Radiography xxx (2018) 1–6

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

Assessment of left ventricular ejection fraction with late-systolic and mid-diastolic cardiac phases using multi-slice computed tomography

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ARTICLE INFO

Article history:
Received 2 January 2018
Received in revised form
8 April 2018
Accepted 19 April 2018
Available online xxx

Keywords:
Left ventricular ejection fraction
Left ventricular volumes
Echocardiography
Computed tomography

ABSTRACT

Introduction: Multi-slice computed tomography (MSCT) is an accurate tool for the assessment of left ventricular ejection fraction (LVEF). However, in order to reduce radiation dose, prospective acquisition protocols are currently used, in which the end-systole and end-diastole are not scanned. Our aim was to study the accuracy of the assessment of LVEF using fixed late-systolic and mid-diastolic cardiac phases compared with echocardiography.

Methods: MSCT-derived LVEF was measured with off-line commercially available software packages, and compared with echocardiography-derived LVEF using the Simpson's method. LVEF was categorized as normal vs. abnormal (50% cut-off) and was also analyzed as a quantitative parameter. Bland-Altman plots and Pearson correlations were used for inter-technique comparisons.

Results: 58 patients were included. The sensitivity and specificity of fixed-phase MSCT when compared with echocardiography for detection of LVEF ≤50% was 79% (95% CI = 65–89%) and 43% (10–82%). Misclassification was associated with older age (68 ± 12 vs. 54 ± 13 years, $p < 0.01$), faster heart rate (79 ± 14 vs. 68 ± 10 bpm, $p = 0.01$), and LV hypertrophy (86% vs. 52%, $p = 0.03$). The quantitative comparison revealed no correlation ($r = 0.095$, $p = 0.478$) and a significantly different LVEF (median [IQR], 57.0[50.5–63.1]% vs. 61.0[57.3–64.3]%, $p = 0.03$). The observed bias between the two methods was −3.7% with broad limits of agreement (±25.5%).

Conclusions: Fixed-phase MSCT assessment using late-systole and mid-diastole agreed in defining normal and abnormal LVEF in 76% of patients when compared with echocardiography. Quantitation of LVEF by this method yielded significantly lower values of LVEF and showed no correlation. Thus, accurate quantitation of LVEF by MSCT requires the acquisition of end-systolic and end-diastolic phases.

Introduction

Multi-slice computed tomography (MSCT) is currently used for non-invasive assessment of coronary arteries as well as for structural cardiac abnormalities.[1,2] Moreover, functional assessment of the left ventricle (LV) with newer MSCT generations has yielded excellent results as confirmed in a recent meta-analysis.[3] Despite being a fast and accurate tool for the diagnosis of cardiac ailments; its costs, availability, and concerns about radiation exposure have limited its widespread use.

Overall safety–efficacy profile of the MSCT technique has considerably improved in the last decade, largely owing to

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https://doi.org/10.1016/j.radi.2018.04.007
1078-8174/

reduction in radiation dose and significant improvement of image quality.[4] Specific protocols have been conceived for MSCT, and a combination of electrocardiography (ECG)-triggered prospective acquisition and dose modulation is currently the most accepted approach.[4] Reduction of rotation times and/or increase of volume coverage by broader detectors allow for dramatically reduced acquisition times and hence even full-heart coverage during one single heartbeat.[5] However, slow and constant heart rates are a requirement for the application of these ultrafast acquisitions.

LV ejection fraction (LVEF) is expressed as a percentage value, and calculated by dividing the stroke volume (end-diastolic volume minus end-systolic volume) by the end-diastolic volume and multiplying by 100.[6] It is considered abnormal if less than 50%.[7] With radiation-dose saving acquisition protocols, end-diastolic and end-systolic volumes are generally not imaged, since analyses are performed in fixed phases within a heartbeat in which motion artifacts are least observed.[8] These phases are late-systole, fixed at 40% of the duration of one heart cycle; and, mid-diastole, fixed at 75% or 80% of the duration of one heart cycle. We aimed to assess the accuracy of LVEF estimation based on those fixed cardiac cycle phases acquired with MSCT, replacing end-diastolic with mid-diastolic volumes and end-systolic with late-systolic volumes, when compared with conventional echocardiography.

Methods

Study population

We retrospectively searched examinations from patients with available MSCT and echocardiographic data with no acute conditions in between the two imaging acquisitions, including patients after heart transplantation. Only adult patients in sinus rhythm were included. Exclusion criteria included a dilated LV, wall motion abnormalities, anomalous septal movement, implanted pacemaker or defibrillator, implanted prosthesis, moderate to severe aortic stenosis, aortic regurgitation, mitral stenosis or mitral regurgitation. Also patients with depressed or dilated right ventricle, with severe tricuspid regurgitation and with pericardial effusion were excluded. The study was approved by the institutional review board and all patients provided informed consent.

Computed tomography protocols

Thirty eight MSCTs were performed using a dual-source scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany) with slice collimation of 64 × 0.6 mm, rotation time of 330 ms, tube voltage of 120 kV, and tube current 330 mAs. Dose modulation was performed in all patients with application of full tube current from 35 to 75% of the RR-interval. Tube output was reduced to 20% outside this window. Automated contrast injection was executed with a programmable power injector into an antecubital vein. An iodine contrast medium was used at a concentration of 400 mg iodine/mL, the flow was set to 5 ml/s and volume adjusted to the body weight. Images were transferred to an external workstation and LVEF was calculated using dedicated, semi-automated software (Circulation, Leonardo Workstation, Siemens Healthcare).

The remainder MSCTs were performed using a 64-slice scanner (Brilliance 64™, Philips Medical Systems, Amsterdam, The Netherlands) with slice collimation of 64 mm × 0.67 mm, rotation time of 400 ms, tube voltage of 120 kV, and tube current time product 800 mAs. Dose modulation was routinely turned on in all patients with a heart rate <80 beats per minute. A bolus of 80 ml iodine contrast agent followed by a 40 ml saline solution at a flow rate of 5 ml/s was injected through an antecubital vein. Images were reconstructed at 10% increments throughout the entire R–R interval (0–90%). All data were transferred to an off-line Philips Brilliance Workstation equipped with the cardiac package (Comprehensive Cardiac, Philips Medical Systems, Amsterdam, The Netherlands) for image post-processing and analysis.

For LVEF analysis, raw data sets already reconstructed in 40% (late-systolic) phase and in 70% or 75% (mid-diastolic) phase were used. Two authors (ES and NP) measured the volumes in all cardiac phases available using semi-automatic algorithms. In all cases, manual corrections were performed after automated endocardial border detection. For most studies, this would imply one late-systolic phase and one mid-diastolic phase. Two approaches were undertaken to present the results: a) a binary categorization (normal [above 50%] and abnormal [below 50%]), and b) a quantitative analysis.

Echocardiography

Echocardiography was performed using the Philips iE33 ultrasound system with the S5-1 transducer (Philips Medical Systems, Best, The Netherlands). Volumes were measured off-line following the Simpson's method with available apical four and two chamber views by two authors (NP and GG) at least 2 months apart from the MSCT measurements and unaware of the MSCT results. End-diastole and end-systole were defined as the frame in which the left ventricle presented the largest and the smallest volumes. Essential echocardiographic assessments such as LV hypertrophy, LV diastolic function and left atrial size were evaluated according to guidelines.[7]

Statistical analysis

Variables were compared with the Fisher's exact test or chi-squared test for categorical data. The Student's t test was used for analysis of normally distributed continuous variables. The nonparametric Wilcoxon rank sum test (for 2-way comparisons) was used to compare continuous variables when the data were not normally distributed. A value of $p < 0.05$ was considered statistically significant. Data are summarized as mean ± SD or median (IQR) as appropriate. Measures of diagnostic performance (sensitivity, specificity, and positive and negative predictive values) were calculated. Bland–Altman plots and Pearson correlations were used for inter-technique comparisons. Analyses were performed with SPSS statistics version 20 (IBM, Armonk, NY, USA).

Results

Fifty-eight patients were included in our analysis, 33 (57%) were males, 13 (22%) had a transplanted heart, and all had MSCT and echocardiography performed within 19 ± 42 days (mean ± SD; range from 0 to 216 days). The diastolic phase was acquired at 70% of the R–R interval in 51 patients and at 75% in the remainder. Mean ± SD heart rate was 70 ± 12 bpm and mean ± SD body mass index was 26.0 ± 4.1 kg/m^2 (Table 1).

Echocardiographic parameters are summarized in Table 2. Notably, 61% of patients had left ventricular hypertrophy (LVH), 69% had diastolic dysfunction, and 30.8% had elevated filling pressures. Mean ± SD LVEF calculated with the Simpson's method was 59.8% ± 7.5%. MSCT parameters are summarized in Table 3. Mean ± SD LVEF estimated using the 40% phase (late-systole) and the 70–75% phase (mid-diastole), was 56.1 ± 11.4%. Mean ± SD LV volume at 70–75% indexed to body surface area (BSA) was 57.4 ± 15.3 ml/m^2, mean ± SD LV volume at 40% indexed to BSA was 24.8 ± 7.7 ml/m^2, and mean ± SD stroke volume indexed to BSA was 32.7 ± 11.8 ml/m^2.

Please cite this article in press as: Spitzer E, et al., Assessment of left ventricular ejection fraction with late-systolic and mid-diastolic cardiac phases using multi-slice computed tomography, Radiography (2018), https://doi.org/10.1016/j.radi.2018.04.007