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Comparison of magnetic resonance feature tracking with harmonic phase imaging analysis (CSPAMM) for assessment of global and regional diastolic function

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ABSTRACT

Aims: Complex post-processing is required for strain-derived assessment of diastolic dysfunction (DD) using CMR-tagging (TAG). Feature-tracking (FT), allows for rapid systolic strain assessment using conventional steady-state free precession (SSFP)-Cine sequences. Aim of this study was to investigate whether FT may be employed for the clinically applicable quantification of DD.

Methods and Results: 40 individuals (20 patients with DD I-III°, 20 controls) were investigated. CSPAMM and SSFP-Cine sequences were acquired in identical short-axis locations. Global and regional early diastolic strain rate (EDSR), peak diastolic strain rate (PDSR), twist, untwist and torsion were calculated from tagged and SSFP-Cine datasets. DD indices were compared, intra- as well inter-observer variability assessed.

Results: for global EDSR correlated strongly ($r = 0.94$), revealed good agreement and no significant differences between both methods. Correlation for regional EDSR was lower, results differed significantly in the anterior wall ($p < 0.05$). Correlation for PDSR was moderate ($r = 0.63$), results in the healthy control group differed significantly ($p < 0.05$). FT derived rotational indices correlated poorly with TAG (twist: $r = 0.28$; untwist: $r = 0.02$; torsion: $r = 0.26$), subgroup analysis revealed significant differences ($p < 0.05$). Intra- and inter-observer variability for FT derived global EDSR and PDSR were comparable to TAG, but significantly higher for regional EDSR and rotational indices.

Conclusion: FT derived global EDSR allows for rapid clinical determination of diastolic dysfunction, revealing good agreement with TAG and low intra- as well as interobserver variability. However, TAG analysis not only yields higher accuracy and reproducibility of global- and regional diastolic strain, but also delivers reliable information about diastolic rotational and untwisting dynamics.

1. Background

Chronic heart failure (CHF) remains the leading cause of hospitalization in patients older than 65 years [1]. While more than two thirds of these cases are attributed to systolic dysfunction (SD), up to 30% of patients with CHF suffer from diastolic dysfunction (DD) [2]. A variety of symptoms indicate systolic heart failure. Among these are dyspnea, tachycardia, peripheral edema and fatigue. Diastolic dysfunction can be more challenging to detect, as patients often lack early symptoms or only show signs of dyspnea upon exertion. End stage heart failure may be averted in patients with DD, if the condition is detected at an early stage [3]. Thus, early and reliable detection of impaired left ventricular relaxation is essential for diagnosis and subsequent monitoring of DD.

Cardiac magnetic resonance (CMR) imaging is now considered the gold-standard for measuring ventricular volumes, mass and strain, due to its image quality, high spatial and temporal resolution as well as excellent intra- and interobserver reproducibility [4]. CMR strain analysis has been shown to be more sensitive for detection of left ventricular (LV) contractile dysfunction than routine assessment using standard cine imaging and is able to detect subtle contractile changes at an early stage [5]. Although myocardial strain values were first derived from CMR tagging (TAG) [6], echocardiography has been established as the clinical standard tool for the assessment of DD as it is more widely available [7]. Practical limitations hinder the routine application of CMR tagging for the detection of DD, as additional time consuming acquisition and analysis of images is necessary. Recently, a significantly faster approach

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which allows for strain calculation from standard cine datasets – feature tracking (FT) – has been presented. The value of FT, but also its limitations, for assessment of regional and global systolic strain have been demonstrated [8,9]. At the moment, there is no data regarding the value of FT for assessment of diastolic function. In this study, we investigated the feasibility of diastolic functional assessment using FT and compared FT derived diastolic functional data from standard cine imaging with strain analysis using TAG.

2. Methods

2.1. Study population

Healthy controls (HC) (Group A) and patients with echocardiographically diagnosed DD grade I-III (Group B) were prospectively enrolled into the study. DD was graded by means of echocardiography. The mitral valve inflow (early (E) and atrial (A) inflow velocities), the pulmonary flow, and the myocardial velocity of the lateral wall were assessed with tissue Doppler imaging. According to the findings patients were then classified as DD grade I (impaired relaxation pattern), grade II (moderate diastolic dysfunction) or grade III (severe restrictive filling). Written informed consent was obtained from all controls and patients. This study was approved by the institutional review board.

2.2. MR Imaging

MR imaging was performed on a clinical 1.5 T MR scanner (Intera, Philips Medical System, Best, the Netherlands). Scout images were acquired in axial, coronal and sagittal orientation. Cardiac functional imaging was performed using retrospectively gated SSFP sequences in the standard cardiac axes. For the assessment of ejection fraction, a minimum of 12 short axis slices were acquired per subject, with 30 phases reconstructed per slice. Prospectively gated SSFP cine images were acquired in the short axis orientation at the basal, midventricular and apical level for calculation of FT derived strain. Prospective ECG gating was chosen to ensure the highest possible congruency of scanning parameters between tagged images and SSFP cine images. 25 cardiac frames were acquired per RR-cycle. Other scan parameters were a field of view of 370 mm, echo time/repetition time (TE/TR) of 1.4/3.0 ms, slice thickness 8 mm, flip angle 50° and an in plane resolution of 1.4 mm. Tagged images were acquired in identical positions using the same number of cardiac frames (25) and an identical trigger delay. For tagged images the following parameters were used: spatial modulation of magnetization in a grid pattern with a grid-gap space of 8 mm; flip angle 25°, typical echo time/repetition time 6/33 ms and a typical field of view of 320 mm.

2.3. FT technique

Using FT, endo- or epicardial borders are “tracked” automatically over the entire RR cycle based on one initial manually drawn contour. Tracking in standard SSFP images is achieved by ascribing each voxel of the endocardial border with a number of attributes (e.g. brightness and dishomogeneities of the tissue with respect to a 256-level gray scale) and detecting specific anatomical variations (e.g. papillaries) [9]. These voxels are then tracked from frame to frame allowing deducting information about mechanical deformation such as circumferential, longitudinal, and radial tissue strain/strain-rate as well as tissue velocity and rotational indices such as twist, torsion, and untwist.

2.4. TAG image analysis

Tagged data was analyzed using harmonic phase-analysis (Tag Track, GyroTools Ltd., Zurich, Switzerland) to calculate strain and myocardial rotation. Short axis circumferential strain (εcc) values were derived from the mid-left-ventricular short axis slice [9,10]. For rotation analysis, apical and basal slices were assessed. Epicardial and endocardial track-lines were detected in a phase with optimal myocardium-blood contrast and manually adjusted to the anatomical contours. Propagation of track-lines throughout the entire RR cycle was then performed automatically using the motion of the grid crossing points as points of orientation. (Fig. 1).

2.5. FT image analysis

CMR-FT strain analysis was performed using dedicated software (Diogenes; TomTec; Germany). Corresponding with the strain analysis of tagged images, LV short axis circumferential strain (εcc) was derived from the same mid-ventricular short-axis slice used for strain calculation with TAG. The LV endocardial and epicardial borders were identified based on an initial manually drawn contour and then tracked from frame to frame (Fig. 1).

2.6. CMR diastolic strain indices

To investigate the feasibility of using FT for assessment of diastolic function and comparison to TAG, established strain derived CMR indices (early-diastolic strain rate (EDSR), peak diastolic strain rate (PDSR)) as well as rotation derived markers (Twist, Torsion, Untwist) were employed.

For analysis, the left ventricle was divided into 4 equiangular segments [11]. For consistency and in order to establish a standard model which allows for accurate segmentation, the RV upper-septal insertion point served as the partition between the first and second segment) Strain was determined for each of the 4 segments. Global and segmental strain curves and subsequently strain rate curves were plotted for both methods. PDSR was defined as the minimum value of the strain rate curve and calculated globally [12]. Global and segmental EDSR was defined as the upward slope from maximum systolic strain to the mid-diastolic strain plateau as previously described [13].

2.7. CMR rotational indices

Rotation and twist were calculated as described by Sengupta et al., [14]. The amount of rotation in degrees for the basal and apical slice, Φ, was calculated as the global rotation of all segments in the slice relative to the LV center axis for each phase. Positive Φ is counterclockwise when viewed from apex to base. The global LV twist, θ, was calculated as the mean difference between Φ at the apex and Φ at the base ($\theta = \Phi_{apex} - \Phi_{base}$). The untwisting rate was calculated as $d\theta/dt$. The peak untwisting rate was calculated as the largest magnitude of $d\theta/dt$ following maximum θ. We additionally calculated the circumferential-longitudinal shear angle, also known as torsion, as described by Russel et al. [15]. This allows for an objective comparison between torsion values, taking cardiac diameter and length of each subject into consideration.

2.8. Reproducibility of tagged and FT strain measurements

Reproducibility was investigated for all employed parameters. For the assessment of intraobserver agreement, analysis of diastolic function was completed twice by the primary investigator. An interval of two weeks was chosen between the first and second analysis. For assessment of interobserver agreement/reproducibility the data was independently analyzed by a