short axis views, which reduces the risk of missing ventricular volume deteriorating the accuracy of LV volumetric analysis. Considering the most basal part of the heart takes the highest relative to ventricular tissue and cavity, inclusion or exclusion of basal volume constitutes substantial variation of overall volumetric measurements. This might explain why overestimation was so consistent in the automated method (with statistical significance) and in the semi-automated method (without statistical significance), compared with manual 2D method.

The second explanation is the different approaches to papillary muscles in automated contour drawing, compared with conventional 2D or manually adjusted semi-automated one. The SAX disc-summation method includes papillary muscles in the volume of the LV cavity. While, in the manual contouring, the endocardial contours were consistently drawn to include papillary muscle in the volume of LV cavity on every single cardiac phase, the automated contouring has the tendency to draw endocardial border to exclude some portion of papillary muscle in the LV cavity. Since the papillary muscle account for around 8.9% of the LV volume, this difference contouring should result in variation of overall LV volumetric measurements (14). This tendency is more evident in systolic phase which the papillary muscle appears more compact pattern relative to cardiac wall (Fig. 1). Indeed, the volumetric change after the manual correction is much larger in systolic phase (79.22 -> 65.49, 17.3 %) compared with the change in diastolic phase (169 -> 171, 1.1%). With the results that the differences with conventional method became much smaller after manual adjustment of automatically drawn contour sets, our data suggest that a considerable degree of random error persist in automatic drawing and that intelligent manual contour delineation is still superior to automated one.

A final rationale for discrepancies of the results may lie in the longitudinal part of heart contraction. Naturally, SAX based disc summation method would be susceptible to the underestimation of the longitudinal motion and this underestimation could contribute the difference between the results of conventional and semi-automated methods. Persistent overestimation of EF and SV of automated and semi-method, with and without statistical significance respectively, may reflects this underestimation of longitudinal contraction in the measurement based on the 2D SAX disc

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summation.

There were limitations to our study. First, our study didn't include the reproducibility of the measurements. Although the semi-automated model has less observer dependency owing to its automaticity, this model also has some points that observer's personal tendency, such as the identification of mitral valve insertion points, can make differences. Second, the best measurement tool is probably that which is the most accurate. Because we measured LV parameters in vivo, we were not able to test for accuracy, among three measurement methods. Therefore, we cannot assess whether one of the three measurements was superior to the others. Third, the sample size 62 may be relatively small, considering wide range of the patients age (7–77). ; However, the sample represents a population with wide spectrum of cardiac disorder from congenital heart disease to chronic ischemic heart disease.

In conclusion, automatic heart model-based tool grossly overestimate EF, SV and LV mass compared with conventional 2D or adjusted automated methods. Hence this method should be used with caution, and its benefits should be weighed against its difference with manual or semi-automated measurement. Therefore, even though the method saves a considerable amount of efforts, further manual adjustment should be considered in critical clinical cases.

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자동화 방식 모델 기반 좌심방 파라미터 측정법: 수동 및 반자동 방식과의 비교

서울대학교병원 영상의학과

채승훈 · 이 활 · 박은아 · 정진욱

목적: 자기공명 심장영상을 이용한 좌심실 파라미터 측정에 있어, 자동화 방식을 적용하였을 경우에 나타나는 효과를 분석하고 이를 수동 및 반자동 방식을 적용했을 경우 나타나는 결과와 비교하였다.

대상과 방법: 1.5T 자기공명 심장영상 촬영을 시행한 62명의 환자를 대상으로, 심장 주기당 20상의 단축 항정상태 자유세차 동영상과 심첨2방 및 심첨4방 영상을 얻었다. 심내막 경계와 심외막 경계를 수동, 자동, 반자동 방식으로 각각 구하여 이를 바탕으로 이완말기와 수축말기 용적, 박출 계수, 일회 박출량, 좌심실 질량을 계산하고 각 방식간 평균값 차이를 일원분산분석법을 이용 통계적 분석하였다.

결과: 이완말기와 수축말기 용적의 경우에는 세 방식으로 측정한 결과는 통계적으로 유의하게 다르지 않았다. (P = .399 and .145). 그러나, 박출 계수, 일회 박출량, 좌심실 질량의 경우에는 통계적으로 유의하게 다르게 나타났으며 (P=.001, 〈 001, 〈 001) 자동화 방식으로 측정한 측정치가 다른 두 방식에 비해 일관되게 큰 결과치를 보였다.

결론: 자동화 방식을 적용하여 측정한 좌심실의 박출 계수, 일회 박출량, 좌심실 질량의 측정치는 수동, 반자동 방식에 비해 과장된 값을 나타낸다. 자동화 방식으로 많은 노력을 절감할 수 있으나, 임상적으로 민감한 케이스에 대해서는 이에 더하여 수동적 교정을 고려해야 할 것이다.

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