

Real-time three-dimensional echocardiographic left ventricular systolic assessment: side-by-side comparison with 64-slice multi-detector cardiac computed tomography

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Aims

To investigate by real-time 3D echocardiography (RT3DE) and cardiac computed tomography (CCT) the analysis of left ventricle ejection fraction (LVEF) and volumes.

Methods and results

A total of 67 patients (37 males, 55 ± 11 years) were studied prospectively by RT3DE and by 64-slice CCT. RT3DE data: LVEF ranged from 30 to 78.6% (63.1 ± 7.33); left ventricular end-diastolic volume (LVEDV) from 44.1 to 210 (104.9 ± 29.7) mL; left ventricular end-systolic volume (LVESV) from 11.4 to 149 (38.9 ± 19.3) mL. CCT data: LVEF ranged from 28 to 86% (66 ± 8.4); LVEDV from 51 to 212 (110.3 ± 31.2) mL; LVESV from 7 to 152 (38.2 ± 19.2) mL. Correlations relative to RT3DE and CCT were: LVEF ($r: 0.79, P < 0.0001$); LVEDV ($r: 0.82, P < 0.0001$); and LVESV ($r: 0.91, P < 0.0001$).

Conclusion

It was observed adequate correlation between RT3DE and CCT ventricular systolic function and geometry assessment.

Keywords

Tridimensional echocardiography • Cardiac computed tomography • Ejection fraction • Volumes

Introduction

For the last three decades, echocardiography has been used as the diagnostic technique of choice for the study of cardiac structures morphology as well as for left ventricular functional assessment. This broad practice has taken into consideration echocardiographic particular characteristics, such as good anatomical correspondence and reproducibility in addition to being a low-cost, easy-to-perform procedure.

However, two-dimensional echocardiography presents limitations due to geometric assumptions for the calculation of cardiac diameters and volumes taken from a few number of

spatial view planes.^{1–7} Real-time three-dimensional echocardiography (RT3DE) has improved such limitations, because it provides cardiac visualization from multiple simultaneous spatial planes. RT3DE left ventricular ejection fraction (LVEF) and LV volumes calculations have been validated in the previous studies that used magnetic resonance imaging (MRI) as gold standards.^{8–11} However, cardiac MRI present some limitations concerning patients with mechanical prosthesis, pacemakers, metallic devices, or obese people. In such context, 64-slice multi-detector cardiac ultrafast computed tomography (CCT) has been developed as a diagnostic alternative tool especially for coronary anatomy visualization. CCT could lead to a better anatomical analysis when

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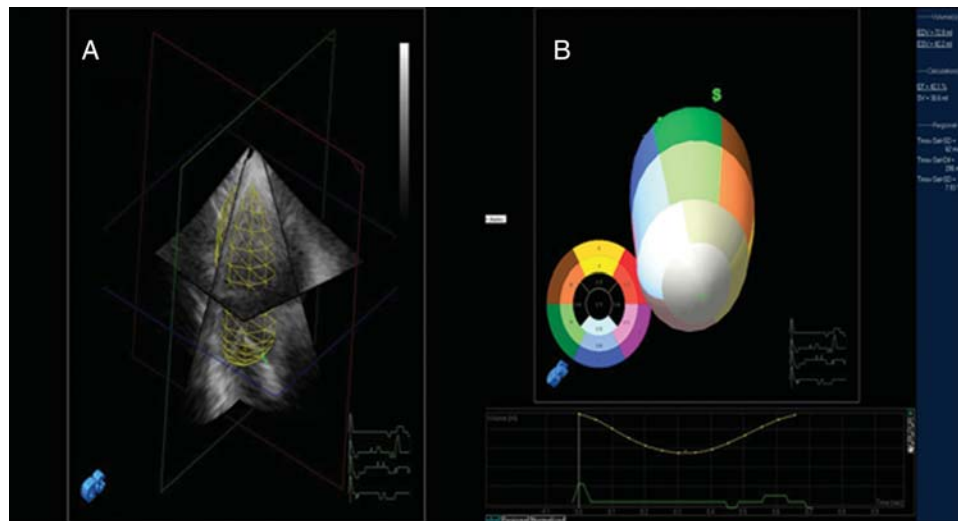


Figure 1 Three-dimensional echocardiographic image (RT3DE) with multiple observation planes of the left ventricle (A); derived RTDE left ventricular ejection fraction and volumes (17-segment model, B).

compared with echocardiography. On the other hand, echocardiography could allow better temporal structural identification. Few investigations have addressed echocardiography and CT comparison for the assessment of LVEF and LV volumes.^{11–14} Thus, the aim of the present study was to compare LVEF and LV volumes as measured by RT3DE and ultrafast 64-slice multi-detector CCT.

Methods

Study population

From November 2007 to August 2008, 75 patients were prospectively studied. Patients whose two-dimensional or three-dimensional echocardiographic images were considered technically inadequate for the analysis of the parameters studied or those presenting significantly irregular heart rhythm were not included in the study. Thus, eight of 75 patients were excluded from the study: four whose images were considered inadequate for left ventricular analysis, and four who presented atrial fibrillation. Of the 67 patients included in the study, 23 had previous history of coronary artery disease, 5 presented idiopathic dilated cardiomyopathy, 39 presented no previous history of cardiac disease. The individuals underwent echocardiographic and tomographic studies in the echocardiography laboratory and in the computed tomography department of Hospital Israelita Albert Einstein, Sao Paulo, Brazil. The mean age of the patients was 55 ± 11 years, and 47 were men. All patients had normal cardiac rhythm (sinus rhythm) and were clinically assessed at baseline by the same investigator (B.T.J.). The study was approved by the Research Ethics Committee of the Teaching and Research Institute of Hospital Israelita Albert Einstein. The individuals underwent two- and three-dimensional echocardiographic study as well as a tomographic study.

Echocardiography

The two-dimensional echocardiographic studies were performed according to the American Society of Echocardiography recommendations, and in a commercially available equipment (Philips IE33, Andover, MA, USA), equipped with a 2–5 MHz transducer and a X3

matrix-array transducer for three-dimensional image acquisition. Two-dimensional images were stored in the hard disk of the echocardiography equipment and analysed off-line in a specific software of the equipment (Q Lab, version 6.0, Philips, Andover, MA, USA). The analyses were carried out by two independent observers.

The following echocardiographic parameters were studied. (i) Two-dimensional echocardiography: (a) left ventricular end-diastolic volume (LVEDV); (b) left ventricular end-systolic volume (LVESV); (c) LVEF (Simpson's rule). (ii) Three-dimensional echocardiography: (a) LVEDV; (b) LVESV; (c) LVEF. A left ventricular 17-segment model was used for the analysis of left ventricular contractility (Figure 1).

Three-dimensional images were acquired after the two-dimensional echocardiographic study. Images were obtained with the same echocardiography equipment using a matrix-array transducer with the patient in expiratory breath-hold, and the image was gated to the electrocardiographic recording. The images were stored in the hard disk of the echocardiography equipment and analysed off-line in a specific software of the equipment (Q Lab, version 6.0, option 3DQ Advanced, Philips, Andover, MA, USA). The analyses were carried out by two independent observers.

Computed tomography

CCT studies were performed in a Toshiba 64-slice multi-detector row CT. Non-ionic iodinated contrast medium (Henetix—350 mg/mL) was injected in a peripheral vein at a 5 mL/s speed, followed by infusion of 50 mL of saline solution. The images were acquired with electrocardiographic gating, with 8–10 s breath-hold period. The image parameters included 0.4 s gantry rotation time, 120 kV tube voltage, 400 mA, and 64×0.5 mm collimation. For the analysis of ventricular function, the images were reconstructed with 1 mm width in 10 phases of the cardiac cycle. Intravenous beta-blocker (metoprolol 5 mg, up to 20 mg) was used in patients with heart rate higher than 65 b.p.m.

Analysis of LVEF and LV volumes was carried out off-line in a workstation. Quantitative analysis of the ventricular function was carried out by means of a semi-automated method (area-length method) by two observers using the cardiac short axis in the apical view for the 17-segment model (Figures 2 and 3).

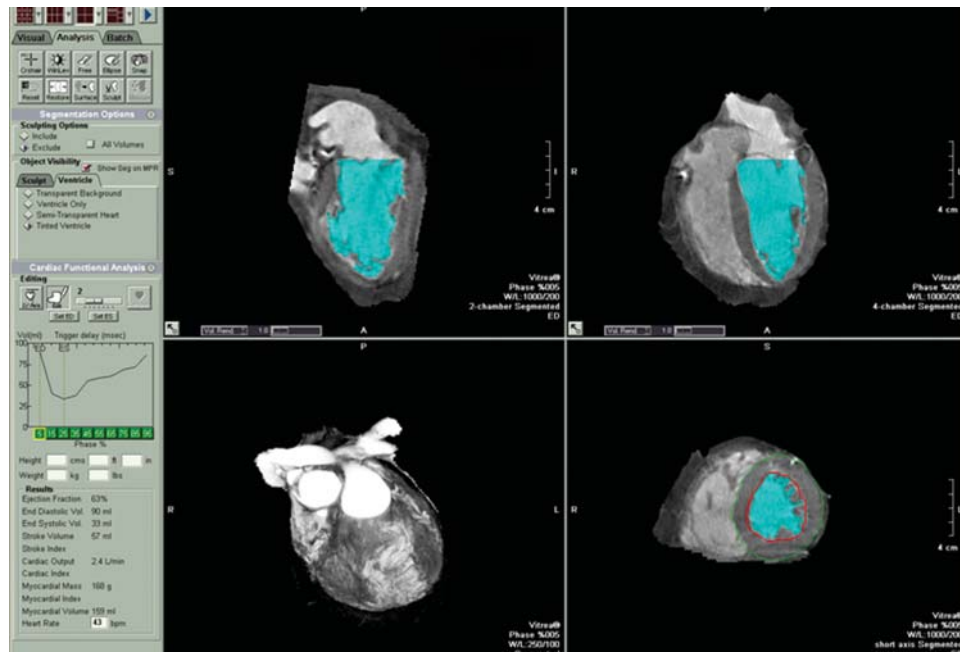


Figure 2 Tomographic image of the left ventricle (short axis, four- and two chambers) for the determination of reference points for ventricular volume measurement (in blue). Left ventricular ejection fraction: 63%; left ventricular end-diastolic volume: 90 mL; left ventricular end-systolic volume: 33 mL.

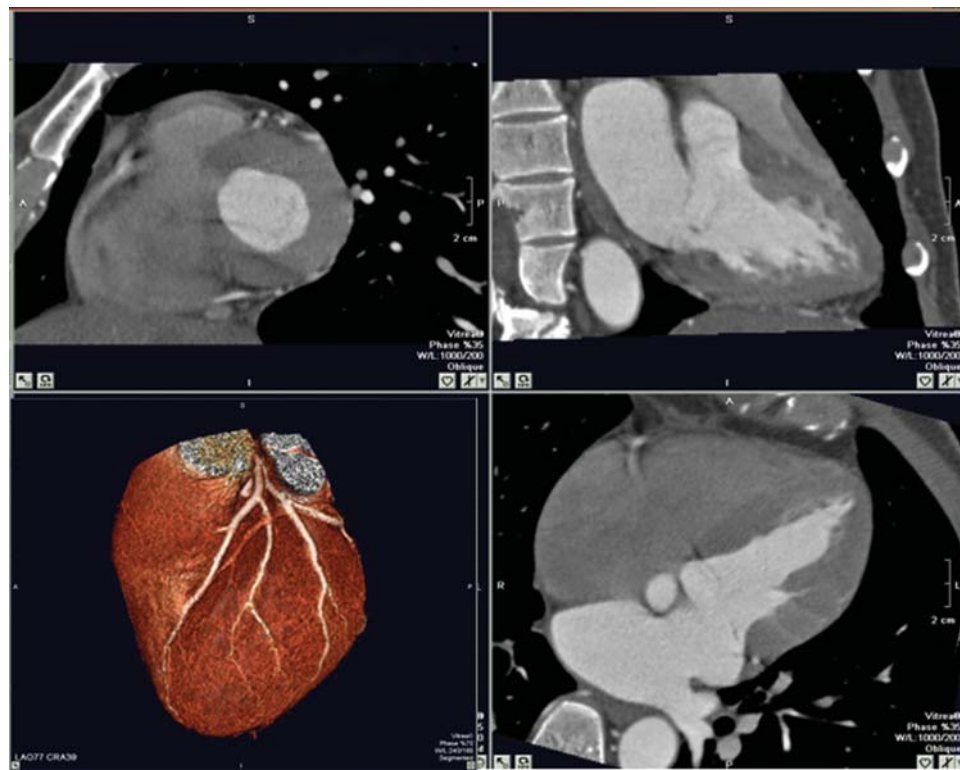


Figure 3 Tomographic image for the three-dimensional determination of ventricular volumes and left ventricular ejection fraction from short-axis images, four- and three chambers (area-length method).

Table 1 Descriptive analysis of the echocardiographic and tomographic characteristics (left ventricular volumes and ejection fraction) of the study population

n = 67	RTDE	CT
LVEF (%)	63.1 ± 7.33 (30–78.6)	66 ± 8.4 (28–86)
LVESV (mL)	38.9 ± 19.3 (11.4–149)	38.2 ± 19.2 (7–152)
LVEDV (mL)	104.9 ± 29.7 (44.1–210)	110.3 ± 31.2 (51–212)

The values are shown as mean ± standard deviation, lowest to highest values. LVEF, left ventricle ejection fraction; RT3DE, 3D real-time echocardiography; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; CT, cardiac tomography.

Statistical analysis

Continuous variables are described as mean values with the corresponding standards deviations, $P < 0.05$. To evaluate correlation analysis, Pearson's correlation method (r) was employed with a 95% confidence interval. The Bland and Altman test was applied to make a comparison between methods. Linear regression test between the parameters obtained with two- and three-dimensional echocardiography was also performed. Measurements were taken by two independent observers. P -values less than 0.05 were considered significant. Reproducibility for LVEF and LV volumes was tested by intraobserver and interobserver concordance coefficients in 17 patients. Intraobserver and interobserver concordance coefficients for LVEF analysis were also tested. Data were processed with statistical analysis software (MedCalc, Mariakerke, Belgium).

Results

Descriptive analysis of the echocardiographic and tomographic characteristics (LVEF and LV volumes) of the population of the study is shown in *Table 1*. Thirty-nine patients had both LVEF and LV volumes (means) within normal limits.

Concordance analysis (Bland and Altman analysis) and linear regression equations for LVEF and LV volumes as measured by three-dimensional echocardiography and computed tomography are shown in *Graphs 1–3* (*Table 2*). For computed tomography, data acquisition heart rate ranged from 55 to 65 (mean 60) b.p.m. Radiation doses concerning CT studies ranged from 13 to 16 mSv.

It was observed good concordance (r) between 3D LVEF and 2D LVEF echocardiographic measurements, with (r): 0.85, $P < 0.0001$, CI: 0.8357–0.9281. The intraobserver concordance for three-dimensional echocardiographic analysis of LVEF was 0.8634, 95% CI (0.7083–0.9436). The interobserver concordance for the three-dimensional echocardiographic analysis of LVEF was 0.8051, 95% CI (0.5976–0.9221). The intraobserver concordance for the tomographic analysis of LVEF was 0.8727, 95% CI (0.7437–0.9579). The interobserver concordance for the tomographic analysis of LVEF was 0.8347, 95% CI (0.6176–0.9291). Concordance (r) between 2D LVEF and LVEF measured by computed tomography was (r): 0.62, $P < 0.0001$, 95% CI: 0.5654–0.8171.

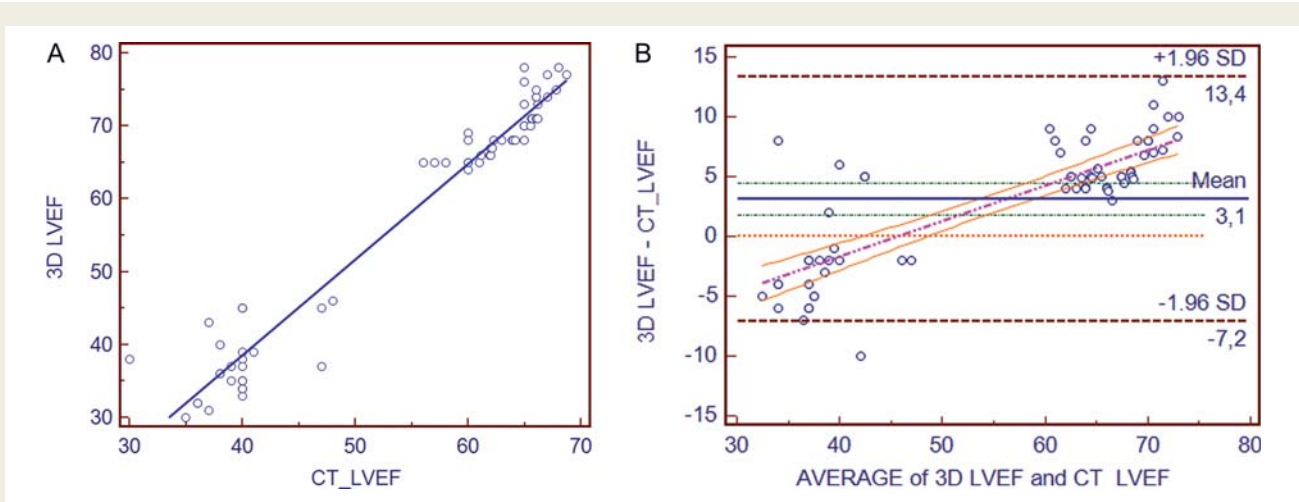
Discussion

The analysis of ventricular systolic function and measurement of ventricular volumes can be performed using different non-invasive imaging modalities. Two-dimensional echocardiography is currently the most widely used method for the anatomical and functional analysis of the heart. It presents some advantages: allows anatomical assessment of the different cardiac structures, analysis of cardiac diastole using the different Doppler echocardiography modalities and can be performed at bedside in intensive care or emergency care environments.

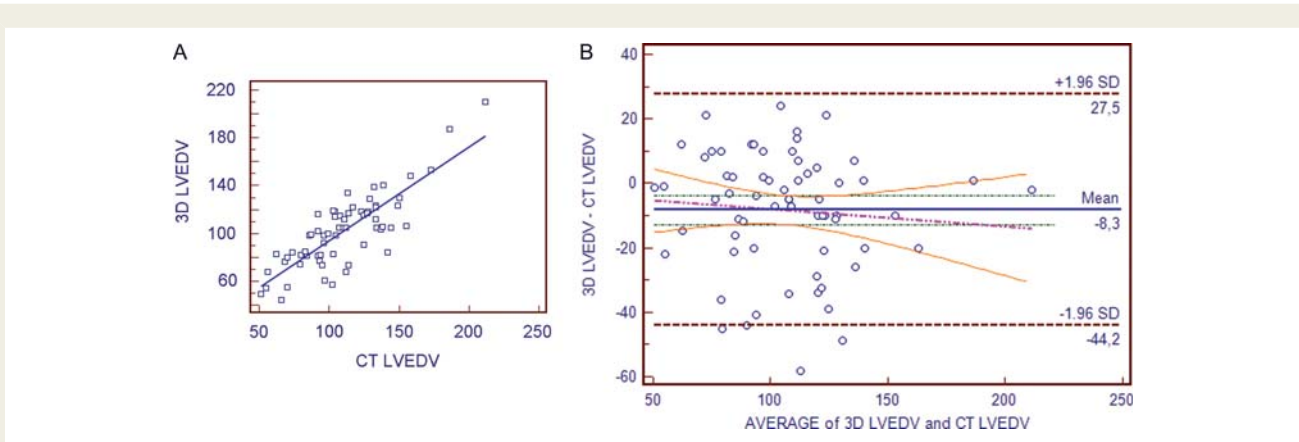
However, it has limitations due to suboptimal echocardiographic images in obese patients or those with chronic obstructive pulmonary disease. Also, it depends to a certain extent on the interpretation of the observer and is limited by the use of a small number of anatomical views for the analysis of the heart. The use of three-dimensional echocardiography increases the possibility of echocardiographic observation of the heart from the structural observation, taking into consideration multiple spatial planes of analysis. The structural analysis is carried out from new identification planes, without the need for the use of geometric extrapolations for the analysis of complex anatomical shapes (for instance, the right ventricle), which are not always limited to a specific mathematical formulation. However, three-dimensional echocardiography requires specific echocardiography training and a stable heart rhythm for a better analysis and also depends on the quality of the initial image for best results.

Today, MRI is considered the reference for the anatomical analysis of most of the structural heart diseases. However, it has limitations regarding costs, or its use in patients with metallic devices; it requires extensive specific training and is not available in the great majority of the hospitals in Brazil. Sixty-four-slice ultrafast computed tomography is a technique that is performed more rapidly than MRI; it allows imaging of patients with metallic devices as well as the observation of ventricular function together with ventricular volumes and coronary circulation. However, CT costs are higher when compared with echocardiographic modalities and also there are possible side effects relative to radiation exposure after repeated tomographic examinations.

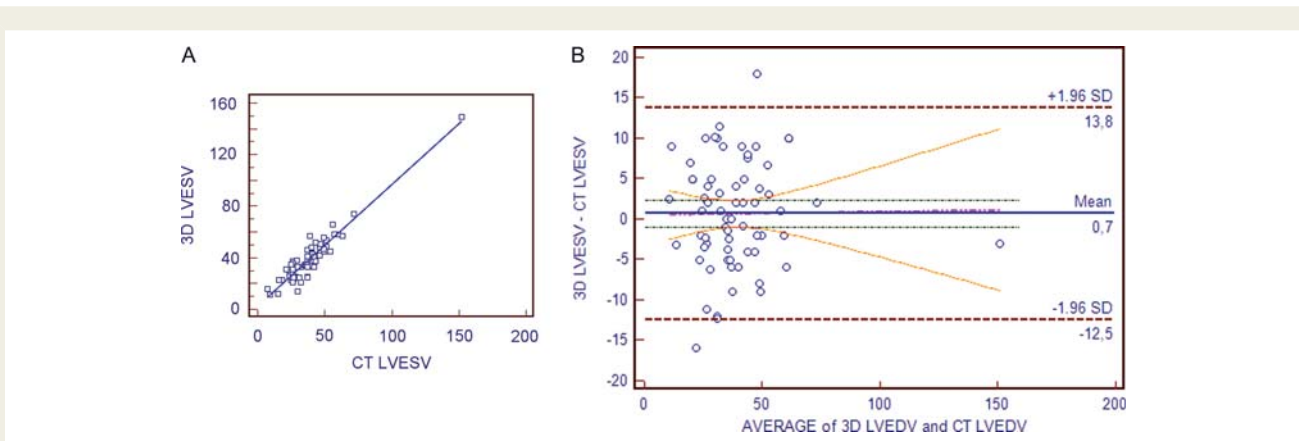
In this study, we observed a good correlation of the analysis of LVEF, LVEDV, and LVESV as measured by three-dimensional echocardiography and 64-slice computed tomography (r : 0.79, r : 0.82, r : 0.91, $P < 0.0001$, respectively). This finding is consistent with that of a previous study in which a good correlation ($r > 0.85$) was observed between left ventricular volumetric and functional analysis using three-dimensional echocardiography and computed tomography.¹¹ LVEF measured by CT was performed using area-length method and not Simpson's rule, because this is the regular standard methodology of the radiology sector. For the analysis of ejection fraction, parameters measured by two-dimensional echocardiography and by 64-slice computed tomography, the concordance observed between the methods was lower (r : 0.62, $P < 0.0001$), but still better than that found in a study with heart transplant patients (r : 0.49),¹³ and similar (r : 0.59) to that of a previous study conducted in patients with suspected coronary artery disease in which 16-detector row computed tomography was used.¹²



Graph 1 Linear regression (Figure 1A) and concordance analysis (Figure 1B) (Bland and Altman plot) for the analysis of left ventricular ejection fraction parameters as measured by three-dimensional echocardiography (3D LVEF) and computed tomography (CT LVEF).



Graph 2 Linear regression (Figure 2A) and concordance analysis (Figure 2B) (Bland and Altman plot) for the analysis of left ventricular end-diastolic volumes as measured by three-dimensional echocardiography (3D LVEDV) and computed tomography (CT).



Graph 3 Linear regression (Figure 3A) and concordance analysis (Figure 3B) (Bland and Altman plot) for the analysis of left ventricular end-systolic volumes as measured by three-dimensional echocardiography (3D LVESV) and computed tomography (CT).

Table 2 Correlation (Pearson: r) and linear regression equation for the comparison between left ventricular volumes and ejection fraction as measured by three-dimensional echocardiography and computed tomography in the study population

RT3DE and CT	LVEF	LVEDV	LVESV
Pearson (r)	$r: 0.79, P < 0.0001, 95\% \text{ CI } 0.6301 - 0.8843$	$r: 0.82, P < 0.0001, 95\% \text{ CI } 0.5995 - 0.8730$	$r: 0.91, P < 0.0001, 95\% \text{ CI } 0.6673 - 0.8975$
Linear regression: RTDE (x) and CT (y)	$y = 19.7862 + 0.6525x, R2: 0.5586, P < 0.0001$	$y = 15.7057 + 0.7823x, R2: 0.6745, P < 0.0001$	$y = 2.7997 + 0.9439x, R2: 0.8828, P < 0.0001$

RT3DE, 3D real-time echocardiography; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; CT, cardiac tomography.

Good concordance was observed for ejection fraction parameters measured by three-dimensional and two-dimensional echocardiography ($r: 0.85, P < 0.0001$). Good reproducibility was also observed regarding ejection fraction measurement by three-dimensional echocardiography (interobserver concordance of 0.8051) and by computed tomography (interobserver concordance of 0.8347).

The results of the present study show that there was good concordance for the analysis of left ventricular morphology and function between the two non-invasive assessment methods with different possibilities of temporal and spatial observation. The better temporal observation provided by three dimensional echocardiography allows a more accurate identification of functional cardiac events, whereas the better anatomical definition provided by the tomographic analysis allows a more detailed structural analysis.

Thus, tomographic analysis provides valuable and specific anatomical information concerning coronary arteries distribution and possible obstruction, pulmonary veins spatial positioning as well as left atrial appendage and thoracic aorta disease. Also, of importance is the ability of tomographic studies concerning the determination of cardiac and extra-cardiac structures relationship, what could be relevant for congenital heart diseases. On the other hand, sequential CT studies may be troublesome concerning cumulative radiation.

Sixty-four-slice multi-detector CCT LV assessment has been compared with other techniques such as invasive left ventriculogram,¹⁵ and it was observed good correlation for EDV, ESV, and LVEF estimation. However, CT tended to overestimate left ventriculogram EDV and ESV and to underestimate LVEF, what was even worst in patients with apical asynergy.¹⁵

When compared with SPECT perfusion imaging derived LVEF, 64-slice multi-detector CCT provided a very good correlation ($r: 0.90$).¹⁶

To our best knowledge, this is the first study that has addressed the analysis of LV ejection fraction and volumes compared by RTDE and 64-slice multi-detector CCT in patients with left ventricular dysfunction, previous studies have compared RTDE with 16-slice multi-detector CCT. Our group has previously showed the comparison between RTDE and 64-slice multi-detector CCT in individuals with normal left ventricular function.¹⁷

In the future, it is important to choose a non-invasive cardiac investigation modality that combines low costs, good reproducibility, diagnostic accuracy, low possibilities of inherent side effects, and availability to the low-income population.

Study limitations

This study comprised a short number of patients with regular heart rhythm. Eventually, further studies with a large number of patients and irregular heart rhythm should be undertaken to confirm the findings of this investigation.

Conclusion

In this series, it was observed adequate correlation for ejection fraction measurements and left ventricular volumes as measured

by real-time three-dimensional transthoracic echocardiography and by 64-slice ultrafast computed tomography.

Conflict of interest: none declared.

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