Inter-study Repeatability of Left Ventricular Strain Measurement using Feature Tracking on MRI Cine Images

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Abstract

Feature tracking (FT) is a novel approach for myocardial strain evaluation from standard cine MRI. Conversely to tagging, an original feature of FT is its ability to analyze all heart chambers, independently of their wall thickness. However, few technical challenges, including its inter-study repeatability need to be investigated and this is the aim of our study.

We studied 10 healthy individuals (59±9 years), who underwent 2 MRI exams, separated by two weeks. For each exam, cine short-axis slices corresponding to left ventricular (LV) basal, mid-LV and apical locations were analyzed, by the same operator, using a custom FT software to extract global peaks of: 1- radial thickening (Er), 2- circumferential strain (Ec), and 3- endocardial radial motion (Erm). Briefly, the FT, based on spatial correlation, was applied to myocardial contours initially drawn on a single time phase.

Bland-Altman analysis revealed low bias for comparison between the 2 exams (mean bias [±1.96·standard deviation] were: 0.02 [-0.11,0.14]% for Er, 0.00 [-0.04,0.05]% for Ec, 0.00 [-0.05,0.06]% for Erm). As expected, strain magnitudes decreased with age. The application of an automated FT on data systematically acquired during MRI provided consistent and reproducible LV myocardial strain measurements.

1. Introduction

Myocardial strain is a strong marker of left ventricular (LV) functional alterations, which are shown to precede the drop in ejection fraction and changes in LV geometry and wall thickness in several pathological conditions, such as hypertrophic cardiomyopathy [1].

In clinical routine, myocardial strain is evaluated either by using speckle tracking in echocardiography, or MRI tagging data. This latter technique is not commonly performed in every MRI exam and requires dedicated post processing software. Since, MRI is able to accurately characterize myocardial tissue alterations, the addition of strain evaluation from standard cine MRI images can be of major clinical usefulness. Such strain evaluation is made possible by feature tracking (FT) techniques, which have two original features: 1) being able to extract strain values from standard cine data, systematically acquired during every clinical MRI exam, and 2) being able to analyze both thick and thin myocardial walls and subsequently all heart chambers, including the left atrium (LA) [2].

In this study a FT technique was proposed and used to assess LV radial and circumferential deformations and inter-study repeatability was studied.

2. Material and methods

2.1. Population and data acquisition

Ten healthy subjects (59±9 years, 4 females) underwent 2 identical MRI exams two weeks apart (Exam 1 and Exam 2). Each subject had a steady state free precession (SSFP) acquisition on a 1.5 Tesla GE magnet in a short axis view, during breath-hold, while using the following scan parameters: acquisition matrix = 224*192, echo time = 1.76 ms, flip angle = 50°, pixel size =0.64*0.64 mm^2, slice thickness = 7 mm. Such acquisitions were performed on 12 slices covering the whole LV with a temporal resolution around 25 ms.

2.2. Feature tracking algorithm

The FT algorithm is inspired from echocardiographic speckle tracking, where the interface between myocardium and the surrounding structures (blood, epicardial fat) is used for tracking rather than myocardial speckle. Indeed, in our method, spatial correlation was used as the main similarity measure for tracking. First, basal, median and apical slices were selected for each subject for both exams. Then, for each slice endocardial and epicardial contours were manually initialized on a single temporal phase corresponding to the diastolic phase with the maximal LV dilation. The initialized points are then tracked from the initial phase towards the end and the beginning of the cardiac cycle.

For the tracking process, a 10 x 10 pixels region of interest is first defined around each point of the initial contour. Then a map with the cross-correlation value between this region and its neighborhood on the next phase is calculated. This map is then weighted with a priori constraints related to physiological knowledge regarding LV contractile function. These constraints comprised: 1) an elastic component used to conserve the continuity of the contour points displacement and 2) a time periodicity component used to take into account the cyclic cardiac motion. This process was applied by the same operator on all slices and exams and no manual correction was performed at the end of the tracking.

2.3. Indices of LV deformation

The tracking provides endocardial and epicardial contours for all cardiac cycle phases, which were then used to extract LV radial and circumferential deformation curves (Figure 1) by calculating the normalized relative change in the LV thickness or contour length. In addition, the magnitude of the radial motion was also calculated.

For each slice, LV deformation curves were used to automatically detect the following global peaks: 1) radial strain (Er), corresponding to the maximal myocardial thickening, 2) circumferential strain (Ec), corresponding to the maximal shortening of the circumference, 3) endocardial radial motion fraction (Erm), corresponding to the maximal radial relative displacement.

2.4. Statistical analysis

All continuous variables are reported as mean values ± standard deviations. Strain values obtained from the 2 exams on a slice or global basis were compared using a non-parametric Wilcoxon test. To study the inter-exam reproducibility in terms of LV strain and motion, a Bland and Altman analysis was performed. A linear regression was used to study the consistency of our strain values in terms of associations with age and the resulting Pearson correlation coefficients are provided. Statistical analysis was performed using the JMP-SAS software.

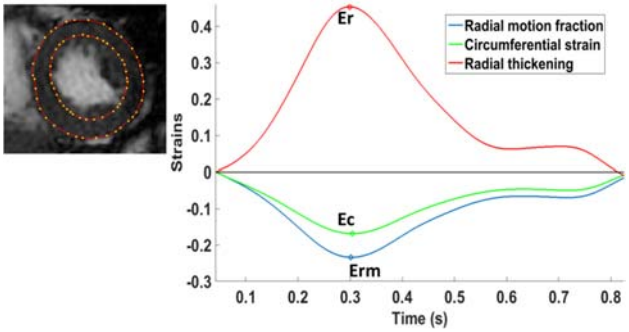

Figure 1: Left: a LV short axis image with the tracked endocardial and epicardial contours. Right: the estimated circumferential strain as well as radial thickening and motion fraction curves. Global peaks of LV strain and motion fraction are highlighted on the curves.

3. Results

3.1. Indices of LV deformation

The FT tool was fast (< 10 seconds/slice level). It performed successfully on all slices for both exams with however few failing points on the most hypertrophied segments, but such mildly failing points were kept for strain analysis to avoid subjective interventions. Table 1 summarizes the global strain and motion fraction peaks for all slice levels and for both exams.

Table 1. Average strains peaks for the MRI exams 1 and 2 and for three considered anatomical levels.

Strain		Exam 1	Exam 2	p
Er				
	Global	0.51±0.12	0.49±0.09	0.49
	Basal	0.46±0.10	0.47±0.07	0.56
	Mid	0.50±0.18	0.53±0.15	0.77
	Apical	0.57±0.19	0.48±0.14	0.13
Ec				
	Global	-0.15±0.02	-0.15±0.02	0.56
	Basal	-0.15±0.02	-0.16±0.03	0.49
	Mid	-0.14±0.03	-0.15±0.03	0.77
	Apical	-0.16±0.03	-0.16±0.03	0.49
Erm				
	Global	-0.25±0.04	-0.26±0.04	0.57
	Basal	-0.25±0.02	-0.26±0.05	0.19
	Mid	-0.23±0.06	-0.24±0.05	0.43
	Apical	-0.27±0.06	-0.26±0.07	0.57

3.2. Inter-study reproducibility

Table 1 reveals that no significant differences were found between LV strain values measured during exam1

and 2. Regarding the agreement between the two exams, Bland-Altman plots (Figure 2) indicated that the FT method resulted in low inter-exam bias with mean bias [limits of agreement]= 0.02% [-0.11,0.14] for Er (Figure 2, A), 0.00% [-0.05,0.06] for Erm (Figure 2, B) and 0.00% [-0.04,0.05] for Ec (Figure 2, C).

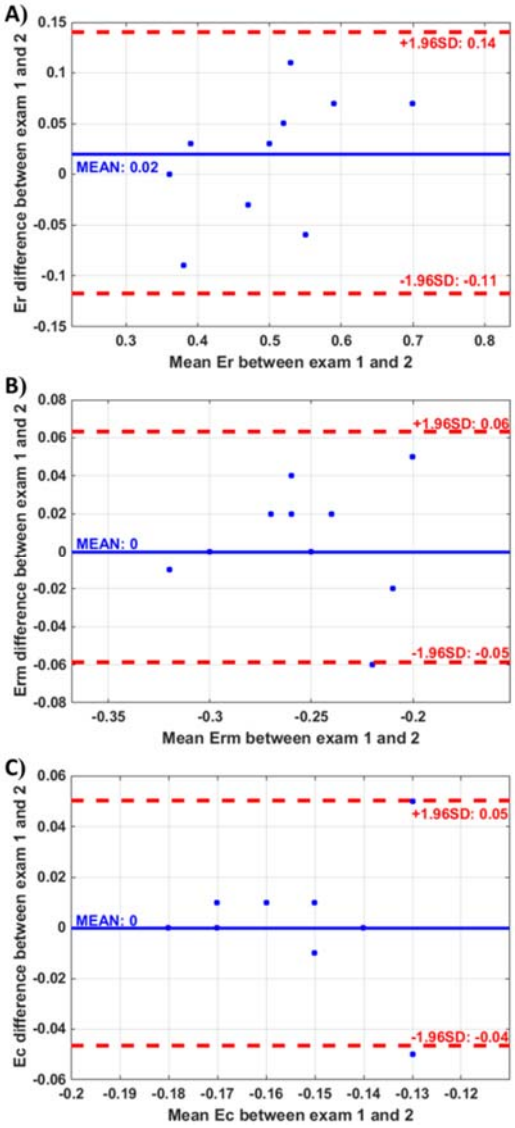

Figure 2. Bland and Altman analysis for comparison between exam 1 and exam 2 in terms of: global peaks of A) radial strain (Er), B) endocardial radial motion fraction (Erm), and C) circumferential strain (Ec).

3.3. Associations with age

Associations between FT strain values and age are shown in Figure 3. The three LV strain indices present an age-related decrease in their global peak magnitude.

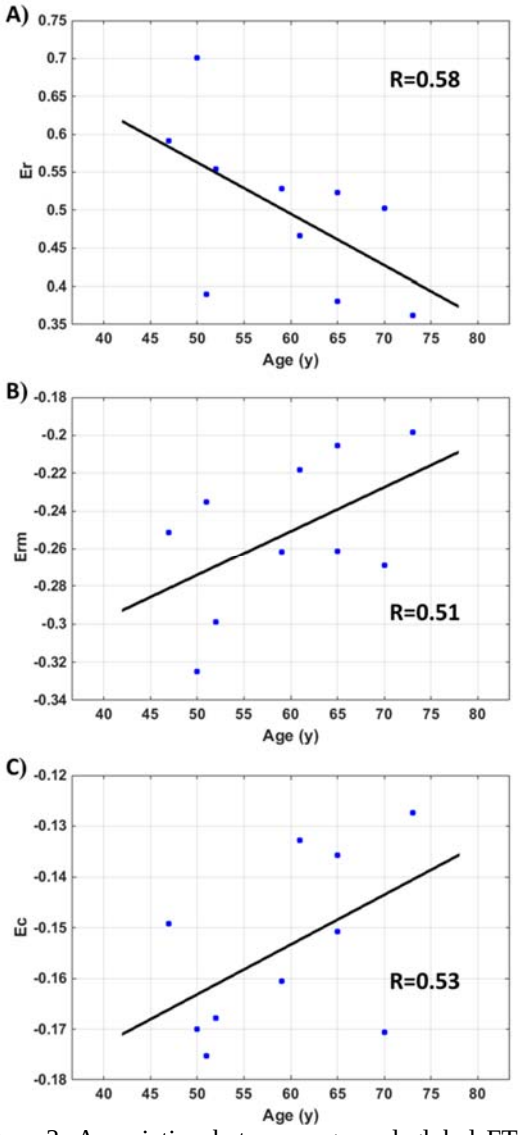

Figure 3. Association between age and global FT strain values averaged over the 2 MRI exams, for: A) Er, B) Erm and C) Ec.

The correlation coefficients related to such associations are summarized in table 2 for global and slice levels LV strains values. While reasonable correlations with age were found for strain values measured on the basal and mid-LV slices, lower correlations were found for indices measured on the apical slices.

Table 2. Association of FT strains, averaged over the 2 MRI exams, with age.

Strain	Global	Basal	Median	Apical
Er	0.58	0.42	0.49	0.43
Ec	0.51	0.59	0.46	0.16
Erm	0.53	0.61	0.53	0.27

4. Discussion and conclusion

Left ventricular strain evaluation using FT techniques has gained interest recently since such tools are based on standard cine SSFP acquisitions which are systematically acquired in every MRI exam. Moreover, conversely to tagging techniques, which are widely used in hypertrophic cardiomyopathy, FT techniques are useful on thin cardiac walls. Such feature is of potential clinical interest in heart structures such as the LA and the right ventricle. Indeed, the difficulty of studying myocardial tissue characteristics in these structures can be counter-balanced by the FT evaluation, which can provide indices of regional myocardial function. Such evaluation added to the volumetric indices, which are accurately estimated by MRI, can be of major clinical usefulness.

In the recent literature, commercial software (TomTec and Toshiba) have been used for the evaluation of LV strains using FT techniques [3,4]. In such studies, images with poor quality are often rejected and the user manually adjusted the contours obtained after tracking, introducing more variability. Another technical challenge of such technique is the inter-exam repeatability.

In the present study custom software was developed and its robustness was tested on repeated MRI exams. Comparison between strain magnitudes obtained for two MRI exams separated by two weeks resulted in low Bland-Altman biases indicating a high inter-study reproducibility of our FT technique. Such low biases are obtained despite the fact that the 2 MRI exams were performed two weeks apart and thus more likely by two different technicians. Furthermore, in line with previous studies, strain magnitudes decreased with age, but such decrease did not reach statistical significance in our small group [5].

The first limitation of this paper is the small population as well as the fact that only healthy subjects are included. However, the study is still ongoing with the inclusion of patients with aortic valve stenosis. Another limitation is the temporal resolution of our MRI data, although it was equivalent to the previous feature tracking MRI studies [6]. Improvement of temporal resolution might enhance feature tracking quality in reducing temporal distances and increasing feature similarity between successive images and allow a reliable estimation of strain rates to provide a better characterization of alterations in rapid LV filling.

Despite these limitations, strain magnitudes obtained by our feature tracking technique were reproducible and consistent with physiological knowledge in relation with age variation of LV strain.

In conclusion, conventional cine MRI SSFP images combined with a fast feature tracking technique resulted in reproducible functional LV radial and circumferential parameters. Such parameters were able to characterize subclinical age related variations in LV function. Since MRI SSFP images used in this study are systematically acquired, the addition of the proposed feature tracking tool might enhance the diagnostic value of routine cardiac MRI exams.

Acknowledgements

We would like to acknowledge the institute of Cardiometabolism and Nutrition (ICAN) for partially funding J Lamy for his PhD. and for funding M Evin for her postdoctoral scholarship.

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