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Left Ventricular Global Function Analysis by Multi-Detector CT Threshold Based Three Dimension Segmentation Method in Patients with Coronary Artery Disease: A Comparative Study with Two Dimensional Echocardiography

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Abstract

Background: Evaluation of global left ventricular function in patients with Coronary Artery Disease (CAD) is important for clinical diagnosis, risk assessment, therapeutic decisions, and prognosis. Because MDCT is a noninvasive imaging modality frequently used for the assessment of coronary artery disease, its ability to assess the LV volumes and EF has to be evaluated and compared with Two Dimensional Standard Echocardiography (2DSE).

Aim of Work: To evaluate the role of MDCT threshold based segmentation method in quantification of global left ventricular function in patients with coronary artery disease and compare MDCT data with 2D-echocardiography as the standard of reference.

Patients and Methods: Sixty patients with suspected coronary artery disease underwent contrast enhanced MDCT using retrospective gating. Ten phases of cardiac cycle were processed to assess end-systolic and end-diastolic phase at LV short-axis view. 2DSE was performed within two weeks before MDCT. Left Ventricular Ejection Fraction (LVEF), Left Ventricular End-Diastolic Volume (LVDV) and Left Ventricular End-Systolic Volume (LVSV) were calculated using the three dimensional threshold based segmentation method (in MDCT) and modified Simpson method (in echocardiography).

Results: LVEF, LVDV and LVSV were 51.9±10.9, 182.5±45.2 and 89.8±40.2 and 51.6±10.5, 175.4±32.3 and 87.2±30.6 on MDCT and echocardiography respectively with excellent correlation between the two modalities (*p*;0.001) using Pearson's correlationcoefficient. A Bland-Altman analysis showed that MDCT had slightly higher LVEF, LVDV and LVSV values with mean value of differences of 0.6%, 7ml and 2.5ml respectively, MDCT segmentation method had an accuracy of 91.6%, 95% and 98.3% respectively.

Conclusion: MDCT threshold based 3D segmentation method is an accurate method for quantitative evaluation of global left ventricular function compared to 2D echocardiography.

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Key Words: *MDCT – Global left ventricular function – Coronary artery disease.*

Introduction

EVALUATION of the left ventricular ejection fraction, left ventricular end-diastolic and end-systolic volumes are of great prognostic and diagnostic values in patients with CAD [1-3]. For decades, 2DSE has been the noninvasive imaging modality used routinely to evaluate LV function in clinical practice. However, it is operator dependent, inaccurate and has a relatively low reproducibility owing to the foreshortened views of the left ventricle and the reliance on geometric modeling [4].

Currently, Cardiac Magnetic Resonance imaging (CMR) is considered the gold standard for ventricular function assessment [5]. However, CMR is costly, time consuming, has limited availability and unfit for patients with metallic devices or claustrophobia [6].

Although the mainstay for cardiac CT is the assessment of coronary artery disease, the isotropic submillimeter spatial resolution, high temporal resolution, good contrast between ventricular lumen and myocardium and the evolving automated and

Abbreviations:

2DSE : Two Dimensional Standard Echocardiography.
CAD : Coronary Artery Disease.
CCTA : Coronary CT Angiography.
CMR : Cardiac Magnetic Resonance imaging.
LVEF : Left Ventricular Ejection Fraction.
LVDV : Left Ventricular End-Diastolic Volume.
LVSV : Left Ventricular End-Systolic Volume.
MDCT : Multi-Detector Computed Tomography.
TTE : Transthoracic Echocardiography.

semi-automated post-processing software make CT very well suited to obtain valuable information on ventricular function in a single breath hold **[6-8]**.

Patients and Methods

Study design and population:

This cross sectional comparative study was carried out at Zagazig University Hospitals; Radiology Department from February 2017 to February 2019. 60 patients were referred from the cardiology out-patient clinic with either known or suspected coronary artery disease for MDCT coronary angiography; they were 49 males and1 1 females; their age ranged from 27 to 72 years, mean age 52 ±11 years. The average heart rate was 62 beats/min. Chest pain (71.7%) and/or dyspnea on exertion (29.3%) were the presenting clinical scenario of the patients. Patients'data are summarized in (Table 1). Patients exclusion criteria were: Renal insufficiency (serum creatinine <1.5), arrhythmias and pulmonary diseases that hinder breath holding during MDCT acquisition, and morbid obesity.

All patients signed a written informed consent and filled a written survey including demographic and clinical data. The CT, echocardiography protocols and the consent forms used in this study were approved by the Institutional Review Board (IRB) of Zagazig University.

To determine coronary artery disease and assess left ventricular function, all patients underwent contrast-enhanced retrospective ECG gated Coronary CT Angiography (CCTA) and 2D echocardiography performed within two weeks before CCTA.

Protocol of CCTA:

Patient preparation:

All patients were premedicated with 50mg metoprolol/day for one day before MDCT examination. Those with pulse exceeding 75bpm were given another 50mg oral metoprolol half an hour before the exam to reduce cardiac motion artifacts. To achieve coronary vasodilatation, sublingual nitroglycerin) was given while the patient lying on the table.

MDCT image acquisition:

All CT angiographic examinations were performed using Philips Ingenuity core 128 TM v3.5.7.25001 (Philips healthcare systems, Netherlands) in Zagazig University Hospital. The following parameters were used: 16 X 0.75mm detector collimation, 0.39s rotation time, pitch of 0.2-0.3, a reconstruction slice width 0.6mm and increment 0.5mm the tube current was 300±40mA at 120-140kV. Scanning direction; cranio-caudal. Mean scan time was 12 seconds ±1.5, and total time for the examination including patient preparation was less than 10 minutes.

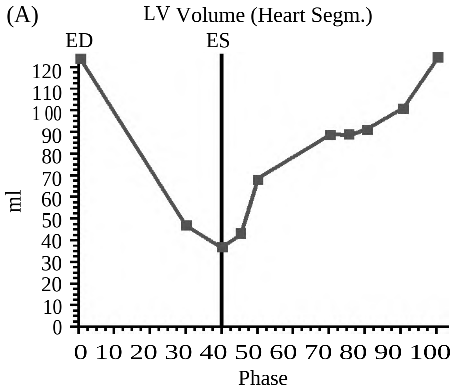
Retrospective ECG gating without dose modulation was performed to allowefficient endocardial borders definition during systole. A bolus of iopromide (Ultravist 370, Bayer Health Care) was injected into an antecubital vein at a flow rate of 5.5ml/s, followed by a 50ml saline chaser using a programmed dual head power injector pump (MedRad; USA). The dose of contrast was calculated according to the patient bodyweight (1-1.5ml/kg). Peak enhancement in the descending thoracic aorta was automatically detected with a threshold of 180 Hounsfield Unit using bolus tracing method. The procedure was done within a single breath-hold (from 10 to 15s).

MDCT image analysis:

Images were reconstructed at 10 phases: 0, 30, 40, 45, 50, 60, 70, 75, 80 & 90% of the R-R interval. Philips Extended intellispaceTM portal Workstation post-processed the images of all ten phases. Global left ventricular function is calculated using threshold based 3D segmentation method. The software generated long-axis and short-axis displays of the heart after the mitral valve or the apical plane have been manually identified. The contrast-filled LV lumen was then automatically segmented for all 10 cardiac phases Fig. (1). Automatic identification of LV cavity was performed using automated software to quantity LV volumes in end-systole and end-diastole to measure left ventricular ejection fraction. Time-volume curve and left ventricular function table were displayed Fig. (2).

Fig. (1): Automated 3D segmentation of the contrast-filled LV lumen by MDCT.

(A)



(B)

Based on Heart Segmentation	Left
ES Ventricular Volume (Phase 40%)	37.2 ml
ED Ventricular Volume (Phase 0%)	125.5 ml
Ventricular Stroke Volume	88.2 ml
Ventricular Ejection Fraction	70%
Ventricular Cardiac Output	4323.3 ml/min
LV Wall Muscle Mass	152.6 gr
HR (Mean)	49 bpm

Fig. (2): MDCT display of time volume curve through all ten phases of the cardiac cycle (A) and MDCT functional table showing LV functional parameters (B).

Echocardiography:

Transthoracic Echocardiography (TTE) is assumed to be the gold standard. All patients were examined in the left lateral decubitus by (Vivid-7; GE-Vingmed, Milwaukee Wis) ultrasound machine. Images were acquired in standard parasternal and apical two-and four-chamber views using a 3.5MHz transducer by a 15-year experienced echocardiologist, blinded to clinical data and MDCT findings, the modified Simpson's biplane method used to trace LV endocardial borders on optimal non-foreshortened apical two-and four-chamber views, and subsequently LV volumes and LVEF were derived.

Statistical analysis:

Continuous data are expressed as mean ± Standard Deviation (SD). Agreement for LVEF and LV volumes by MDCT and echocardiography was determined by Pearson's correlation coefficient and the Bland-Altman analysis. The 95% limits of agreement were defined as the range of values ±2 SDs from the mean value of differences. Then, echocardiography is assumed to be the gold standard and the sensitivity and specificity of MDCT to evaluate global LV function were calculated .To assess the diagnostic performance of MDCT. We considered EF below 55%, LVEDV above 200ml and LVESV above 90ml is abnormal by both imaging modalities [9].

Results

The current study enrolled 60 patients (18.3% were females & 81.7% were males) with known or suspected CAD. 36.7% (n; 22) of them underwent coronary artery revascularization procedures either CABG (26.7%) or stenting (10%).

In this study, the average LVEF was 51.9±10.5% (range 20-70%) when calculated by MDCT using 3D segmentation, compared to 51.9±10.9% (range 24-70%) on 2D ECHO, whereas the average LVEDV was 182.5±45.2ml (range 124-348ml) when calculated by MDCT compared to 174.4± 32.3ml (range 130-257ml) on 2D ECHO. The average LVESV was 89.8±40.2ml (range 37-241ml) on MDCT compared to 87.2±30.6ml (range 39-195ml) on 2D-TTE (Table 2).

Table (1): Patient's data.

Demographics	Values
Age (years):	
Mean ± SD	52.1±11.4
Range	27-72
Sex male/female	49/11
Cardiovascular risk factors:	
Hypertension n (%)	39 (35%)
Diabetes mellitus n (%)	25 (41.7%)
Hypercholesterolemia n (%)	32 (46.7%)
Smoking	25 (41.7)%
Clinical presentation:	
Chest pain n (%)	43 (71.7%)
Dyspnea on exertion	17 (29.3%)
History of coronary artery intervention:	
Coronary artery bypass graft (CABG) n (%)	16 (26.7%)
Coronary artery stent n (%)	6 (10%)

Table (2): Comparison between 2DSE and MDCT 3D segmentation method regarding left ventricular global function measurements.

	ECHO mean ± SD (range) median	MDCT 3D segmentation method mean ± SD (range) median	*t*-test	*p*-value
EF%	51.6±10.5 (24-70) 52.5	51.9±10.9 (22-70) 52.5	0.187	0.85
LVEDV (ml)	175.4±32.3 (130-257) 167.5	182.5±45.2 (124-348) 171.3	0.983	0.33
LVESV (ml)	87.2±30.6 (39-195) 79	89.8±40.2 (37-241) 78	M.W 0.289	0.98

M.W: Mann-Witenny U-test.

* : Statistically significant difference ($p \leq 0.05$).

The correlations:

Evaluation of EF showed excellent correlation between both methods of MDCT and 2D ECHO (r=0.96, p:0.001) Fig. (4A). By Bland-Altman method, a mean value of differences of 0.4%, and the 95% limits of agreement ranged from –5.5% to 6.2%; p;0.001) was detected Fig. (4B). Also the correlation between MDCT and 2D ECHO for the measurement of end diastolic volume was excellent (r=0.94; p:0.001) Fig. (5A). Bland Altman plot revealed overestimation of LVEDV in MDCT3D segmentation compared to ECHO with a mean value of differences of 7ml and the 95% limits of agreement ranged from –28.7 to 42.8ml Fig. (5B).

An excellent correlation was found between MDCT and 2D ECHO for the measurement of ESV (r=0.95; p:0.001). Bland Altman plot revealed overestimation of LVESV in MDCT3D segmentation in comparison to 2D-TTE with a mean value of differences of 2.6ml and the 95% limits of agreement ranged from –24.1 to 29.3ml.

Diagnostic performance of MDCT for assessment of left ventricular function:

Considering transthoracic echocardiography as a gold standard for left ventricular function assessment, MDCT 3D segmentation had a sensitivity of 94.1%, 100% and 100%, a specificity 88.4%, 93% and 97.3%, and an accuracy of 91.6%, 95% and 98.3% compared to echocardiography in detection of EF, LVEDV and LVESV respectively.

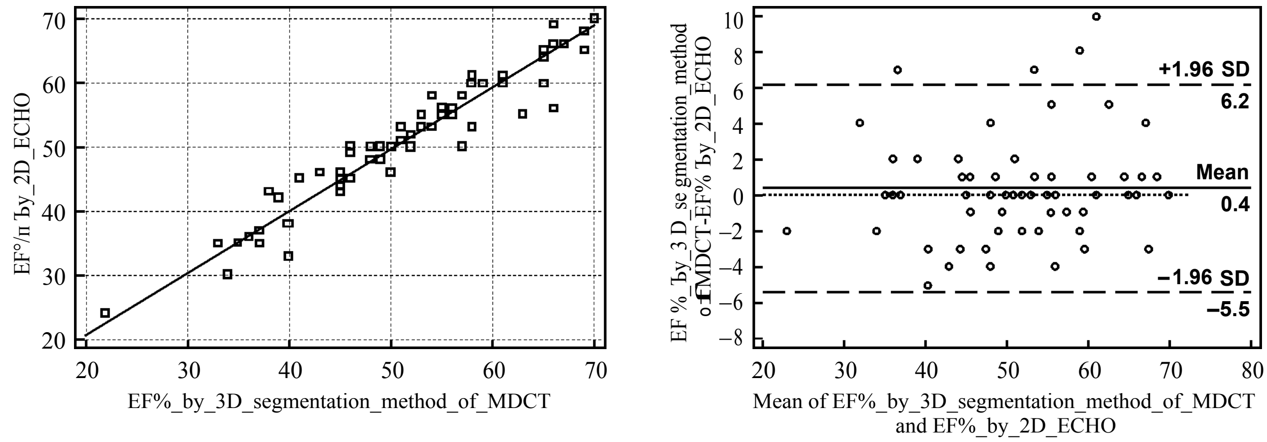


Fig. (3): Left Ventricular Ejection Fraction (LVEF). (A) Scatter plot representing the correlation between MDCT 3D segmentation method and 2DSE measurements. (B) Bland-Altman analysis representing the mean difference between MDCT and 2DSE.

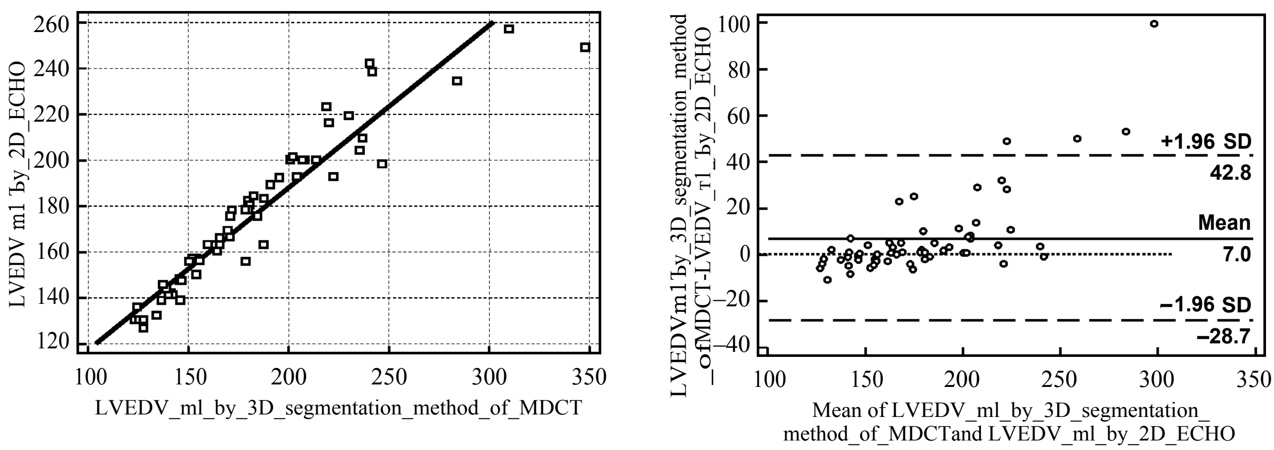


Fig. (4): Left Ventricular End Diastolic Volume (LVDV). (A) Scatter plot representing the correlation between MDCT3D segmentation method and 2DSE measurements. (B) Bland-Altman analysis representing the mean difference between MDCT and 2DSE.

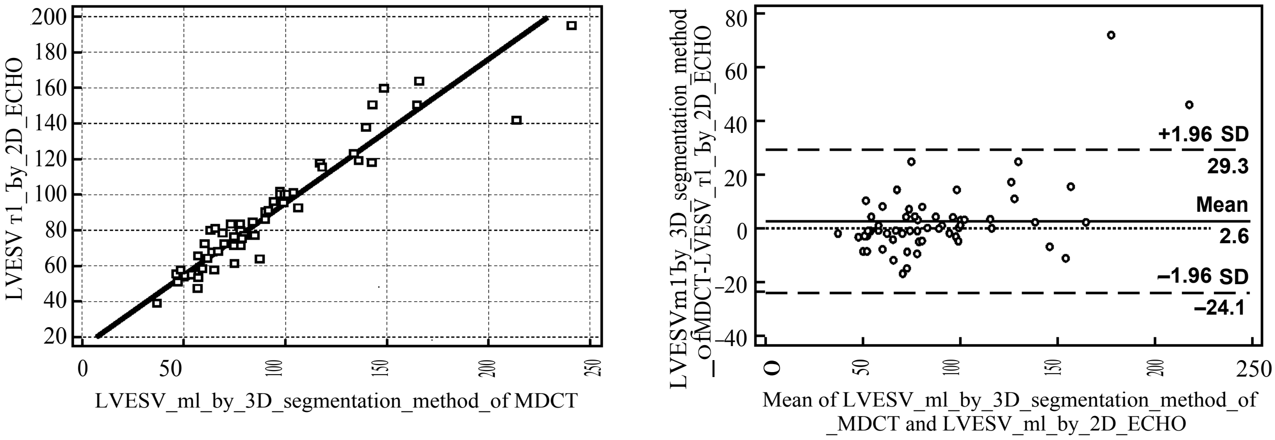


Fig. (5): Left Ventricular End Systolic Volume (LVSV). (A) Scatter plot representing the correlation between MDCT 3D segmentation method and 2DSE measurements. (B) Bland-Altman analysis representing the mean difference between MDCT and 2DSE.

Discussion

The retrospective ECG-gated coronary CT angiography helps to acquire volumetric data from whole the cardiac cycle, which used for image reconstruction. The major drawback of such method is the higher radiation exposure [10].

Recently, prospective ECG-gated technique had been developed and the radiation dose effectively decreased. It provides data about cardiac anatomy, the size of its chambers, and the pericardium. Unfortunately, it is not used to measure LV or RV systolic or diastolic functions; so long they are linked to a single cardiac phase [11]. Another efficient method to for dose reduction is the ECG table dependent tube current modulation. It can reduce the dose up to 50% [12] as approximately 25% of the maximum tube current is used during systole compared to diastole, since coronary motion is minimal during diastole, and coronary assessment is optimally performed in this phase [13], this will affect the assessment of LVESV. A study of Lim et al., on 30 patients with atypical chest pain using 128-row MDCT with ECG gated tube current modulation and compared it with 2DSE and found some discrepancy between two modalities with higher MDCT values and explained that tube current modulation may affect image quality results in poor endocardial definition and limited evaluation of coronary arteries during the period of low tube current especially in a patient suffering from arrhythmia [14].

Multiple studies have demonstrated that the evaluation of global LV function parameters by MDCT is possible in good agreement with widely used imaging modalities such as cineventriculography, echocardiography, and CMR. Although MDCT is not considered to be the first modality for evaluation of LV function, this technique allows a combined assessment of coronary arteries and cardiac function from the same data with no additional contrastor radiation exposure.

With improvements in post-processing software clinical applicability of global LV functional assessment is well-known. MDCT threshold-based 3D segmentation and Simpson methods provide accurate assessment of LV volume and function with excellent correlation with results of 2D TTE. Threshold-based 3D segmentation is preferred over Simpson method as it is less time consuming with no subjectivity.

Our study revealed excellent correlation between MDCT segmentation method and 2D TTE regarding LVEF, LVDV and LVSV (r=0.96, 0.94 and 0.95 respectively; $p<0.001$). MDCT 3D segmentation showed a higher accuracy compared to echocardiography in detection of LVEF, LVDV and LVSV.

Our result showed that MDCT provided higher values of EF, LVESV and LVEDV compared to 2D ECHO. The 2DSE technique may leads to an inaccurate delineation of endocardial border due to acquisition of 2D images in comparison to the 3D reconstruction of MDCT high quality images [15]. This is attributed to foreshortening of images in apical views by 2D-echocardiography. Also, Myocardial trabeculations may contribute to the underestimation of LV volumes by 2DSE as it reduce endocardial border definition [13]. Additionally the use of beta-blockers during MDCT examination may lead to disagreement of measurement of LV volumes between 2D ECHO and MDCT. This was agreed by Rigolli et al. [16].

Past reviews have found good correlation between 2DSE and MDCT in evaluation of global LV function [3,7,13-15,17-22]. Most of these studies had used 4-, 8-, 16- and 64-row MDCT in evaluation of LV function. Kim et al., studied 19 patients with CAD using 16 row MDCT and detected moderate correlation in calculation of LVEF between the two modalities (r=0.846; p<0.05) [7]. Salm et al., demonstrated excellent agreement between 16-row MDCT and echocardiography in 25 patients (r=0.96; p<0.0001) [20]. Henneman et al., found excellent correlation between 64-row MDCT and echocardiography in 40 patients (r=0.91, p<0.0001) [3]. Ko et al., and Maffei et al., proved good correlation between the two modalities (r=0.71; p<0.05 & r=0.87; p<0.001 respectively) [23,24]. Amin et al., also found excellent correlation between 128-row MDCT and echocardiography in 50 patients (r^2=0.9, p<0.0001) [15] and this was consistent with our results.

Most of studies used Simpson method (short axis planimetry) for evaluation of global LV function [3,7,14,15,19,20] whereas 3D segmentation method was used in studies done by Yamamuro et al., and Annular et al., [25,26]. Juergens et al., and Mühlenbruch et al., stated that MDCT 3D segmentation method can assess LV global function parameters and significantly reduces post-processing time compared to an established Simpson method. However, optimized contrast bolus planning is crucial in order to facilitate automated segmentation which is in line with our study [27,28], also Nasis et al., found an excellent correlation between 3D segmentation MDCT and 2DECHO using 320 detector CT (r^2=0.9; p=0.001) [13].

In this study, we have got a bigger sample size than the aforementioned studies; comparing 128-row MDCT with 2DSE which is the most available and commonly used imaging modality in clinical practice for estimation of left ventricular function. We performed retrospective gating MDCT without dose modulation to provide a high-quality image during systole to enable accurate endocardial delineation and avoiding overestimation of MDCT values.

The drawbacks of our study that we did not perform the CMRI of patients. So, we were not able to compare MDCT and CMRI. An excellent correlation between both modalities had been demonstrated in previous studies [4,26,29,30]. Second, we did not use contrast or 3D echocardiography which may increase the accuracy of the echocardiographic measurement. It is better to perform larger studies to clarify the correlation between 128-row MDCT, 3D contrast echocardiography and CMR for the measurement of global LV function.

Conclusion:

MDCT threshold based 3D segmentation method is an accurate method for quantitative evaluation of global left ventricular function compared to 2D echocardiography.

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تحليل الوظيفة العامة للبطين الآيسر عن طريق الآشعة المقطعية متعددة الكواشف بواسطة طريقة التجزئة ثلاثية الآبعاد فى مرضى قصور الشريان التاجى: دراسة مقارنة بالموجات فوق الصوتية ثنائية الآبعاد

إن تقييم الوظائف العامة للبطين الآيسر آساسية فى تقييم مرضى القصور فى الشريان التاجى لآنها توفر معلومات قيمة تساعد على تشخيص وتنبؤ حالة المريض. وقد آوضحت دراسات عديدة آن نتائج تقييم وظيفة البطين الآيسر بواسطة الآشعة المقطعية متعددة المقاطع يمكنها الإتفاق بشكل جيد مع طرق التصوير القلب المستخدمة على نطاق واسع مثل الموجات فوق الصوتية والرنين المغناطيسى على القلب. وعلى الرغم من آن الآشعة المقطعية متعددة المقاطع لا تعتبر آول طريقة لتقييم البطين الآيسر، إلا آنها تجمع بين تقييم حالة الشرايين التاجية ووظيفة القلب من نفس البيانات دون آى تعرض إضافى للإشعاع آو تعاطى كمية إضافية من الصبغة. وتعطى الآشعة المقطعية متعددة الكواشف فرصة فريدة لتقييم الحالة العامة للبطين الآيسر فى وجود كثير من القيود التى تواجه الطرق الآخرى المتاحة لتصوير القلب وتقييم وظائفة فهى تتيح تصوير المرضى مع زراعة شريحة معدنية لضبط نبضات القلب، وآيضاً تسمح بتصوير المرضى الذين يعانون من البدانة وآمراض الرئة المزمنة وقبل جراحة القلب. وقد آوضحت هذه الدراسة آن هناك إتفاق وإرتباط قوى بين الآشعة المقطعية والموجات فوق الصوتية فى التقييم الكمى لسعة تجويف البطين الآيسر فى نهاية إنقباضه وإرتخائه وآيضاً لنسبة الضخ لدى البطين الآيسر، فقد كان بيرسون معامل الإرتباط آكثر من تسعة من عشرة. كما فاقت دقة الآشعة المقطعية ٩٠٪ مقارنة بالموجات فوق الصوتية على القلب.