European Journal of Radiology 83 (2014) e123–e130

Contents lists available at ScienceDirect

European Journal of Radiology

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

Quantitative analysis of left ventricular strain using cardiac computed tomography

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ARTICLE INFO

Article history:
Received 21 August 2013
Received in revised form 21 October 2013
Accepted 23 November 2013

Keywords:
Left ventricular function
Congestive heart failure
Two-dimensional strain echocardiography
Cardiac CT

ABSTRACT

Objectives: To investigate whether cardiac computed tomography (CCT) can determine left ventricular (LV) radial, circumferential and longitudinal myocardial deformation in comparison to two-dimensional echocardiography in patients with congestive heart failure.
Background: Echocardiography allows for accurate assessment of strain with high temporal resolution. A reduced strain is associated with a poor prognosis in cardiomyopathies. However, strain imaging is limited in patients with poor echogenic windows, so that, in selected cases, tomographic imaging techniques may be preferable for the evaluation of myocardial deformation.
Methods: Consecutive patients ($n = 27$) with congestive heart failure who underwent a clinically indicated ECG-gated contrast-enhanced 64-slice dual-source CCT for the evaluation of the cardiac veins prior to cardiac resynchronization therapy (CRT) were included. All patients underwent additional echocardiography. LV radial, circumferential and longitudinal strain and strain rates were analyzed in identical midventricular short axis, 4-, 2- and 3-chamber views for both modalities using the same prototype software algorithm (feature tracking). Time for analysis was assessed for both modalities.
Results: Close correlations were observed for both techniques regarding global strain ($r = 0.93$, $r = 0.87$ and $r = 0.84$ for radial, circumferential and longitudinal strain, respectively, $p < 0.001$ for all). Similar trends were observed for regional radial, longitudinal and circumferential strain ($r = 0.88$, $r = 0.84$ and $r = 0.94$, respectively, $p < 0.001$ for all). The number of non-diagnostic myocardial segments was significantly higher with echocardiography than with CCT (9.6% versus 1.9%, $p < 0.001$). In addition, the required time for complete quantitative strain analysis was significantly shorter for CCT compared to echocardiography (877 ± 119 s per patient versus 1105 ± 258 s per patient, $p < 0.001$).
Conclusion: Quantitative assessment of LV strain is feasible using CCT. This technique may represent a valuable alternative for the assessment of myocardial deformation in selected patients with poor echogenic windows and general contraindications for magnetic resonance imaging.

1. Introduction

Objective and reproducible cardiovascular imaging methods for quantification of LV systolic and diastolic function are of critical importance for patient management, therapy monitoring and outcome studies [1,2]. Echocardiography, as a widely available and bed-side diagnostic procedure, allows for the accurate assessment of LV contractile function with high temporal resolution. Strain imaging, determines velocity gradients between two points in space and has demonstrated excellent accuracy in defining regional systolic and diastolic function in radial, circumferential, longitudinal or if required in torsional direction [3]. Especially

Abbreviations: 2D/3D/4D, two-dimensional/three-dimensional/four-dimensional; 2D-CCT, two-dimensional strain cardiac computed tomography; 2D-Echo, two-dimensional strain echocardiography; CRT, cardiac resynchronization therapy; CCT, cardiac computed tomography; EF, ejection fraction; ESV, end-systolic volume; EDV, end-diastolic volume; LV, left ventricle.

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http://dx.doi.org/10.1016/j.ejrad.2013.11.026

two-dimensional strain imaging has emerged as a descriptor for LV functional assessment [3,4]. Due to the intricate myocardial architecture, global and regional left ventricular function is determined not only by radial, but also by circumferential, longitudinal and torsional components. In patients with cardiomyopathies, longitudinal and circumferential left ventricular function represent independent prognostic variables for clinical outcomes [5,6].

However, the methods described above are either dependent on individual examiner's experience or their acquisition. In addition, analysis may be time-consuming and affected by poor image quality. Therefore, newer imaging methods are needed that measure LV function faster and more accurately. In this regard, cardiac CT (CCT) allows for accurate and reproducible two-dimensional assessment of LV contractile function with high spatial resolution. To date however, limited data exist on the ability of this technique to assess LV strain [7,8]. Novel two-dimensional feature tracking techniques have already been successfully used in conjunction with cardiac magnetic resonance cine sequences demonstrating promising results [9].

In the present study we sought to compare the ability of dual-source CCT derived strain imaging (2D-CCT) with two-dimensional strain echocardiography (2D-Echo), in patients with congestive heart failure and using the same software approach (feature tracking imaging).

2. Materials and methods

2.1. Patients

The study population consisted of 27 consecutive patients (27 male, 70 ± 8 years old) who were considered for a clinically indicated CCT prior to CRT device implantation. The subjects were part of a previous report [10] and image analysis was performed retrospectively. CRT implantation was indicated according to current guidelines and using the following criteria: (i) congestive heart failure NYHA class II–III for at least 12 months due to ischemic (n = 13) or dilative (n = 14) cardiomyopathy; (ii) wide QRS complex (>130 ms) of LLLB-like morphology; and (iii) impaired LV function by two-dimensional echocardiography (ejection fraction <40%). The study protocol was approved by our local ethics committee and all subjects gave written informed consent.

2.2. 2D and real-time 3D echocardiography

Patients were studied using a commercially available ultrasound system. The image acquisition was performed within 2 h before or after CCT. No selection of patients was performed based on the presence of appropriate echogenic windows. The acquisition was performed from the apical windows with the patient in the same position as for a standard 2D examination, using an iE33 (Philips, Andover, MA, USA) and for LV volumetry with a phased array matrix transducer (xMatrix, X3-I). Data sets for 2D strain analysis (2D-Echo) were acquired using ECG R-wave triggering during an unforced single breath-hold covering three consecutive heartbeats and with a final image resolution of >30 Hz using the standard S5-1 transducer. For LV volumes and ejection fraction assessment of the full volume data sets were then analyzed offline using a commercially available software package (4D LV Analysis, TomTec Imaging Systems GmbH, Munich, Germany), as previously described in detail [10].

2.3. Dual source CT image acquisition protocol and image reconstruction

Retrospectively ECG-gated 64-slice coronary CT angiography examinations were performed with dual-source CT (Somatom Definition, Siemens Medical Solutions, Forchheim, Germany) during end-inspiration. Imaging direction was cranio-caudal from above the origin of the coronary arteries to the diaphragm. Tube voltage of 120 kV and tube current of 410 mAs for both tubes were employed with dose modulation, reaching a minimum level of 20% between intervals of maximum radiation (pulsing window at 75% of the cardiac cycle). Detector collimation was 32 × 0.6 mm, slice acquisition 64 × 0.6 mm by means of a z-flying focal spot and a gantry rotation time 0.33 s.

For CCT a bolus of 80 mL of contrast agent (Ultravist 370, Bayer Healthcare, Germany) was injected via an antecubital vein (flow rate of 5 mL/s). As soon as the signal in the descending aorta reached a predefined threshold of 100 HU, data acquisition started automatically and the entire volume of the heart was acquired during one breath-hold in 4–7 s with simultaneous ECG recording.

In order to maximize the accuracy of the depiction of end-systolic and end-diastolic images of the heart and for the subsequent calculations of the LV ejection fraction, end-systolic and end-diastolic volumes, a multi-segment reconstruction algorithm was selected. Temporal resolution was thereby varying as a function of the patient's heart rate between 83 and 42 ms. Using dual-source CT in the multi-segment reconstruction mode, a mean resolution of 60 ms can be established [11]. Medium smooth convolution kernel (B26f) and an image matrix of 512 × 512 pixels were used. Image series were directly reconstructed from the raw data in 5% steps throughout the entire cardiac cycle (0–95% of the R–R interval) resulting in 20 phases per cardiac cycle with a reconstruction thickness of 0.75 mm. No manual ECG editing was performed. All images were suitable for analysis. Reconstructed images were transferred to an external workstation (Leonardo, Siemens Medical Solutions, Forchheim, Germany) equipped with a dedicated cardiac post-processing software tool (Syngo, Siemens Medical Solutions, Forchheim, Germany). After exporting the reconstructed images to a workstation the Cartesian reconstructed volume-time series were loaded into the 4D LV Analysis CT prototype (TomTec Imaging Systems, Unterschleissheim, Germany) for further LV volume analysis, as previously described [10]. In a second step the images were reconstructed and exported into an audio video interleave format for further 2D strain analysis.

2.4. Evaluation of two-dimensional strain with the feature tracking algorithm with 2D-CCT and 2D-Echo

The feature tracking software (2D CPA MR prototype, TomTec Imaging Systems, Munich, Germany) is a two-dimensional deformation analysis tool which has been previously validated [12–14]. Feature tracking measures radial, circumferential and longitudinal strain and strain rate along a user defined endocardial border throughout one cardiac cycle initially drawn in end-diastole of standard cine long- and short axis echo images. The software algorithm then automatically tracks features like image inhomogenities, tissue patterns of the myocardium or anatomic structures throughout the remaining cardiac cycle. The values are derived from the image by comparing the movement of the features in relation to each other along the initially drawn border. In case of inadequate tracking, after finishing the first measurements, the software allows editing of the border. The LV-endocardial contours are marked in the midventricular short-axis view and the apical 4-, 2- and 3-chamber views, with exclusion of the papillary muscles and are then tracked automatically frame by frame starting from end-diastole. Correction of the contours can be performed manually if necessary.

For segmental analysis, the midventricular short axis view the ventricle was divided into 6 segments according to the 16 Segment model of the American Heart Association. From these views we derived peak circumferential and radial strain and strain rate,