Original Research Paper

Measurements of Mitral Annular Displacement in 2D Echocardiography Images

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Abstract: Mitral Annular Displacement (MAD) in echocardiography has been described as a variation in mitral annulus position between the end-diastolic and the end-systolic in a complete cardiac cycle. It could be used as a rapid and reproducible method of determining the LV global systolic function and could be an easily detectable index for wall motion abnormalities. In this study, a computational method of MAD was implemented based on the mitral annulus motion tracking at both sides; namely the lateral side and the septal side using 2D-Echocardiographic (2DE) datasets. This method comprises three main processing stages: 2DE dataset preparation, Region Of Interest (ROI) selection and MAD measurements. For each 2DE dataset, MAD was computed as the movement distance toward the LV apex at both sides individually in two-consecutive frames using the 'Euclidian distance' method. Then, the maximum displacement occurs during a complete cardiac cycle was measured in millimetres (mm) for each side. The overall datasets used are 178 original 2D-echocardiography images in 4-chamber view. The experimental results for MAD measurements were compared with results that obtained by TMQ Advanced technique using QLAB software. The comparative analysis was done qualitatively by visual observation of two expert and the comparison scores show that the proposed method of MAD measurements has high acceptability of 85%. Furthermore, the quantitative analysis of the MAD method is comparable with TMAD measurements by QLAB and there is no significant differences in displacement measurements.

Keywords: LV Systolic Function, Displacement Measurements, QLAB Software, Statistical Analysis, Mitral Annulus

Introduction

Echocardiography is the application of diagnostic ultrasound imaging to the heart which allow direct visualization of cardiac structure and wall motion. It has received in the evaluation of cardiac disease and in characterizing the structure and function of the heart. In clinical practice, echocardiography is widely used, non-invasive and cost-effective technique. It could be a useful diagnostic tool for assessing the abnormality of LV systolic function which based on the wall movements (Rahmat *et al*., 2012; Nandagopalan *et al*., 2010; Jagatheeswari *et al*., 2009). The measurement of MAD has been considered as a rapid and reproducible method of determining the LV global systolic function and could be an easily detectable index for wall motion abnormalities (Hedberg *et al*., 2006). The main goal of this study is to measure the MAD based on Septal and Lateral motion tracking in a complete cardiac cycle.

A variety 2D-echocardiographic images through complete cardiac cycle was used for experimental results in many investigative researches (Dawood *et al*., 2011; Ahanathapillai and Soraghan, 2010; dos Reis *et al*., 2008; Salvador *et al*., 2003). Due to the anatomical structure difficulties in 2D-echocardiography images including speckle noise, low contrast and signal

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dropouts, not all images provided clear tissues of myocardial wall and in some cases, spatial filtering was needed (Sun *et al*., 2013; Al-Surmi *et al*., 2013; Dawood *et al*., 2012; Hoque and Al-Mahfuz, 2011; Ahmed and Nordin, 2011). In the literature, most of the common tracking methods for measuring MAD which depending on the myocardial tissue structure (Storaa *et al*., 2004; Pan *et al*., 2001). Measurement of MAD by M-mode echocardiography from apical four-chamber view has been described during recent years as a simple and reliable index for assessment the left ventricular function (Eto *et al*., 2005; DeCara *et al*., 2005; Emilsson *et al*., 2000). MAD was measured using tissue tracking method based on Doppler tissue imaging that allows rapid semi quantitative visual assessment of the systolic distance of tissue motion along the Doppler axis by a graded colour display (Zahid *et al*., 2013; Ito *et al*., 2007). On the other hand, two-dimensional echocardiography was performed to evaluate MAD results based on speckle tracking (Black *et al*., 2013; Buss *et al*., 2012). Tissue Mitral Annulus Displacement (TMAD) measurements are done by 'TMQ Advanced' technique using QLAB software. Three points are placed by the specialist (i.e., clinical cardiologist) in the first frame; two at septal and lateral leaflets of mitral annulus and third at the apex (Narayanan *et al*., 2007).

Materials and Methods

2DE Dataset Preparation

In this study, 2D-echocardiography images obtained with permission from the Malaysian National Heart Institute (IJN). These images were acquired using the 'iE33 Philips' medical machine with QLAB software under the supervision of a Consultant cardiac anesthesiologist. Accordingly, the 2DE dataset acquisition and preparation stage consists of three major steps: Firstly, a matrix array transducer of TEE probe is connected to a capable echocardiography system be used on a normal subject. In the second step, all acquired data is transferred from the 'on-line' medical system directly to the 'off-line' workstation by running the QLAB software. Finally, each 2DE video broken down into its constituent frames according to the frame rate. Each of the frames are saved in the Windows BMP format. The steps in 2DE image dataset collection and preparation that were used in this study are shown in Fig. 1.

ROI Selection

Three ROI were identified manually in the first frame of 2D echocardiography video by the specialist (clinical cardiologist). The first two ROI were placed at the septal side and the lateral side of the mitral annulus and the third ROI was placed at the apex of LV. To reduce the time-consuming, the desired ROI was cropped from background and saved it in a new small image for processing. Those three ROI in apical four-chamber view are shown in Fig. 2. The selected ROI of Septal and Lateral are individually saved in a new sub-image of 40×40 pixels window size.

MAD Measurements

As mentioned earlier, the MAD measurements is a useful method that could be used to determine the global LV systolic function and a reliable index for myocardial wall motion abnormalities. Therefore, for each 2DE image sequences, the movement distance was computed in pixels toward the apex at both the lateral and septal sides individually in two-consecutive frames based on the Euclidian distance method as represented in Fig. 3. The parameter P refers to the point in frame f and the parameter $P^{`}$ refers to the point in the next frame $f+1$. The x-y coordinates for each labeled point $P$ are saved in two scalars $xP$ and $yP$ while the x-y coordinates for each labeled point $P^{`}$ are saved in two scalars $x^{□}$ and y · Hence, the distance values of two points P and $P^{`}$ are calculated from Equation 1 and saved in voxel Dt for each two consecutive frames f and $f+1$ as follows:

$$D_{tk,i} = \sqrt{(xP_i - x□_i) + (yP_i - y□_i)^2} \quad (1)$$

Where:
k = The number of labeled points (Lateral and Septal)
i = The frame number

Then, the movement distance computation will be applied to the next pair-frames and so on until the last frame. Accordingly, for each labeled point, the maximum value of displacement is measured according to the cumulative distances Dt in pixels for each pair-frames through complete cardiac cycle. This displacement value (*Dispt*) is computed as in Equation 2.

$$Dispk = Max\left[\sum_{i=1}^{n} Dt_{k,i}\right] \quad (2)$$

Where:
n = The total number of frames
k = The number of labeled points (Lateral and Septal)

In order to convert the MAD measurements from pixels into millimeters (mm), it is required to know the resolution of image in dot per inch (dpi). For this purpose, a method to compute the input image resolution was proposed using the mathematical calculation based on the depth parameter which used in acquiring 2D-echocardiography images and the standard convertor formula.

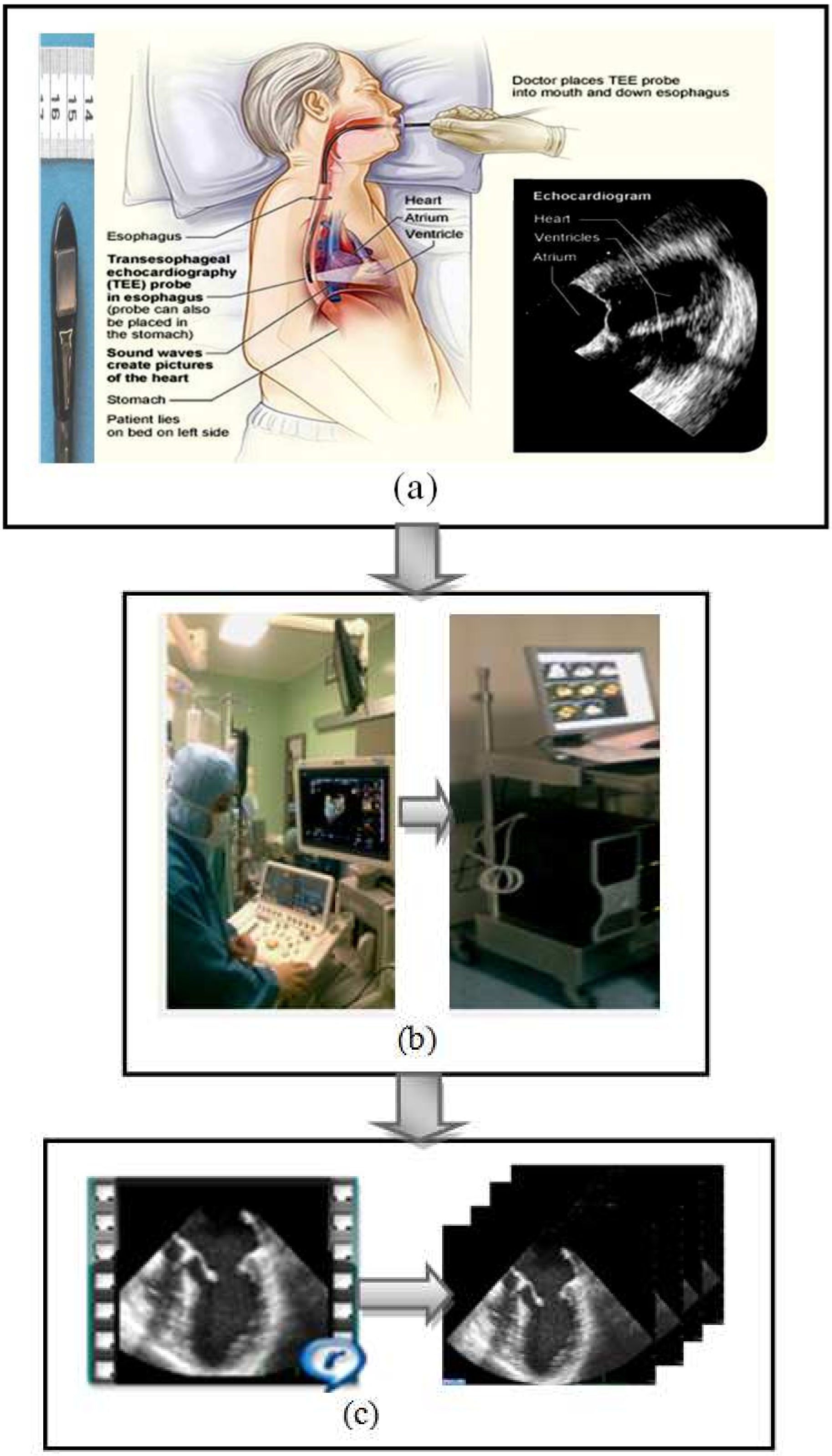


Fig. 1. Three steps of 2DE dataset collection and preparation; step1: 2DE dataset acquisition (a), step2: Dataset transformation (b) and step3: 2DE images preparation (c). Image in (a) adopted from: "National Heart, Lung and Blood Institute", 2012

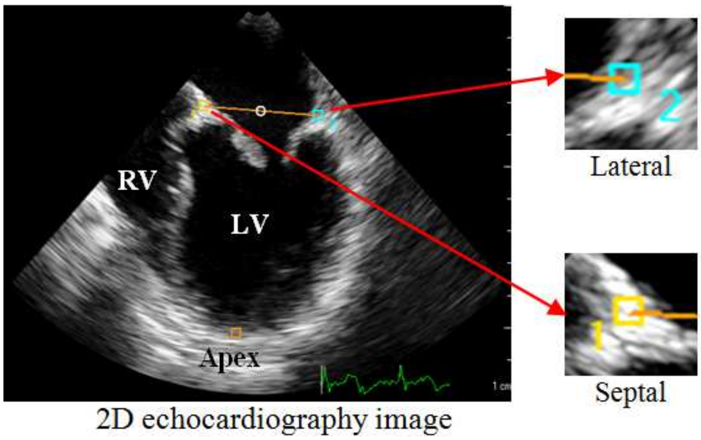
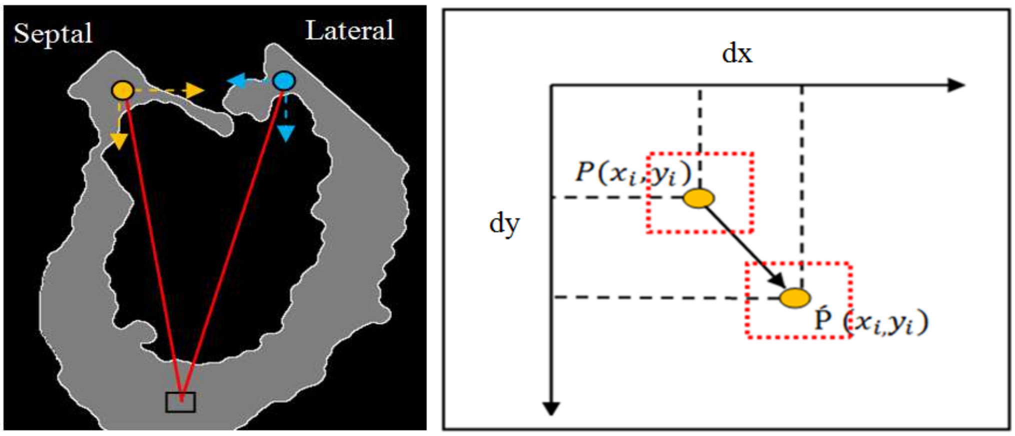
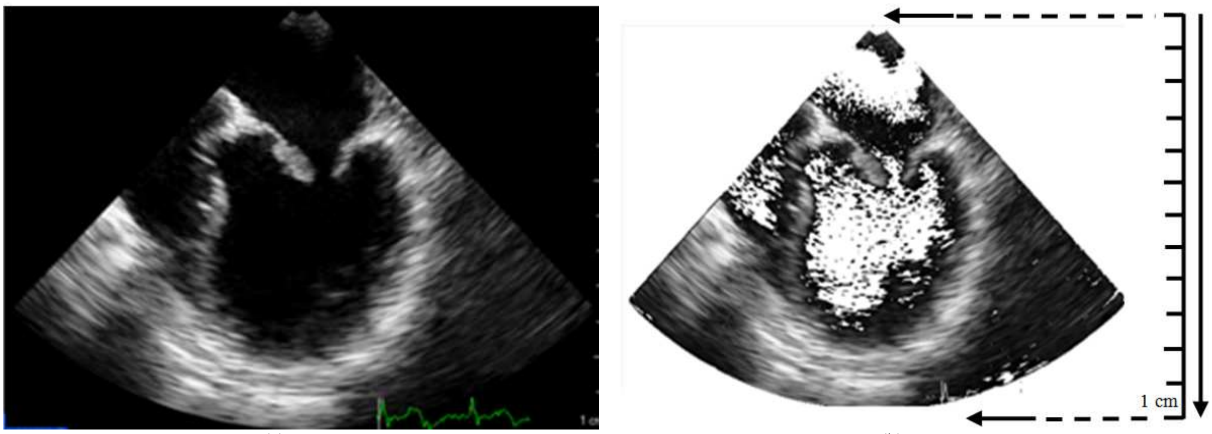


Fig. 2. Example of three ROI selection were manually placed at first frame: (1) The septal side, (2) the lateral side of the mitral annulus and (3) the apex of LV. LV, left ventricle; RV, right ventricle



(a) (b)

Fig. 3. The representative example of mitral annular at both sides of Septal and Lateral (a) and the computation of movement distance for each labeled-point in two-consecutive frames (b)



(a) (b)

Fig. 4. Experiment of the resolution calculation based on depth parameter used in 2DE image acquisition (a) and the height Y of extracted ROI (b)

In variety of acquired data, the depth parameter (P) is different from one 2DE dataset to another such as the sample illustrated in Fig. 4a and has a depth of 12 cm. Therefore, the proposed method for the resolution calculation in 2DE image comprises from three main steps:

Step1: Extract the Region Of Interest (ROI) from black background of input image, consider this ROI as the reference object and save it in a new image S of size N × M as shown in Fig. 4b.
Step2: Identify the height (H) of the new image based on Y-axis and then divide it on the depth to calculate the total pixels in each centimeter (P_{cm}).
Step3: Compute the image resolution (dpi) according to the standard convertor formula from pixels into centimeter and thus the dpi value can be derived from Equation 3:

$$dpi = \frac{(H * 2.54)}{} \qquad (3)$$

Where:
H = The height of image S in pixels
P = The depth parameter used in 2DE dataset acquisition process

Then, the displacement measurements will be converted from pixels into millimeter (mm) by multiplying the P_{cm} value by 10 and the new values of displacement individually saved in a profile to be used as input parameter for comparison process and statistical analysis.

Results and Discussion

As mentioned in section 2.1, all 2DE datasets were acquired using a matrix array X2-7t transducer (TEE) which connected to the medical system 'iE33 Philips' at the Malaysian National Heart Institute. To justify the accuracy of the displacement measurements based on the findings of the resolution calculation, the datasets were divided into two groups. The first group (Group1) was used for the proposed method implementation of MAD measurements which contains original 2DE videos of 4-chamber views within a complete cardiac cycle for seven different patients that saved in AVI format. Each video was converted into frames (2DE images) with a total numbers of 178 2DE frames for all datasets. In the second group (Group2), the same seven 2DE videos with tissue mitral annulus displacement TMAD measurements were used to validate the performance of the proposed method via a comparative analysis. TMAD measurements have been done for all datasets using 'TMQ Advanced' technique (Narayanan *et al*., 2007), where QLAB has been used as a reference to validate the accuracy of the results by qualitative and quantitative assessment. Three points are marked by the specialist (clinical cardiologist) in the first frame; two at the septal and lateral leaflets of the mitral annulus and the third at the LV apex as shown in Fig. 5.

In the experiments, the Mitral Displacement Annulus (MAD) for lateral and septal points were measured using the proposed method of displacement calculations based on the x-y coordinate of these two points. However, the accuracy of the experimental results depend mostly on how the proposed method successfully measures the MAD at septal side (MAD_S) and lateral side (MAD_L) of the LV myocardial wall. The experimental results of MAD measurements using the proposed method have been qualitavely evaluated for all datastes by two experts users; the clinical cardiologist and the cardiac technician. A comparative analysis of MAD measurements were made between the results obtained by the proposed method and the results from QLAB by 'TMQ Advanced' technique. Several examples of the experimental results for mitral annular displacement measurements with Time/curve which obtained from the proposed method and QLAB software respectively are presented in Fig. 6.

The acceptability comparison of our measurements (MAD) against QLAB measurements (TMAD) have been done according to the opinion of two experts, which is represented by a score as shown in Table 1. The experts scores highly depended on the reliability of the representative results by the proposed method. The MAD measurements were implemented for all datasets including Group1 using the proposed method and Group2 by TMQ measurements from QLAB software.

The measurements values of MAD_L and MAD_S in both methods of Group1 and Group2 are listed in Table 2. For quantitative assessment, the statistical calculations by mean values ± standard deviation (Mean ± SD) have been done to compare the differences of MAD measurements for each method. The comparative analysis were made between these two groups using Mann-Whitney test for MAD_L and MAD_S values. The variance in Mean ± SD values of MAD_L and MAD_S between Group1 and Group2 are presented in Table 3.

Accordingly, the statistical results of the comparison between Group1 and Group2 using the 'Mann-Whitney' test showed no significant differences between displacement measurements for MAD_L ($P = 0.55$) and MAD_S ($P = 0.61$). In Fig. 7, the comparative analysis results of the MAD_S and MAD_L measurements are shown. Based on these experiments, both qualitative and quantitative assessments were found the results of Group1 and Group2 to be comparable. Therefore, the proposed method for displacement measurements is justified based on the finding of resolutions calculations and can be considered as an accurate method.

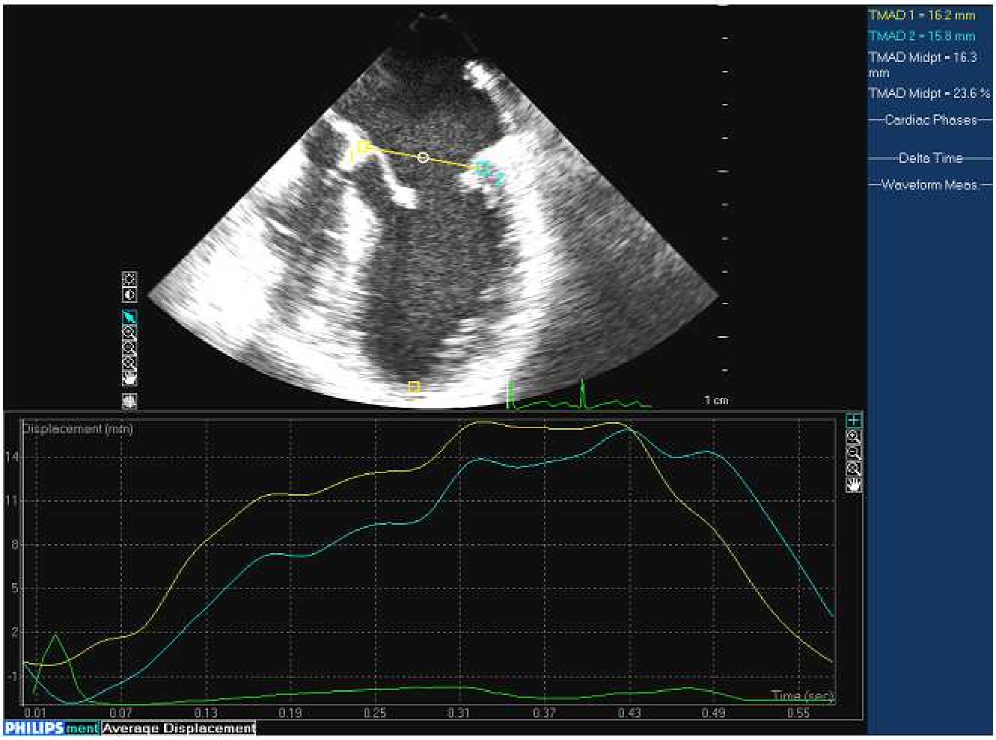


Fig. 5. The results of TMAD measurement using 'TMQ Advanced' technique by QLAB software

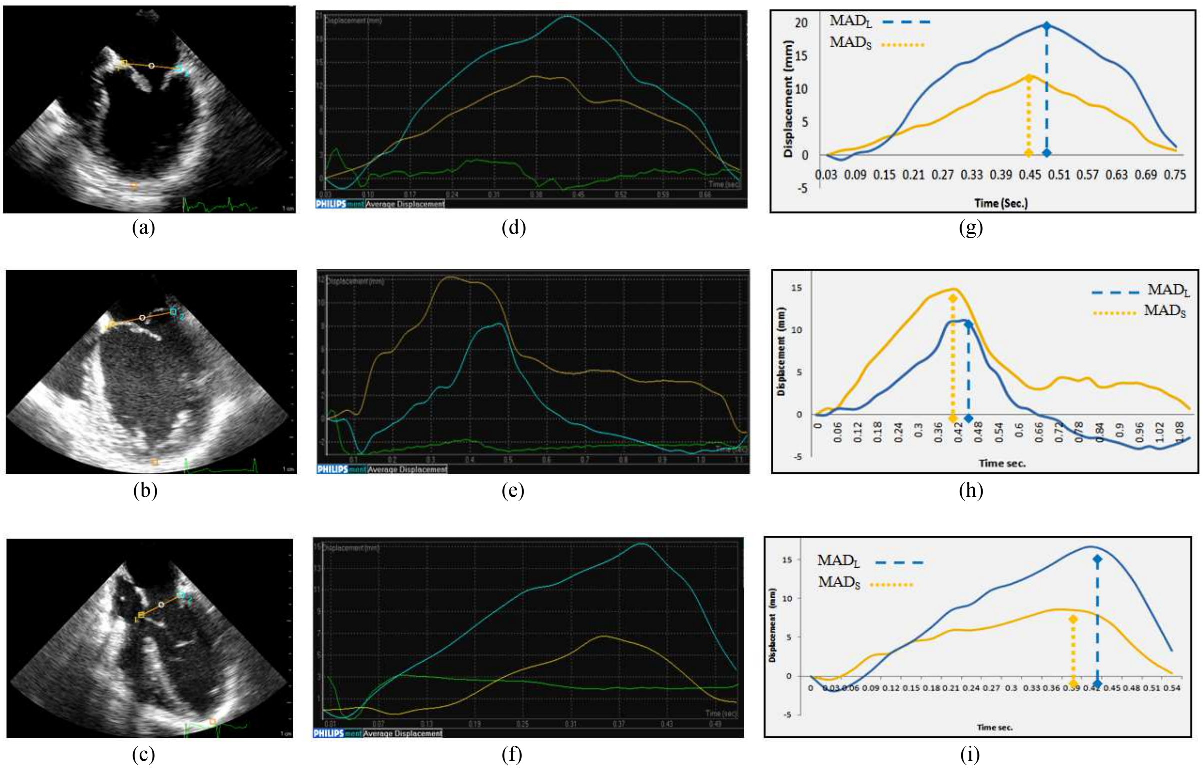


Fig. 6. Several examples of the mitral annular displacement measurements with Time/curve in 4-chamber view of 2D-echocardiography images (a-c) using 'TMQ Advanced' technique by QLAB software (d-f) and the proposed method of MAD measurements (g-i)

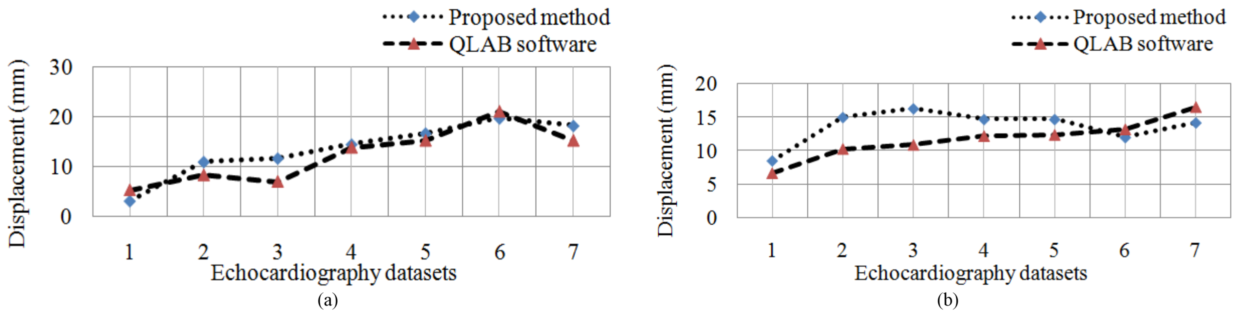


Fig. 7. The comparative analysis results of MADL (a) and MADS (b) measurements to all datasets using the proposed method and QLAB software

Table 1. The qualitative assessment for MAD measurements by visual observation of two experts with their check mark in black and red colour

2DE images N = 178	Evaluation scores: Low	Acceptable	High
Pt #1			√√
Pt #2		√	√
Pt #3		√√	
Pt #4			√√
Pt #5			√√
Pt #6			√√
Pt #7			√√

Table 2. The MAD_L and MAD_s measurement values in millimetres (mm)

	Group1		Group2	
2DE datasets	MAD_L	MAD_S	MAD_L	MAD_S
Pt #1	14.5	14.2	15.8	16.5
Pt #2	3.8	8.4	5.3	10.9
Pt #3	11.0	14.7	8.0	12.2
Pt #4	16.7	8.5	15.2	6.7
Pt #5	11.7	17.3	7.3	12.4
Pt #6	19.7	12.0	20.6	13.2
Pt #7	19.5	15.0	13.7	10.3

Table 3. The quantitative assessment for MAD measurements by statistical measurements of Mean ± SD

N = 7	Group1 Mean ± SD	Group2 Mean ± SD
MAD_L	13.78±5.81	12.82±5.63
MAD_S	12.58±3.17	11.73±2.91

Conclusion

In this study, the main aim is to measure the mitral annular displacement MAD based on Septal and Lateral motion tracking through a complete cardiac cycle in 2D-echocardiography images. In clinical practice, MAD measurement is a reproducible method of determining the LV global systolic function and could be an easily detectable index for wall motion abnormalities. A computational method of MAD measurements was proposed based on the findings to estimate the image resolution. The comparative analysis of displacement measurements have been done qualitatively and quantitatively between the proposed method of MAD and TMAD measurements by QLAB software. In the context of qualitative assessment, the results clearly demonstrated that the MAD measurements has high acceptability of 85% according to the opinion of two experts by visual observation. Furthermore, the quantitative analysis shows that the MAD measurements method is comparable with TMAD measurements by QLAB and there is no significant differences in displacement measurements.

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Author's Contributions

Faten A. Dawood: Designed the research plan and organized the study. Coordinated the overall framework and participated in all experiments, data-analysis as well as contributed to the writing of the manuscript.

Rahmita W. Rahmat: Designed the research plan and organized the study. Participated in all experiments, coordinated the overall framework and contributed to the writing of the manuscript.

Suhaini B. Kadiman: Designed the research plan and organized the study. Participated in all clinical experiments, coordinated the data-acquisition and analysis.

Lili N. Abdullah: Participated in the research plan and organized the study. Reviewing the research and participated in the results analysis.

Mohd D. Zamrin: Participated in the research plan. Coordinated in the comparative study of experiments and the results analysis.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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