Research Article

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The Probability of Multidetector Row Computed Tomography (MDCT) for Assessment of Transmitral Flow Velocities and Transannular flow Velocities in Comparison with 2-Dimensional (2D) Echocardiography

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ABSTRACT
Two-Dimensions (2D) echocardiography using TDI has been used most commonly to evaluate diastolic LV function. Although the role of MDCT imaging for evaluation of coronary atherosclerosis has been explored extensively. Moreover, assessment of LV volumes and systolic function using MDCT were studied before and showing accurate myocardial border delineation despite its clinical significance use regarding radiation and contrast. The probability to evaluate diastolic function using MDCT has not been studied well yet. The present study was aimed to evaluate the probability of cardiac CT for assessment of diastolic function in a direct comparison with 2-dimensional (2D) echocardiography using combined assessment of transmitral velocity and transannular mitral velocity.

One hundred and twenty patients' consecutive patients who had been referred for 64-MDCT imaging were prospectively selected from our clinical registry. After exclusion criteria had been applied, forty patients who had undergone 64-MDCT and 2D echocardiography with TDI were enrolled. MDCT and 2D echocardiography were performed within the same day and no acute coronary events or worsening of angina occurred between the examinations and no changes in the use of medication occurred between both examinations.

A good correlation was found for demonstrate the probability of multidetector row computed tomography (MDCT) for assessment of trans-mitral flow velocities and trans-annular flow velocities in comparison with 2-dimensional (2D) echocardiography using tissue Doppler imaging (TDI).

Keywords: Echocardiography, MDCT, Diastolic Dysfunction, Transmitral Flow Velocities, Transannular Flow Velocities, Coronary Artery Disease

Introduction

Diastolic left ventricular (LV) function plays an important role in the evaluation of clinical symptoms, therapeutic options, and prognosis in patients with cardiovascular disease. More specifically, it has been shown that diastolic dysfunction represents a clinical syndrome. Obesity, AF, Hypertension, Diabetes mellitus, chronic kidney disease and coronary artery disease are multiple predisposing conditions for Diastolic dysfunction [1].

Several indices of diastolic function can be quantitatively assessed, and some can be quantified by more than one measure. Doppler echocardiography represents the most commonly and feasible used approach for evaluation of diastolic function. For the evaluation of diastolic function, trans-mitral velocity has been used frequently as a noninvasive alternative to directly measured LV filling pressures. Combined assessment of trans-mitral velocity, transannular mitral velocity and Left atrium volume (LA) by tissue doppler will be more accurate for the evaluation of diastolic LV function [2].

Cardiac computed tomography (CT) is a noninvasive imaging modality for the evaluation of coronary atherosclerosis. In specific subsets of patients, multiphase CT imaging may be indicated to ensure diagnostic image quality for visualization of the coronary arteries. Multiphase CT studies have been restricted to LV systolic function analysis, and a little information is available on the ability of cardiac CT imaging to assess diastolic LV function [3,4].

Accordingly, the present study was aimed to evaluate the probability of cardiac CT for assessment of diastolic function in a direct comparison with 2-dimensional (2D) echocardiography using combined assessment of transmitral velocity and transannular mitral velocity.

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Materials and Methods

Materials

One hundred and twenty patients' consecutive patients who had been referred for 64-MDCT imaging were prospectively selected from our clinical registry. MDCT imaging was performed to evaluate known or established Coronary artery disease (CAD). 2D Echocardiography with TDI was performed. Both examinations had been performed sequentially, in random order on the same day. Patients without evidence of CAD on previous diagnostic tests were suspected to have CAD (and therefore referred for CT coronary angiography). Coronary artery disease was defined as previous myocardial infarction, revascularization or evidence of CAD on previous diagnostic tests.

Study exclusion criteria was based on: (1) poor MDCT image quality (2) absence of Doppler echocardiography examination within 3 months (3) valvopathy (mitral or aortic valve dysfunction), (4) supra ventricular arrhythmias, (5) pulmonary hypertension and (6) severe LV systolic dysfunction. Additionally, patients with unstable angina pectoris or acute coronary syndrome were excluded from further analysis. After exclusion criteria had been applied, only 40 patients were randomised to 2 groups.

Method

MDCT Analysis

MDCT imaging was performed with a 64-slice dual source MDCT scanner (Siemens, Somatom, sensation definition). Prior to MDCT imaging, patients were monitored for blood pressure and heart rate. Patients with a heart rate ≥80 beats/min were given Atenolol 50 or 100 mg orally, unless contra-indicated. All scans were acquired in a retrospective ECG-gated mode time delay to scan after contrast administration was detected by test bolus technique where 10 ml of contrast was injected through IV-line to calculated time delay needed for starting the injection till peak contrast concentration reaches the ascending aorta. For the contrast-enhanced helical scan, collimation was 64x0.5 mm with a rotation time of 400 ms. Tube current and voltage were 350 mA and 120 kV. Planned images were carried out after injecting calculating volume of contrast depending on scan volume and table pitch (the contrast used was non-ionic iso-osmolar with an iodine concentration of 370 mg/dl). Scanning was performed during an inspiratory breath hold of 8 to 12 seconds.

Data were reconstructed with a slice thickness of 1 mm and a reconstruction interval of 1 mm. With the use of half reconstruction algorithms, the actual temporal resolution was 200 milliseconds. Segmented reconstruction algorithms yielded a temporal resolution of up to 50 milliseconds, depending on the actual imaging acquisition conditions (pitch, rotation time and heart rate). Images were reconstructed at intervals (from 30% to 70% of the R-R interval with 5% increments) and transferred to a separate workstation where cardiac volumes and measurements analysis were done manually for each phase. Contrast-enhanced scans were analyzed by an independent observer who was blinded to all ECHO data.

MDCT - Mitral Valve Area

Mitral valve area (cm^2) was measured to enable direct comparison of volumetric indices derived from MDCT with velocity-based parameters as assessed with 2D echocardiography. The mitral valve area (cm^2) was measured by plainmetery was calculated [5]. (Figure 1)

Figure 1: Measurement of Mitral Valve Area by Cardiac CT

MDCT - Transmitral Velocity

The Transmitral velocity (cm/s) was calculated by the following formula: Transmitral velocity = transmitral flow (mL/s) / corresponding mitral valve area (cm^2) = cm^3/ cm^2 = cm/sec.

How to get Transmitral flow (mL/s) by MDCT?

At first, LV volumes were calculated for mentioned cardiac phases (each phase represented 5% of the cardiac cycle). For each phase, endocardial contour detection was performed manaually on 1 mm sliced reconstructed short axis images ranging from mitral valve annulus to the cardiac apex. Papillary muscles were regarded as part of the LV cavity and were included in the LV volume analyses. (Figure 2)

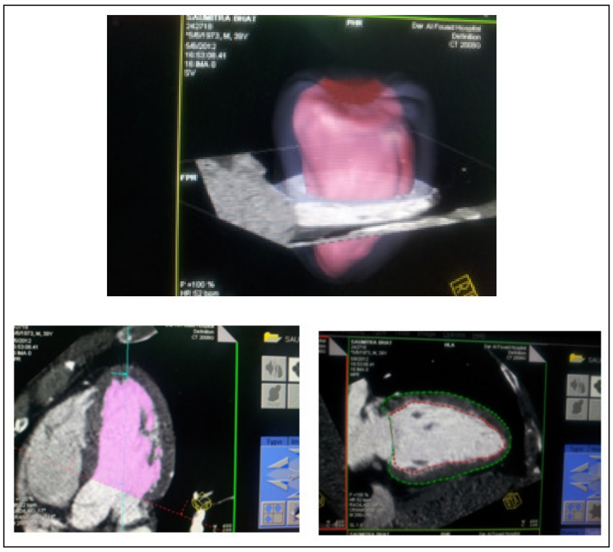

Figure 2: Measurement of LV volumes

Next, LV volumes were plotted in a volume versus time curve. In addition, changes in LV volumes between two consecutive phases (first derivative) were derived and used to calculate the transmitral flow (mL/s) per phase. Subsequently, the maximal transmitral flow (mL/s) in early and late diastole was derived using the transmitral flow versus time curve.

To allow direct comparison with 2D echocardiography, the maximal transmitral flow (mL/s) in early and late diastole was divided by their corresponding mitral valve area (cm^2) (which was measured during early and late diastole, as described below), yielding an early and late peak transmitral velocity (cm/s) and the E/A ct. (Figure 3)

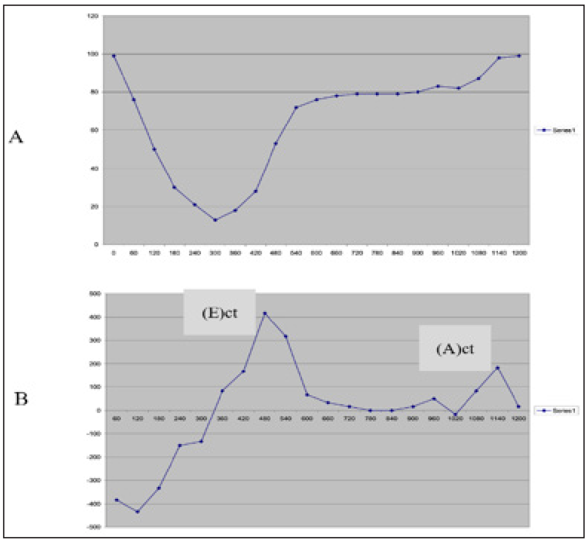

Figure 3: (A) volume versus time curve (B) first derivative from the volume versus time curve was plotted in another curve showing peak change of transmitral volume (ml/s) in early (E)ct and late (A) ct diastole.

Peak transmitral velocity (cm/s) was expressed as early (E) ct and late (A) ct diastole. The peak value represents the highest mean value of the measurements obtained during early and late diastole [5].

How to get MDCT - Mitral Septal Tissue Velocity?

Myocardial tissue velocity (cm/s) was measured at the septal level of the mitral valve annulus attachment. Measurements of peak mitral septal tissue velocity (cm/s) during early diastole (Ea)ct. For mentioned phases, LV length (mm) was calculated as the distance between two anatomical markers, positioned at the mitral septal annulus (MA) and cardiac apex. Anatomical markers were positioned at reconstructed 4-chamber view. The LV length (mm) per phase was plotted in an LV length versus time curve. Changes in LV length between two consecutive phases were calculated (first derivative) and used to generate a velocity versus time curve. In this curve, mitral septal tissue velocities were plotted against time. The maximal tissue velocity (cm/s) during early diastole represented early peak mitral septal tissue velocity (cm/s) (Ea)ct. Finally, the estimation of LV filling pressures (E/Ea)ct was calculated by dividing early transmitral velocity (E)ct (cm/s) by the mitral septal tissue velocity (Ea)ct (cm/s) [5]. (Figure 4)

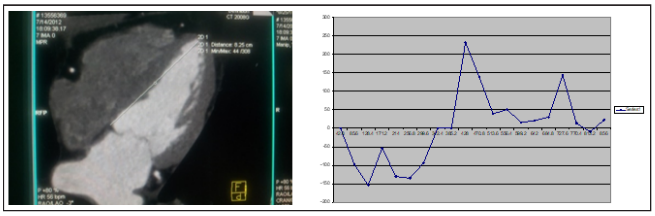

Figure 4: Mitral septal tissue velocity Ea (ct)

Transthoracic 2D Echocardiography using Tissue Doppler Imaging Acquisition

Transthoracic 2D echocardiography was performed in left lateral decubitus position using a commercially available system (Vivid-7, General Electric). Standard parasternal (long- and short-axis) and apical views (2- and 4-chamber) were obtained. In addition, continuous-wave and pulsed-wave Doppler examinations were performed. Echocardiographic analyses were performed by an independent and blinded observer [6].

2D Echocardiography - Transmitral Velocities

Standard pulsed-wave Doppler imaging was performed to assess early (E) and late (A) peak transmitral peak velocity (cm/s). Early and late peak transmitral velocity (cm/s) were used to calculate the E/A. Doppler sample volume was placed at the tip of the mitral valve leaflets, on a 4-chamber view. Subsequently, early and late peak transmitral velocities (cm/s) were obtained in diastole [6].

2D Echocardiography - Mitral Septal Tissue Velocity

Early peak mitral septal tissue velocity (cm/s) (Ea) was assessed using pulsed wave tissue doppler on a 4-chamber view. Doppler velocities (cm/s) were measured from the apical 4-chamber view positioned at the basal septal mitral valve annulus). Pulsed wave tissue Doppler images from three consecutive heartbeats were analyzed using dedicated offline software [6].

Detection of Diastolic Dysfunction

To evaluate the accuracy of MDCT to detect diastolic dysfunction, diastolic function was graded in four categories using the following criteria; normal diastolic function (E/A=0.85-1.5, E' septal more than 8 and E/Ea ≤ 8), impaired relaxation pattern (diastolic dysfunction grade I) (E/A < 0.8, Ea Septal is less than 7 and E/Ea ≤ 8), pseudonormal pattern (diastolic dysfunction grade II) (E/A=1-2, Ea Septal is less than 7 and E/Ea ≥ 9 to ≤ 12) and restrictive filling pattern (diastolic dysfunction grade III) (E/A ≥ 2, Ea Septal is less than 7 and E/Ea ≥ 14).

Based on these criteria, the patient population was divided into two groups; patients with normal diastolic function and patients with diastolic dysfunction (including impaired LV relaxation, pseudonormal and restrictive LV filling pattern) [6].

Statistical Analysis

The data were collected, revised, coded and entered to the statistical package for social science version (17). Qualitative data were presented as number and percentages and compared together using Chi-square test. While qualitative data were presented as mean, standard deviations and ranges and compared together using Independent t-test. Pearson correlation coefficient was used to assess the relation between the studied parameters and also the receiver operating characteristic curve (ROC) was used to assess the best cut off point with a sensitivity and specificity.

The confidence interval was set to 95% and the margin of error accepted was set to 5%. So, the p-value was considered significant as the following:

- $P > 0.05$: Not significant
- $P < 0.05$: Significant
- $P < 0.01$: Highly significant

Results

This study prospectively assessed 40 patients who underwent MSCT and echo.

Baseline Demographic Data

Age, Sex and Conventional Risk Factors

A total of 40 patients (34 (85%) men, mean age 50.38 ±12.2 years) were included. Table 1

Table 1: Age and Sex Among the Studied Patients

		No.	%
Sex	Female	6	15
	Male	34	85
Age	Mean ±SD	50.38±12.2	
	Range	28 - 76	

Baseline characteristics of the patient population are listed in Table below. Clinical referral for MDCT was based on 23 symptomatic patients and 17 asymptomatic patients. The risk factors of the patient population are listed in Table 2.

Table 2: Risk factors of study population

Risk Factors		No.	%
DM	Negative	28	70
	Positive	12	30
HTN	Negative	18	45
	Positive	22	55
Dyslipidemia	Negative	27	67.5
	Positive	13	32.5
Smoking	Negative	16	40
	Positive	24	60
FH	Negative	28	70
	Positive	12	30
HPI	Symptomatic	23	57.5
	Asymptomatic	17	42.5

The Echocardiographic findings of the studied patients showed a range of ejection fraction (EF) from 50-72% with a mean of 61.35 ±6.20. There was no mitral regurgitation (MR) or mitral stenosis (MS) or aortic regurgitation (AR) or aortic stenosis (AS) in all the 40 patients.

Transmitral Velocity

The E/A mean value in echo was 1.10 ±0.42 and in MDCT was 1.26 ±0.58 with a highly significant P-value (p<0.01). Pearson's correlation showed a good correlation for E/A (r=0.708, p<0.01). Table 3, figure 5

Table 3: Comparison between Echo and MDCT to evaluate transmitral velocity E/A

	Echo E/A	
	R	p-value
E/A(ct)	0.708	0.000

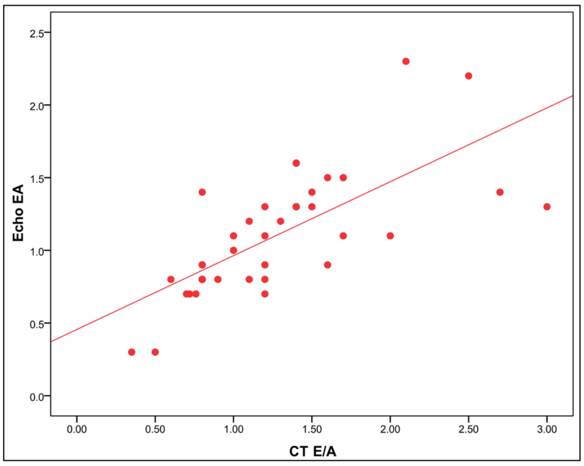

Figure 5: Comparison between Echo and MDCT to evaluate transmitral velocity E/A

Mitral Septal Tissue Velocity

The Ea mean value in echo was 11.07 ±2.87 and in MDCT was 11.44 ±3) .Pearson's correlation showed a good correlation for Ea (r=0.504, p<0.01).

The E/Ea mean value in echo was 6.49 ±2.96 and in MDCT was 6.57 ±3.35. Pearson's correlation showed a good correlation for E/Ea (r=0.404, p<0.01). Table 4, Figure 6

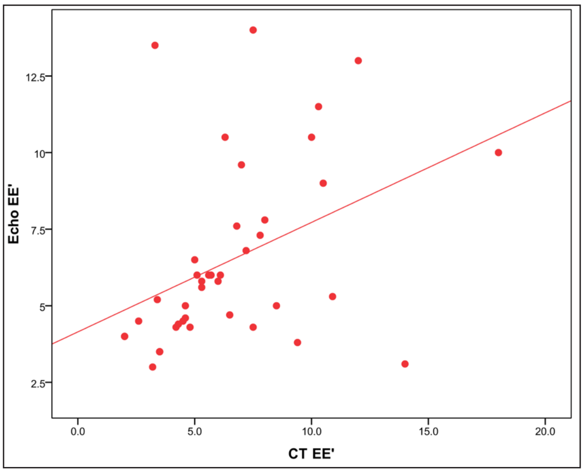

Figure 6: Comparison between 2D echocardiography and MDCT for E/Ea

Based on these criteria, the patient population was divided into two groups; patients with normal diastolic function and patients with diastolic dysfunction (including impaired LV relaxation, pseudonormal and restrictive LV filling pattern). Table 5, Table 6

Table 5: Diastolic Function Parameters for Cardiac CT and 2D Echocardiography.

		Mean	SD	t	P-value
E/A	Echo	1.10	0.42	2.549	0.01
	MSCT	1.26	0.58		
E`	Echo	11.07	2.87	0.745	0.461
	MSCT E	11.44	3.42		
E/Ea	Echo	6.49	2.96	0.137	0.892
	MSCT E/Ea	6.57	3.35		

Table 6: Comparison between Echo and MDCT for evaluation of diastolic function

DD	ECHO		MDCT		Chi-square test	
	No	%	No	%	X^2	P-value
Normal	15	37.50%	17	42.50%	0.208	0.648
Abnormal	25	62.50%	23	57.50%		
Total	40	100.00%	40	100.00%		
Concordance value	98.2%					

In total, 15 (37.5%) patients showed normal diastolic function, whereas 25 (62.5%) patients showed diastolic dysfunction using Doppler echocardiography. Of the patients with diastolic dysfunction on Doppler echocardiography, 23 patients were scored similarly using MDCT, yielding a sensitivity of 80% (95% CI 59.3 93.2). Normal diastolic function was found in 17 patients using MDCT, yielding a specificity of 80% (95% CI 51.9 - 95.7). Figure 7

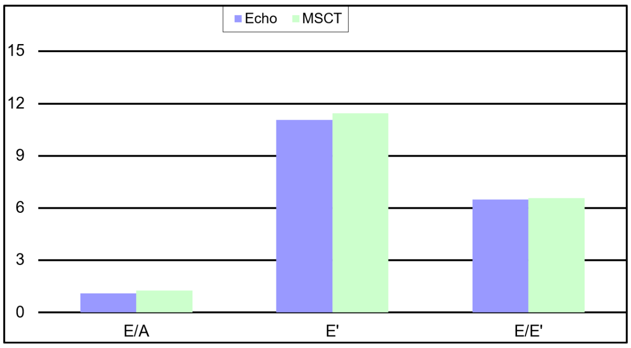

Figure 7: Diastolic Function Parameters for Cardiac CT and 2D Echocardiography

Discussion

Diastolic left ventricular (LV) function is an essential parameter to be assessed in patients with cardiovascular disease. Currently, 2D echocardiography using TDI has been used most commonly to evaluate diastolic LV function. Although the role of MDCT imaging for evaluation of coronary atherosclerosis has been explored extensively. Moreover, assessment of LV volumes and systolic function using MDCT were studied before and showing accurate myocardial border delineation despite its clinical significance use regarding radiation and contrast. The probability to evaluate diastolic function using MDCT has not been studied well yet [7].

The purpose of this study was to demonstrate the probability of multidetector row computed tomography (MDCT) for assessment of trans-mitral flow velocities and trans-annular flow velocities in comparison with 2-dimensional (2D) echocardiography using tissue Doppler imaging (TDI). Forty patients who had undergone 64-MDCT and 2D echocardiography with TDI were enrolled. Diastolic function was evaluated using early (E) and late (A) transmitral peak velocity (cm/s) and peak mitral septal tissue velocity (Ea) (cm/s). Peak trans-mitral velocity (cm/s) was calculated by dividing peak diastolic trans-mitral flow (mL/s) by the corresponding mitral valve area (cm^2). Mitral septal tissue velocity was calculated from changes in LV length per cardiac phase. Subsequently, the estimation of LV filling pressures (E/Ea) was determined. MDCT and 2D echocardiography were performed within the same day and no acute coronary events or worsening of angina occurred between the examinations and no changes in the use of medication occurred between both examinations. Unlike Boogers et al. study in which MDCT and 2D echocardiography were performed within 3 months [5].

Although invasive measurements of LV filling pressure are considered the most accurate approach for evaluation of diastolic LV function, they are not ideal for widespread application and follow-up examinations. Consequently, several cardiac imaging techniques (particularly Doppler echocardiography) have been used to assess trans-mitral velocity as a noninvasive alternative. Doppler echocardiography has been validated for the assessment of transmitral velocity as a noninvasive alternative of direct LV filling pressures [8-10].

Accordingly diastolic function was graded in four categories using the following criteria; normal diastolic function (E/A=1-2 and E/Ea ≤8), impaired relaxation pattern (diastolic dysfunction grade I) (E/A <1 and E/Ea ≤8), pseudonormal pattern (diastolic dysfunction grade II) (E/A=1-2 and ≥9 E/Ea ≤12) and restrictive filling pattern (diastolic dysfunction grade III) (E/A ≥2 and E/Ea ≥13) Based on these criteria, the patient population was divided into two groups; patients with normal diastolic function and patients with diastolic dysfunction (including impaired LV relaxation, pseudonormal and restrictive LV filling pattern) [11].

In current study Combined assessment of transmitral velocity (E/A) and mitral septal tissue velocity (E/Ea) representing an estimation of LV filling pressures showed good correlation between MDCT and 2D echocardiography with TDI. Accordingly, the current study showed that MDCT is a possible method for measurement of trans-mitral and trans-annular velocities. Additionally, in our study, the evaluation of trans-mitral velocity (E/A) showed a good correlation (r=0.708, P> 0.01) more better than the mitral septal tissue velocity which also showed a good correlation but with (r=0.404, p> 0.01).

The importance of diastolic function in patients with coronary atherosclerosis has been demonstrated in several studies. A meta-analysis pooled 3396 patients with documented myocardial infarction from 12 prospective studies and demonstrated that patients with a restrictive LV filling pattern had a significantly higher mortality rate than patients with a non-restrictive LV filling pattern (11.3 % vs. 28.7%, p<0.01) [12].

Boogers et al. evaluated whether MDCT was feasible for evaluation of transmitral velocity in 60 patients. Good correlations were found between Doppler echocardiography and MDCT for early and late transmitral velocity and E/A ratio. In Boogers study, the feasibility of MDCT was demonstrated indicating good correlations between MDCT and Doppler echocardiography for E/A ratio. In our study, although we measured LV volumes in semi-automated manner overcoming the errors of automated measurements used in Boogers et al. the probability of MDCT was demonstrated indicating good correlations between MDCT and Doppler echocardiography for E/A ratio ($r=0.708$, $p<0.01$). In both studies, correlations were not excellent for trans-mitral velocity and this may be related to other parameters that could influence trans-mitral velocity measurements, including filling pressures, degree of LV relaxation, myocardial elastic recoil and stiffness [13].

In both studies however, these measurements were not performed as these studies was only performed to evaluate the probability of MDCT. Additionally, it has been suggested to combine trans-mitral velocity and mitral septal tissue velocity measurements when evaluating diastolic heart function [11-14].

In line with the study by (Mark J. Boogers, et al) trying to open the door for MDCT to measure velocities and pressures and these measurements may help in the near future in valvular assessment by MDCT and it can make a big shift in MDCT world not only in evaluation of the cardiac anatomy but also in cardiac physiology.

The current study reported good correlations for E/Ea ($r=0.404$, $p<0.01$). Although combined assessment of early trans-mitral velocity and mitral annular velocity using MDCT showed improved correlation in Boogers et al. the assessment of LV filling pressures was performed by measuring early diastolic mitral septal tissue velocity with color-coded TDI in mentioned study. This technology provides lower values of tissue velocities as compared to pulsed-wave used in our study [11].

Accordingly, additional post-processing for diastolic dysfunction may have the potential to enhance the clinical evaluation derived from cardiac CT, particularly in patients with evidence of coronary atherosclerosis but normal LV systolic function. Moreover, the probability of MDCT for assessment of diastolic function is of particular interest as the number of patients referred for noninvasive evaluation of known or suspected coronary atherosclerosis with MDCT imaging has increased substantially over the recent years. In these patients, retrospective gating represents a good number of patients using this approach [15].

In a large multicenter observational study, including 21 university hospitals and 29 community hospitals, recently showed that retrospective electrocardiographic gating was still applied in 94% of the 1965 enrolled patients. Importantly, in patients imaged with retrospective gating evaluation of LV function volumes provides additional information without additional radiation exposure [15].

Some limitations need to be considered. At first, transmitral velocity parameters were assessed with Doppler echocardiography and MDCT as a noninvasive alternative to directly measured LV filling pressures. Although direct measurements of LV filling pressures would have been preferred, they are not ideal for routine clinical examination. Second, patients with valvular regurgitation were excluded. Severe valvular regurgitation may disturb accurate velocity measurements, leading to an inaccurate diastolic LV function analysis. Additional studies are needed to evaluate this potential confounding effect. Finally, one has to take into consideration that the sample size was rather small and needs larger number of patients in further studies.

Conclusion

A good correlation was found for demonstrate the probability of multidetector row computed tomography (MDCT) for assessment of trans-mitral flow velocities and trans-annular flow velocities in comparison with 2-dimensional (2D) echocardiography using tissue Doppler imaging (TDI). Additionally, MDCT imaging showed good correlation for the estimation of LV filling pressures when compared to 2D echocardiography.

Further investigations and larger randomized trials should be done for more accurate assessment of the diastolic function by MDCT.

Further studies needed in the field of assessment of velocities and pressures by MDCT.

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Author Contributions

Conceptualization: Mohamed Abdelkader
Investigation: Ahmed Basuoni
Methodology: Ahmed Basuoni, Mohamed Abdelkader
Formal Analysis: Ahmed Adel
Writing - original draft: Ahmed Basuoni
Review & editing: Sameh Shahin, Tarek Rashid, Mohamed El-Mahdy

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