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3D Echocardiographic Assesment of Left Ventricle Size and Function with Automated Adaptive Software in Patients with Right Heart Dominant

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ABSTRACT

Background: Accurate measurement of cardiac chamber size and function is essential in cardiac imaging, with echocardiography being the primary noninvasive tool for real-time visualization. Technological advancements have introduced real-time three-dimensional echocardiography (3DE) and myocardial deformation imaging. While 2D echocardiography remains fundamental, 3DE offers more precise measurements of the left ventricle (LV) without relying on geometric assumptions. Automated 3DE quantification software has emerged, promising enhanced efficiency and reproducibility.

Methods: This study aimed to validate automated 3DE measurements against manual 3DE and 2D echocardiography in patients with severe mitral stenosis (MS) and atrial septal defect (ASD). From January to June 2019, 60 patients at the National Cardiovascular Centre Harapan Kita, Jakarta, were evaluated. Echocardiographic imaging was conducted using Philips EPIQ 7, and measurements of LV end-diastolic volume (LVEDV), LV end-systolic volume (LVESV), and LV ejection fraction (LVEF) were compared using automated (HeartModel) and manual (QLAB) 3DE techniques. Statistical analyses included linear regression, Pearson correlation, and Independent Sample T-tests.

Results: Among 60 patients, automated quantification failed in 16 due to higher tricuspid regurgitation and valve gradient. In the remaining 44 patients, automated 3DE significantly reduced analysis time (75 ± 45 sec vs. 183 ± 65 sec, $p < 0.0001$). Automated measurements of LVEDV and LVESV were larger than manual measurements, while LVEF was smaller, with good correlation but significant differences indicating non-equivalence.

Discussion: Automated 3DE significantly reduces analysis time and provides accurate LV measurements. However, it is less effective in patients with significant right heart chamber alterations, requiring further validation against cardiac magnetic resonance imaging for broader clinical application.

Conclusion: Automated 3DE quantification is feasible and time-efficient for assessing LV volumes and function in patients with MS and ASD, though it cannot fully replace manual 3DE in all cases. Future studies should address its applicability in more diverse patient populations.

INTISARI

Latar Belakang: Pengukuran ukuran dan fungsi bilik jantung yang akurat sangat penting dalam pencitraan jantung, dengan ekokardiografi menjadi alat non-invasif utama untuk visualisasi real-time. Kemajuan teknologi telah memperkenalkan ekokardiografi tiga dimensi real-time (3DE) dan pencitraan deformasi miokard. Meskipun ekokardiografi 2D tetap fundamental, 3DE menawarkan pengukuran yang lebih tepat dari ventrikel kiri (LV) tanpa bergantung pada asumsi geometris. Perangkat lunak kuantifikasi otomatis 3DE telah muncul, menjanjikan peningkatan efisiensi dan reproduktibilitas.

Metode: Studi ini bertujuan untuk memvalidasi pengukuran 3DE otomatis terhadap ekokardiografi 3DE dan 2D manual pada pasien dengan stenosis mitral (MS) dan defek septum atrium (ASD) berat. Dari Januari hingga Juni 2019, 60 pasien di Pusat Kardiovaskular Nasional Harapan Kita, Jakarta, dievaluasi. Pencitraan ekokardiografi dilakukan menggunakan Philips EPIQ 7, dan pengukuran volume akhir diastolik LV (LVEDV), volume akhir sistolik LV (LVESV), dan fraksi ejeksi LV (LVEF) dibandingkan menggunakan teknik 3DE otomatis (HeartModel) dan manual (QLAB). Analisis statistik termasuk regresi linier, korelasi Pearson, dan Uji T Sampel Independen.

Hasil: Di antara 60 pasien, kuantifikasi otomatis gagal pada 16 pasien karena regurgitasi trikuspid dan gradien katup yang lebih tinggi. Pada 44 pasien yang tersisa, 3DE otomatis secara signifikan mengurangi waktu analisis (75 ± 45 detik vs. 183 ± 65 detik, $p < 0.0001$). Pengukuran otomatis LVEDV dan LVESV lebih besar daripada pengukuran manual, sementara LVEF lebih kecil, dengan korelasi yang baik tetapi perbedaan signifikan menunjukkan ketidaksetaraan.

Diskusi: 3DE otomatis secara signifikan mengurangi waktu analisis dan menyediakan pengukuran LV yang akurat. Namun, ini kurang efektif pada pasien dengan perubahan signifikan pada bilik jantung kanan, memerlukan validasi lebih lanjut terhadap pencitraan resonansi magnetik jantung untuk aplikasi klinis yang lebih luas.

Kesimpulan: Kuantifikasi 3DE otomatis layak dan efisien waktu untuk menilai volume dan fungsi LV pada pasien dengan MS dan ASD, meskipun tidak dapat sepenuhnya menggantikan 3DE manual dalam semua kasus. Studi di masa depan harus mengatasi penerapannya pada populasi pasien yang lebih beragam.

INTRODUCTION

The measurement of cardiac chamber size and function are the foundation of cardiac imaging. Echocardiography is considered the most commonly noninvasive tool to provide real-time images of the cardiac chamber and function. Measuring cardiac chambers accurately is maintained by creating official recommendations, which are then followed by practitioners to provide uniformity. Nowadays, echocardiographic technology has continued evolving, with the new and refined products being real-time three dimensionl (3D) echocardiography (3DE) and myocardial deformation imaging.[1]

Two Dimensional (2D) images constitute the essential views of a complete examination. 2D examination will present essential elements of the Doppler examinations and measurements involving these echocardiographic tools. 3D imaging is now widely available. Quantification of Left Ventricle (LV) size and systolic function is the most widely used 3D application. Recording and analyzing steps for measuring an ejection franction (EF) with a 3D volume set are dependent on the system and software used to calculate the 3D volume. To obtain an optimal 3D volume set of the LV for calculation of EF, the 2D image should be optimized by adjusting focus, gain and compression for better and adequate postprocessing of the 3D volume. Once all the imaging parameters are optimized, should be asked to hold breath to help eliminate during recording image. Multiple beat recordings result in higher and better spatial resolution for overall better results.[2]

Presently, real-time 3DE is a practical tool for the measurement of LV volumes and LVEF. Several studies have shown that 3DE is more accurate and reproducible than 2DE, because direct assesment of volumes can be reached without the need for geometrical assumptions about cavity shape and others limitations related with foreshortened views. Unfortunately, this modality is not routinely used for various reasons, such as the need for 3DE-spesific expertise and because it is considered by some time consuming. Today, some echocardiographic machine providers already have developed automated quantification software that can be implemented in order to avoid delays in the workflow.[3]

A growing number of studies have already demonstrated that automated quantification software has strong correlations and agreement with manual measurements and other modalities. Several claim that automated measurements are feasible and require minimal 3D software analysis training. Accordingly, this technique has been found to be very reproducible and timesaving, and is promising to implement these automated measurements into daily clinical practice.[4]

Recently, research using automated quantification was applied in patients with normal geometry of the left and right heart chambers. All study results proved that automated quantification software is very easy to use and time saving. No data have been provided about using automated quantification software in patients with right chamber dominant. This present study was designed to : 1) validate LV measurements obtained by using automated quantification software against manual 3DE measurements and manual 2D measurement; 2) examine the relationship between LV measurements obtained by using these each techniques; and 3) compare the reproducibility and analysis time of the automated quantification software with conventional manual 3DE and 2D measurements.

METHODS

Population and study design

From January to June 2019, patients were prospectively selected with uncorrected severe mitral stenosis (MS) and uncorrected atrial septal defect (ASD) who were referred for clinically indicated echocardiography examinations at the National Cardiovascular Centre Harapan Kita (NCCHK), Jakarta, Indonesia. Each group enrolled 30 patients. The final number of subjects included 60 patients. The ethics committee of the hospital approved the study protocol, and informed consent was obtained from all participants. Basic demographic evaluations and echocardiographic evaluations were collected at the same time and no follow up was required. Inclusions criteria were: Age ≥ 18 years old, sinus rhythm, patients with diagnose uncorrected ASD, patients with diagnose uncorrected severe MS. Exclusion criteria were: Uncooperative patients, patient with complex congenital heart disease, and image not detected properly by system.

Echocardiographic Imaging

Imaging was performed using EPIQ 7 (Philips Healthcare, Netherland) and X5-1 phased-array transducer with the patient in the left lateral decubitus position. Image acquisition included a wide-angled 'full-volume' 3DE datasets of four cardiac cycles, each from the apical position during a single breath-hold. Measurements were performed included Left Ventricle End Diastolic Volume (LVEDV), Left Ventricle End Systolic Volume (LVESV), Left Ventricle Ejection Fraction (LVEF) by two 3DE techniques: the new automated analysis (HeartModel (HM); Phillips Healthcare) and the conventional manual analysis (3DQ – QLAB; Phillips Healthcare). Analysis from each technique was performed by two different technicians.

Table 1. Baseline Characteristics of the study subjects

Number of patients	60
Women[a]	46 (77%)
Age (y)[b]	30 ± 12
Body surface area (m^2)[b]	1.62 ± 0.21
RAESA (mm)[b]	20.4 ± 7.3
RV Basal Diameter (mm)[c]	46 (40-54.5)
LAVI (ml/m^2)[c]	46.4 (27-78.1)
TR Maximum Velocity (m/s)[c]	3.4 (2.5-4.5)
TVG (mmHg)[c]	46 (26.3-81.8)

[a]Values are expressed as number (%).
[b]Values are expressed as mean ± SD.
[c]Values are expressed as median (range).
RAESA, Right Atrial End Systolic Area; RV, Right Ventricle; LAVI, Left Atrial Volume Index; TR, Tricuspid Regurgitation; TVG, Tricuspid Valve Gradient

DATA ANALYSIS

The automated 3DE derived values of LVEDV, LVESV, LVEF were compared with the corresponding manual 3D sets of Transthoracic Echocardiography (TTE) values using linear regression with Pearson correlation coefficients and Independent Sample T - Test analysis to assess the agreement between the two methods. Sub group analysis was performed between software working group versus software not working group to find the parameters that could cause software to not work properly. Measurements from the two groups were compared using the Mann Whitney U Test or T-Test. Values of $p < 0.05$ were considered significant.

RESULTS

Baseline characteristics are presented in Table 1. A total of 30 patients was enrolled for each group (MS & ASD). Among the 60 patients whose 3D TTE full-volume data sets were acquired, the automated quantification software did not work in 16 patients (8 patients from MS group; 8 patients from ASD group). As a result, the final population consisted of 44 patients. In patients where the software did not work properly, the Tricuspid Regurgitation (TR) Maximum Velocity and Tricuspid Valve Gradient (TVG) was higher than in patients where the software worked well and the results were statistically significant (Table 2). Table 3 shows the data for the time required for data analysis from manual 3DE method and automated 3DE method. Analysis time was shortened with the use of automated 3DE software. The time required for the full analysis was significantly less with the fully automated method (75 ± 45 sec) compared with the manual method (183 ± 65 sec) ($P < 0.0001$). Of special note, total time saved for analysis was 60% when automated 3DE software was performed (Figure 1).

Table 2. Automated Software Analysis

	Software Working	Software Not Working	*P*
Number of patients	44	16	
RAESA (mm)[a]	19.8 ± 6.6	21.9 ± 8.9	0.4
RV Basal Diameter (mm)[b]	44 (39-55)	46.5 (41.3-51.8)	0.54
LAVI (ml/m^2)[b]	45.6 (25.9-75.2)	51.5 (27.7-95)	0.6
TR Maximum Velocity (m/s)[b]	2.9 (2.5-4.3)	4.1 (3.5-4.7)	0.01
TVG (mmHg)[b]	34 (25-74)	65.5 (49-89.3)	0.01

[a]Values are expressed as mean ± SD.
[b]Values are expressed as median (range).
RAESA, Right Atrial End Systolic Area; RV, Right Ventricle; LAVI, Left Atrial Volume Index; TR, Tricuspid Regurgitation; TVG, Tricuspid Valve Gradient

Table 3. Time Analysis		
N = 44	Time (sec)[a]	*P*
Automated 3DE	75 ± 45	<0.0001
Manual 3DE	183 ± 65	

[a]Values are expressed as mean ± SD.
3DE, 3-Dimensional Echocardiography

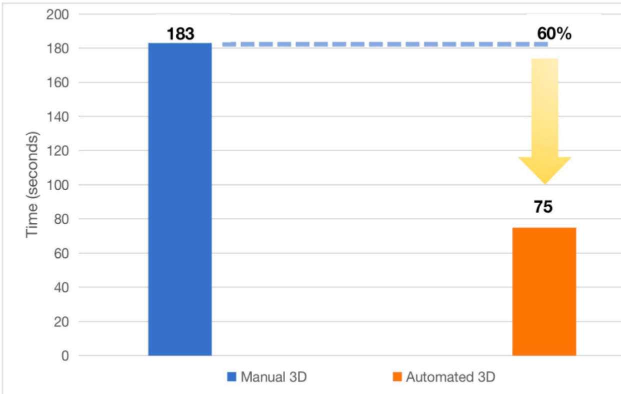

Figure 1. Time to complete LV measurements. Compared with manual 3D measurement a decrease analysis time of 60% was noted when automated 3D software was performed.

Automated 3DE versus Manual 3DE Measurements

The automated 3DE measurements of LVEDV and LVESV were larger than the averaged manual 3DE measurements and the results were significant statistically. However, the automated 3DE measurements of LVEF were smaller than the averaged manual 3DE measurements and it was not significant statistically (Table 4). There was good correlation between automated 3DE and manual 3DE measurements of LVEF, LVEDV, LVESV (Table 5).

Table 4. Comparison Between Automated 3DE Versus Manual 3DE Measurements

	Automated 3DE	Manual 3DE	Mean difference (95% CI)	*P*
LVEF (%)[a]	55 ± 9	57 ± 9	2.19	0.267
LVEDV (ml)[a]	75 ± 23	65 ± 21	10.72	0.027
LVESV (ml)[a]	34 ± 13	28 ± 12	5.93	0.031

[a]Values are expressed as mean ± SD.
3DE, 3-Dimensional Echocardiography; LVEF, Left Ventricle Ejection Fraction; LVEDV, Left Ventricle End Diastolic Volume; LVESV, Left Ventricle End Systolic Volume

Table 5. Correlation Between Automated 3DE Versus Manual 3DE Measurements

	Automated 3DE	Manual 3DE	Correlation	*P*
LVEF (%)[a]	55 ± 9	57 ± 9	0.83	<0.001
LVEDV (ml)[a]	75 ± 23	65 ± 21	0.79	<0.001
LVESV (ml)[a]	34 ± 13	28 ± 12	0.86	<0.001

[a]Values are expressed as mean ± SD.
3DE, 3-Dimensional Echocardiography; LVEF, Left Ventricle Ejection Fraction; LVEDV, Left Ventricle End Diastolic Volume; LVESV, Left Ventricle End Systolic Volume

To assess the agreement between these two methods, Independent Sample T - Tests were use in the analysis. In the analysis of LVEF, LVEDV, LVESV from automated 3DE against manual 3DE measurements, these two methods (Automated 3DE and manual 3DE) did not agree equally in LVEF, LVEDV, LVESV measurement. Table 6 shows that there are significant differences between these two methods. This finding means that although these two methods have a good correlation still these two methods did not produce the same results.

Table 6. Agreement Analysis

	95% Confidence Interval of the Difference		Mean Difference	*P*
	Lower	Upper		
LVEF	-3.8247	-0.5571	-2.19091	0.01
LVEDV	6.2384	15.1934	10.7159	<0.0001
LVESV	3.8297	8.0385	5.9341	<0.0001

LVEF, Left Ventricle Ejection Fraction; LVEDV, Left Ventricle End Diastolic Volume

LVESV, Left Ventricle End Systolic Volume

DISCUSSION

Left-heart chamber measurements are critical for both clinical management and clinical trials. The recent guidelines emphasize that 3DE measurements should be preferred over 2DE. However, 3DE has not been widely used and implemented into the routine practice because of the fact that it is currently time consuming and requires special expertise.[5] The new automated software is able to overcome the current limitations associated with conventional 3DE chamber measurements, resulting in significant time savings.[6] Because of its simplicity, minimal training is needed, in contrast to the conventional manual 3DE methodology.[7]

Although most previously published studies have reported about automated techniques for 3DE evaluation of LV volumes for clinical use, their patients were mostly in normal heart condition. To the best of our knowledge, this is the first study to test the new automated 3DE approach for simultaneous LV and LV function assessment based on an adaptive analytics algorithm in patients with right heart dominant.

The present study showed that automated chamber quantification analysis can provide accurate measurements of LVEDV, LVESV and LVEF. Also, the use of this program resulted in reduced duration of examination. Overall, the automated software provides bigger volumes than manual measurements. In the present study there were 16 patients that that automated software could not be applied. Compared with previous studies, patients in the present study have a unique anatomical right heart chamber. Naturally, patients with uncorrected ASD and severe MS will have developed some dilatation of right heart chamber, which results in changes anatomically and structurally of the left heart chambers. Typically, the left ventricle will be pressed and some cases indicate the left ventricle will become smaller. This can be one reason for why in present study the automated software could not be applied in 16 patients. In those patients where the software did not work properly, we found that Tricuspid Regurgitation (TR) Maximum Velocity and Tricuspid Valve Gradient (TVG) is higher than in patients where the software worked well and this finding was statistically significant (Table 2).

The automated software uses a unique adaptive analytics algorithm that works in 3 stages.

First, and most related with the present study, is knowledge-based identification is used, in which an echocardiographic atlas of cardiac chamber shapes is screened and, based on the overall morphological size, shape, curvature, and volume of the 3DE data under study, the best "matching" shapes are selected.4 So, if there are anatomically and structurally changes in the left ventricle and the automated software does not yet have a sample study about the structure it will cause the software to fail in tracing the myocardium, and the automated software cannot be applied.

The use of the automated software significantly reduced the average time per patient compared with manual analysis ($p < 0.0001$) (table 3). These findings are similar with previous published data4. Total time saved for analysis in the present study was 60%, which is similar with previous study where total time saved for analysis in previous study was 63%3. The anatomical and structural changes in the present study can be one reason why the present study needed more long time to complete the full analysis. Even though it needs more time to analysis, the use of automated software still had statistically significantly reduced average time examination per patient compared with manual measurement.

LVEF from automated measurement was smaller than manual 3D measurement. In contrast, LVEDV and LVESV have larger volumes than manual 3D measurement, which is similar with previous published data[4]. In the present study there was good correlation between automated 3DE and manual 3DE measurements of LVEF, LVEDV, and LVESV (Table 5). Unfortunately, the agreement analysis shows that these two methods (Automated 3DE and manual 3DE) do not agree equally in LVEF, LVEDV, and LVESV measurements (Table 6). This finding means that these two methods cannot produce the same results. Accordingly, in daily clinical practice these two methods cannot replace each other especially in cases where the patient's condition is as in this study sample. Which method is more suitable for these populations remains to be determined in future studies. In view of these results, it is better to compare these methods with Cardiac Magnetic Resonance Imaging.

Clinical Impact

In this study, the use of automated analysis software significantly reduced the time required to obtain LVEF, LVEDV and LVESV. This outcome is important: in an echocardiography laboratory in which 30 echocardiographic studies are interpreted per day, if on average it requires 180 seconds to measure these data from one 2D study, then in 1 day, >90 minutes are spent performing these measurements. With the use of this automated program, this time is decreased to only about 30 minutes per day, a time saving of more than 60%.

Study Limitations

The number of study patients was relatively small and only patients with sinus rhythm were enrolled in present study. These results cannot be extrapolated to patients with irregular rhythms. The applicability and accuracy in these populations remains to be determined in future studies.

CONCLUSION

This study is the first to demonstrate that automated software can be used in patients with severe mitral stenosis and uncorrected atrial septal defect measuring the LV volumes and LVEF. Furthermore, we found that this automated software was significantly faster than manual 3DE analysis and thus can help overcome the time-consuming use of 3DE manual measurements.

Disclosures and Ethics

The Author declares no conflict of interests.

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