Cardiac magnetic resonance feature tracking: a novel method of assessing myocardial strain. Comparison with echocardiographic speckle tracking in healthy volunteers and in patients with left ventricular hypertrophy

Stefan Orwat[1], Aleksander Kempny[1], Gerhard-Paul Diller[1], Pia Bauerschmitz[1], Alexander Ch. Bunck[2], David Maintz[2], Robert M. Radke[1], Helmut Baumgartner[1]

[1]Department of Cardiology and Angiology, Adult Congenital and Valvular Heart Disease Centre, University Hospital of Muenster, Muenster, Germany

[2]Department of Clinical Radiology, University Hospital of Muenster, Muenster, Germany

A b s t r a c t

Background: Left ventricular longitudinal strain (LV-LS) and strain rate (SR) are sensitive markers of early systolic dysfunction.

Aim: To evaluate the feasibility of a novel, cardiac magnetic resonance (CMR) based method known as feature tracking (FT) for the assessment of strain and SR, and to compare the CMR based results to those obtained on standard transthoracic echocardiography (TTE) in healthy volunteers and in patients with left ventricular hypertrophy cardiomyopathy (HCM).

Methods: Overall, 20 healthy volunteers (ten male, mean age 24 ± 3 years) and 20 consecutive patients with HCM (12 male, mean age 47 ± 19 years) were included. Longitudinal and circumferential strain and SR of the left ventricle were measured on CMR at 1.5 Tesla and TTE and interobserver variability was assessed.

Results: FT measurements were feasible in all subjects. A good agreement between global LV-LS measured on CMR (controls: 20.8 ± 3.0; HCM: 17.6 ± 3.8) and TTE (controls: 19.4 ± 2.1; HCM: 16.6 ± 2.9) was found, while the agreement was worse for circumferential strain and all SR measurements. For the left and right ventricles, interobserver reproducibility was higher for strain measurements compared to SR. Coefficients of variation were lowest for LV-LS (13.2%) by CMR.

Conclusions: FT analysis is a novel CMR based method for the analysis of myocardial strain and SR that is simple and correlates well with the echocardiographic measurements. Since CMR is unaffected by inadequate acoustic windows, FT may represent an attractive alternative to echocardiography in assessing the increasingly important parameters of myocardial deformation.

Key words: feature tracking, strain, cardiac magnetic resonance, echocardiography, left ventricular hypertrophy

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INTRODUCTION

Strain and strain rate (SR) echocardiography have emerged as promising measures of systolic myocardial left ventricular (LV) and right ventricular (RV) function. Their value in the early detection of LV systolic dysfunction has been demonstrated in several settings, such as coronary artery disease [1, 2], post myocardial infarction [3, 4], aortic stenosis [5, 6] and adult congenital heart disease [7]. It has been suggested that longitudinal myocardial dysfunction may precede impairment in conventional parameters of LV systolic function such as ejection fraction [8].

Currently, quantification of myocardial deformation using speckle tracking is largely based on two dimensional (2D)-echocardiography. Despite its widespread use and

reproducibility [9], echocardiographic assessment of strain and SR is limited by inadequate acoustic windows or poor image quality in some patients. Cardiac magnetic resonance imaging (CMR) is increasingly used to assess cardiac patients due to its advantages of a wide field of view, lack of anatomic plane restriction and superior reproducibility. However, assessment of myocardial strain and SR has been cumbersome on CMR until recently. Measuring myocardial strain by magnetic resonance imaging has required tagged imaging or harmonic phase (HARP) analysis, but the need for additional imaging sequences and the inherent complexity has limited the uptake of these techniques. Recently CMR based feature tracking analysis has become available, providing multi-planar strain data without the need for tagged images [10–13].

Although based on different physical principles compared to echocardiography, it has been demonstrated that pixel patterns obtained in CMR are stable across frames [11]. This technique, therefore, allows for the identification of specific myocardial segments in a manner similar to echocardiographic speckle tracking, in which speckles function as natural acoustic markers that can be tracked throughout the cardiac cycle and velocity and strain are obtained by automated measurement of distance between speckles.

In this study, we evaluated the clinical usefulness of feature tracking CMR by assessing interobserver variability and comparing measures of global longitudinal and circumferential strain and SR on CMR with those obtained by transthoracic echocardiography in healthy volunteers and in patients with LV hypertrophy cardiomyopathy (HCM).

METHODS

Healthy volunteers were recruited prospectively. Additionally, a series of consecutive patients with HCM referred for CMR were included. A clinical diagnosis of HCM was made in the presence of unexplained LV hypertrophy according to the current guidelines [14]. All subjects underwent conventional 2D transthoracic echocardiography (TTE) and CMR on the same day. The local ethics review committee approved the study and written informed consent was obtained from subjects.

Echocardiographic assessment

All echocardiograms were performed by two experienced echocardiographers using a GE Vivid 7 Dimension System (Vingmed, General Electric, Milwaukee, WI, USA) according to a standardised local protocol. Loops were recorded in accordance with published recommendations, with subjects in the left lateral position [15, 16]. All recordings were stored digitally for offline analysis. The cine loops for assessment of peak longitudinal 2D strain (during the whole heart cycle) of the LV and RV were recorded in apical four-chamber and parasternal short axis views and optimised through changing the transducer scan width to achieve a frame rate of at least 40 per second.

Further analysis was conducted with dedicated, commercial software (TomTec, Unterschleissheim, Germany) by two independent investigators (SO and AK). In agreement with the main aim of the study, and due to inadequate visualisation of the RV free wall in some patients, speckle-tracking analysis was performed only for the LV and consisted of marking the endocardium, defining the width of the region of interest, reflecting the distance from endocardium to pericardium, and running the automatic analytic algorithm. Within the defined region of interest, the software performs motion analysis of natural acoustic markers (speckles). This enables calculation of longitudinal global strain if performed in the apical four-chamber view, and circumferential global strain in the short axis view. The strain definitions have been provided elsewhere [17]. For the LV, longitudinal (LV-LS and LV-LSr) and circumferential (LV-CS and LV-CSr) global strain and SR were obtained.

Magnetic resonance imaging

CMR was performed on a 1.5-T MR system (Achieva R. 2.6.3.5., Philips Healthcare, Best, the Netherlands) using a standard five-element cardiac phased array coil. Imaging acquisition was performed according to current guidelines [17].

For cine imaging, a single-slice 2D balanced steady-state free precession (b-SSFP) sequence in breathhold technique and with retrospective electrocardiography triggering was used. Imaging parameters were chosen as follows: echo time (TE) and repetition time (TR) were set to shortest, resulting in an average TR of around 4 ms and a TE of 2 ms slightly varying with slice orientation; reconstructed in-plane resolution 1 mm; slice thickness 6 mm for axial planes and 8 mm for short axis planes. Number of heart phases was set to 25 resulting in a temporal resolution of 30 to 40 ms depending on the heart rate.

Data was stored in DICOM format without special adjustments and strain and SR measurements were performed offline by two independent investigators (SO and AK).

Myocardial feature tracking was performed based on standard CMR image data (Image-Arena VA Version 3.0 and 2D Cardiac Performance Analysis MR Version 1.1.0; TomTec Imaging Systems, Unterschleissheim, Germany), which has been recently introduced [11, 12]. The software does not require specific CMR acquisition such as tagged imaging or HARP analysis. It tracks voxel motion of cine-CMR images on routine steady state free precession or gradient echo images to assess circumferential and radial myocardial strain using a vector-based analysis tool. After manually delineating the endocardium in one frame, the software tracks the motion of the wall through the entire cardiac cycle [11]. From this information, the feature tracking software derives parameters like circumferential, longitudinal and radial tissue velocity, displacement and strain/SR. An average value of the measurement in six segments was used. The tracing of the myocardium is manually repeated three times and the mean value of the

Figure 1. **A–D**. Example of feature tracking based assessment of the left ventricle on cardiac magnetic resonance

functional measurements is provided. For both ventricles, longitudinal (LV-LS; LV-LSr; RV-LS and RV-LSr) and circumferential (LV-CS; LV-CSr; RV-CS and RV-CSr) peak global strain and SR during the whole heart cycle were obtained. We recently pointed out that reproducibility of regional strain on feature tracking was poor [18]. Nonetheless, no segments were excluded from the analysis due to poor tracking.

The offline analysis of the echocardiographic and CMR recordings was performed on anonymised data sets by two independent investigators (SO and AK) in random order (Fig. 1). In addition to the peak strain measurements of the whole heart cycle, conventional parameters of ventricular volume and function were measured and are presented. This includes LV end-systolic volume and LV end-diastolic volume, which were measured in the apical four-chamber view and LV ejection fraction calculated for each volunteer.

Statistical analysis

Results are expressed as mean ± standard deviation (SD). Based on the results obtained by both independent observers, the intraclass correlation coefficient was calculated. In addition, the coefficient of variability between observers was expressed as the SD of the difference divided by the mean as described previously [19].

The agreement between strains measured by the different methods was evaluated by Bland-Altman statistics with calculation of the 95% limits of agreement [20]. Statistical analyses were performed using MedCalc for Windows, version 11.6.1.0 (MedCalc Software, Mariakerke, Belgium) and R-package version 2.13.0.

Table 1. Characteristics of the studied population

Variable	Controls (n = 20)	HCM (n = 20)	P
Age [years]	24 ± 3	47 ± 19	< 0.0001
Gender: male/female	10/10	12/08	0.75
LVESV	148 ± 27	169 ± 37	0.059
LVEDV	52 ± 11	59 ± 23	0.22
Ejection fraction [%]	64.4 ± 5.3	65.5 ± 8.4	0.62
LV-CS CMR	22.6 ± 2.8	27.6 ± 6.8	0.0043
LV-CS TTE	25.8 ± 4.9	28.0 ± 5.4	0.18
LV-LS CMR	20.8 ± 3.0	17.6 ± 3.8	0.0053
LV-LS TTE	19.4 ± 2.1	16.6 ± 2.9	0.0012
RV-LS CMR	24.3 ± 3.5	24.5 ± 5.8	0.91

All volumetric data is based on cardiac magnetic resonance imaging. Values are given as mean ± SD; LVEDV — left ventricular end-diastolic volume; LVESV — left ventricular end-systolic volume; LV-CS — left ventricular circumferential strain; LV-LS — left ventricular longitudinal strain; RV-LS — right ventricular longitudinal strain; TTE — transthoracic echocardiography; CMR — cardiac magnetic resonance imaging

RESULTS

Overall, 20 healthy volunteers (ten male, mean age 24 ± 3 years) and 20 consecutive patients with HCM (12 male, mean age 47 ± 19 years) were included. Strain and SR calculations of the LV were possible in all subjects, based on CMR and echocardiographic imaging. The results of the conventional measures of ventricular function are summarised in Table 1. No significant difference in LV volume and ejection fraction was found between the two groups (Table 1).

Interobserver variability of feature tracking and speckle tracking of the LV

Figure 2 and Table 1 present the interobserver reproducibility results for feature tracking based on CMR imaging. It illustrates that reproducibility was higher for strain measures compared to SR. Bland-Altman plots showed no evidence of a systematic over- or underestimation between measurements. The results of the interobserver reproducibility for speckle tracking on echocardiography are presented in Table 2. In addition, Bland-Altman plots were constructed, again showing no evidence of a systematic relationship between measurement error and the average value (Fig. 3).

Agreement between feature tracking and speckle tracking analysis for the LV

A good agreement between LV-LS measured on CMR and TTE was found, while the agreement was poorer for CS and all SR measurements (Fig. 4). Table 2 illustrates the degree of agreement between the methods. The coefficient of variation was lower for LV-LS on CMR compared to TTE.

Interobserver variability of feature tracking and speckle tracking of the RV

Figure 5 presents the interobserver reproducibility results for feature tracking based on CMR imaging of the RV. Similarly to the LV, it illustrates that reproducibility was higher for strain measures compared to SR. Bland-Altman plots were constructed to illustrate the results, showing no evidence of a systematic over- or underestimation between measurements.

DISCUSSION

Speckle-tracking on TTE and feature tracking on CMR represent different forms of pattern matching technologies. The former is based on stochastic reflections of the ultrasound beam due to random imperfections of the tissue [21]. These scatters create the impression of speckles in the myocardium. As speckle patterns are relatively stable between echocardiographic frames, they can be used to identify points in the myocardium and track these over time. Various algorithms have been developed to this end. These include algorithms aimed at minimising the absolute sum of squares, absolute difference, or maximise cross-correlation. All these algorithms provide information on displacement, velocity and tissue deformation. As speckles do not exist on CMR due to the lack of scattered reflections, different considerations apply to feature tracking algorithms. The feature tracking algorithm — as implemented in the TomTec software [12] — is based on a combination of a border tracking and a pattern tracking algorithm capitalising on the inhomogeneity of tissue brightness, anatomical features (such as papillary muscles or trabeculations) and 'roughness' of the cavity-myocardial border [12]. In addition, to achieve acceptable computation time and spatial coherence, coarse-to-fine approaches on pyramid data structures

Table 2. Reproducibility data for feature tracking on cardiac magnetic resonance imaging and speckle tracking on echocardiography for the left ventricle

	Mean difference	Standard deviation	Coefficient of variation
CMR vs. CMR			
LV-LS	0.81	3.45	13.2%
LV-LSr	0.06	0.33	16.3%
LV-CS	0.75	3.90	11.1%
LV-CSr	0.14	0.48	20.1%
TTE vs. TTE			
LV-LS	0.52	3.84	15.2%
LV-LSr	0.03	0.30	18.6%
LV-CS	0.33	3.70	9.4%
LV-CSr	0.21	0.09	16.5%
TTE vs. CMR			
LV-LS	0.82	3.72	14.4%
LV-LSr	0.32	0.37	27.2%
LV-CS	3.11	6.49	19.4%
LV-CSr	0.26	0.67	25.6%

LV-LS — left ventricular longitudinal strain; LV-LSr — left ventricular longitudinal strain rate; LV-CS — left ventricular circumferential strain; LV-CSr — left ventricular circumferential strain rate; TTE — transthoracic echocardiography; CMR — cardiac magnetic resonance imaging

(so called hierarchical algorithms) and combinations of filters are commonly used [12]. Despite the obvious differences in the underlying physical principles, the current study shows that measurement of myocardial deformation is feasible using feature tracking analysis based on conventional CMR imaging, and provides comparable values to those measured by speckle tracking based on echocardiography, while having the advantage of superior reproducibility. Furthermore, due to the wider field of view, comprehensive assessment of the deformation of the RV is possible based on feature tracking algorithms.

Over the last few years, global longitudinal strain and SR have gained increasing clinical interest [22]. This is mainly due to the fact that it has been suggested that strain and SR may be more sensitive in detecting early myocardial dysfunction, may be superior to conventional parameters of ventricular function (most notably ejection fraction) for assessing systolic function in the setting of LV hypertrophy, and may outperform ejection fraction in predicting prognosis in heart failure patients [23]. Unfortunately, measurement of these parameters has traditionally been limited to echocardiographic techniques. While TTE continues to be the cornerstone of routine cardiac imaging in patients with established or suspected heart disease, it is not feasible in all patients due to obvious limitations related to inadequate acoustic windows. In addition, patients may undergo CMR for other reasons and measurement of strain and SR may be desired. To this end, the advent of feature
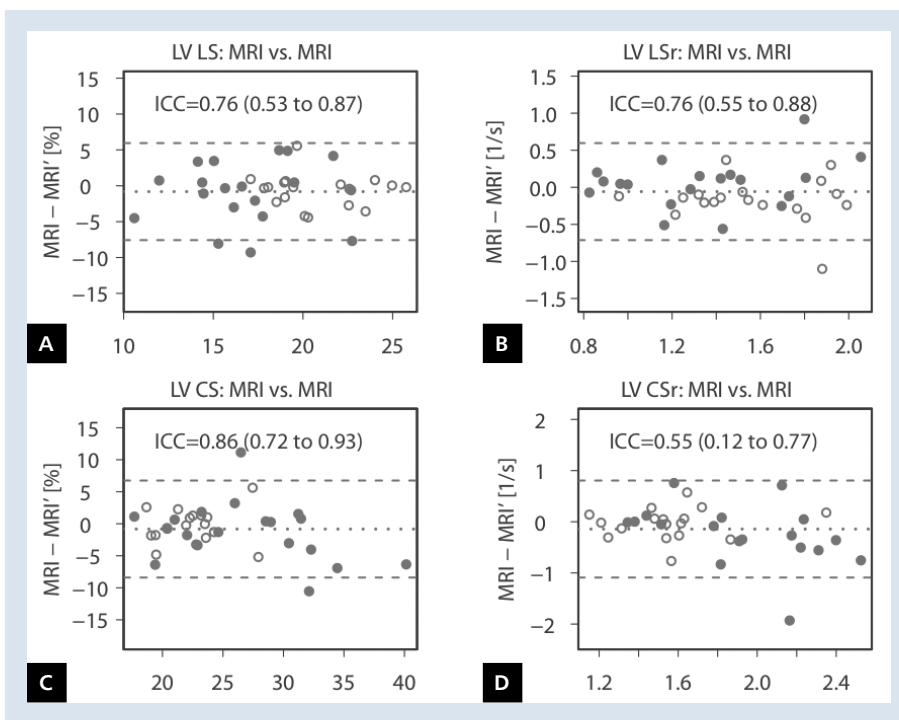
Figure 2. **A–D**. Bland-Altman plots illustrating the reproducibility of feature tracking on cardiac magnetic resonance imaging (MRI). In addition, interclass correlation coefficients (ICC) with 95% confidence intervals are provided; CS — circumferential strain; CSr — circumferential strain rate; LS — longitudinal strain; LSr — longitudinal strain rate; LV — left ventricle; open circles — healthy volunteers; closed circles — patients with hypertrophic cardiomyopathy
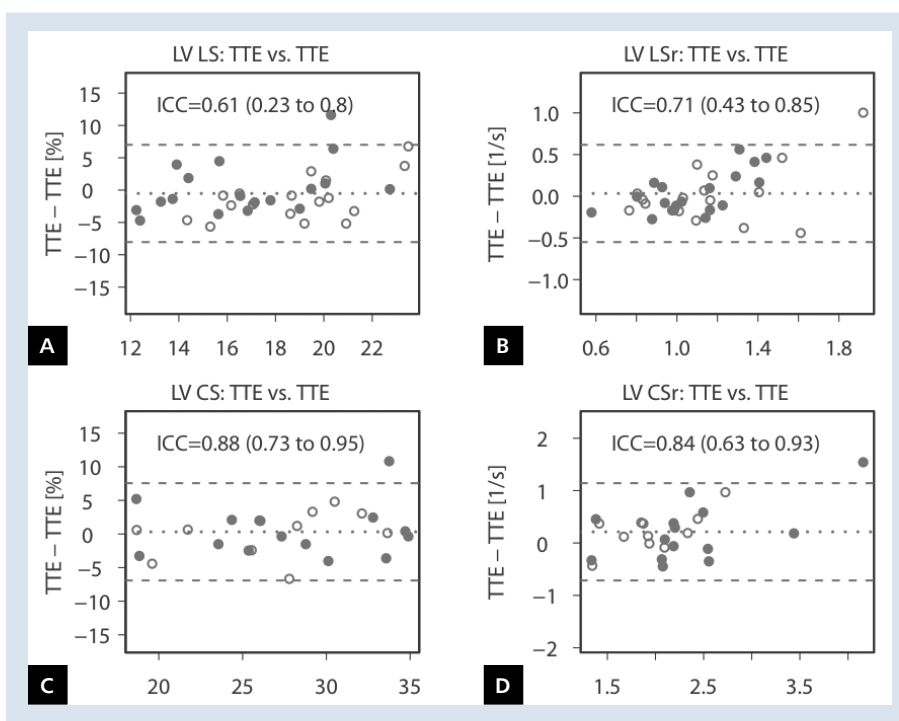

Figure 3. **A–D**. Bland-Altman plots illustrating the reproducibility of speckle tracking on transthoracic echocardiography (TTE). Interclass correlation coefficients (ICC) with 95% confidence intervals are provided; CS — circumferential strain; CSr — circumferential strain rate; LS — longitudinal strain; LSr — longitudinal strain rate; LV — left ventricle; open circles — healthy volunteers; closed circles — patients with hypertrophic cardiomyopathy
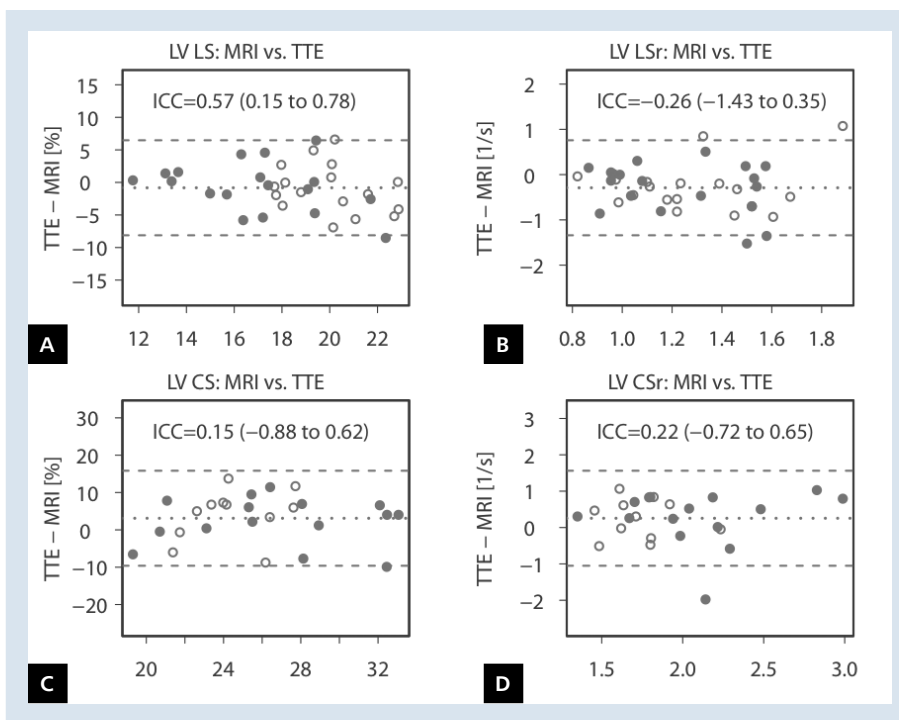
Figure 4. A–D. Bland-Altman plots comparing speckle tracking on transthoracic echocardiography (TTE) to feature tracking on cardiac magnetic resonance imaging (MRI). Interclass correlation coefficients (ICC) with 95% confidence intervals are provided; CS — circumferential strain; CSr — circumferential strain rate; LS — longitudinal strain; LSr — longitudinal strain rate; LV — left ventricle; open circles — healthy volunteers; closed circles — patients with hypertrophic cardiomyopathy
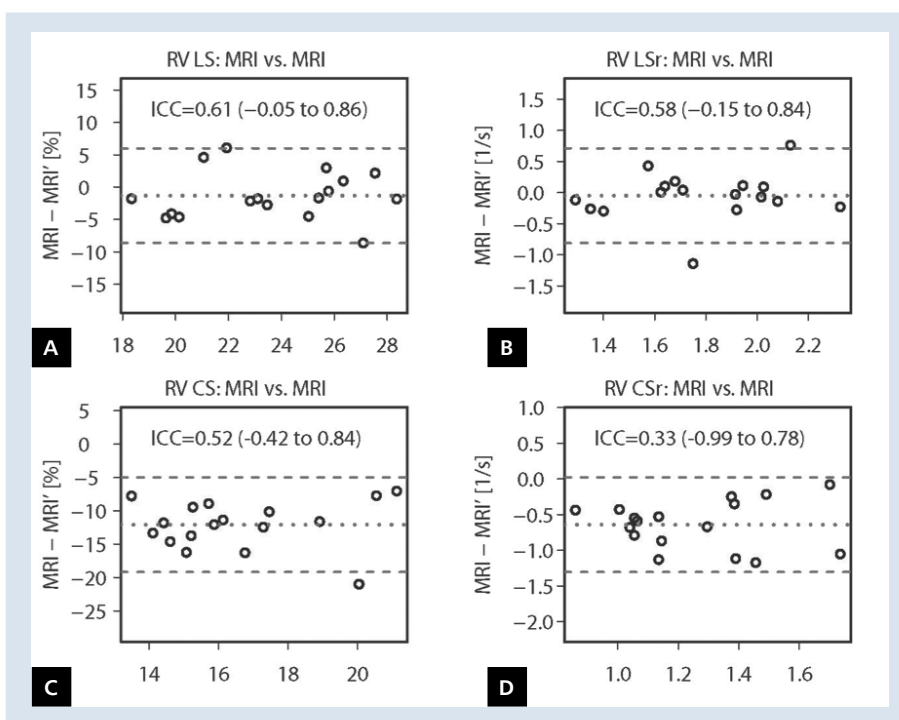

Figure 5. A–D. Bland-Altman plots illustrating the reproducibility of feature tracking on cardiac magnetic resonance imaging (MRI) for the right ventricle (RV). Interclass correlation coefficients (ICC) with 95% confidence intervals are provided; CS — circumferential strain; CSr — circumferential strain rate; LS — longitudinal strain; LSr — longitudinal strain rate

tracking CMR may complement our armamentarium of cardiovascular imaging.

Magnetic resonance based feature tracking employs the most commonly used pulse sequence for the evaluation of ventricular function characterised by a high signal-to-noise ratio combined with an excellent temporal resolution [24]. Unlike speckle-tracking echocardiography, inadequate visualisation of cardiac structures, especially the lateral wall segments, is unproblematic on feature tracking. Overall, the results of the current study support the observation that the feature tracking algorithms benefit from the trabeculations present within the RV as illustrated by the better reproducibility of LS of the RV compared to the LV (coefficient of variation 11.5% vs. 13.2%). Despite this, feature tracking is possible both in the LV and RV, and provides reproducible data that compares well to the established speckle tracking technique.

It appears however that the reproducibility of circumferential strain measures is superior on CMR compared to longitudinal strain. We speculate that this could be related to an occasional problem with inadequate tracking of the fast moving basal segments of the LV in apical four-chamber view. This could also be due to the fact that these particular ventricular segments often lack clear distinctive myocardial features that might assist feature tracking.

Additionally, measures of SR were less reproducible compared to global strain parameters by both investigated techniques. We believe this is related to the relatively limited temporal resolution of the techniques compared to speckle tracking [25].

Limitations of the study

Echocardiograms and CMR studies were performed on the same day but at different times of the day, and we cannot completely exclude changes in physiologic variables between the tests. However, this reflects normal clinical practice and we do not expect this to have an important impact on the results. Both methods are based on a 2D algorithm and do not account for out of plane motion of voxels. In the future, 3D speckle tracking/feature tracking have the potential of offering a more comprehensive assessment of myocardial deformation using fewer geometric assumptions. What represents 'good agreement' between studies is a subjective judgment based on clinical requirements. We provide Bland-Altman plots comparing feature tracking to speckle tracking echocardiography.

Based on the results presented, clinicians need to decide whether reproducibility and intermethod agreement are sufficient for their particular patient population and clinical question. Importantly, however, from a clinical perspective and based on recently published normal values of LV global strain [26, 27] measured by speckle tracking, none of the healthy controls included in this study would be misclassified as having abnormal LV systolic function on CMR.

CONCLUSIONS

Feature tracking analysis is a novel CMR based method to analyse the increasingly important parameters of myocardial strain and SR that can easily be obtained and correlates well with the echocardiographic measurements of these parameters. Considering the advantage of acoustic window independence and good reproducibility, feature tracking CMR may become an attractive alternative to echocardiography for the assessment of myocardial function in a clinical setting.

Conflict of interest: none declared

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Nowa metoda pomiaru odkształcenia mięśnia sercowego na podstawie techniki śledzenia cech obrazów ruchomych rezonansu magnetycznego serca. Porównanie z echokardiograficzną metodą śledzenia markerów akustycznych u zdrowych ochotników i u chorych z przerostem lewej komory

Stefan Orwat[1], Aleksander Kempny[1], Gerhard-Paul Diller[1], Pia Bauerschmitz[1], Alexander Ch. Bunck[2], David Maintz[2], Robert M. Radke[1], Helmut Baumgartner[1]

[1]Department of Cardiology and Angiology, Adult Congenital and Valvular Heart Disease Centre, University Hospital of Muenster, Muenster, Niemcy

[2]Department of Clinical Radiology, University Hospital of Muenster, Muenster, Niemcy

Streszczenie

Wstęp: Odkształcenie podłużne lewej komory (LV-LS) i prędkość odkształcenia (SR) są czułymi wskaźnikami wczesnej dysfunkcji skurczowej.

Cel: Celem niniejszej pracy były: ocena nowej metody pomiaru odkształcenia mięśnia sercowego na podstawie techniki śledzenia cech (FT, *feature tracking*) obrazów ruchomych rezonansu magnetycznego serca (CMR) oraz porównanie wyników uzyskanych w CMR do rezultatów standardowej przezklatkowej echokardiografii (TTE) przeprowadzonej u zdrowych ochotników i u chorych z kardiomiopatią przerostową (HCM).

Metody: Do badania włączono 20 zdrowych ochotników (10 mężczyzn, średnia wieku 24 ± 3 lata) i 20 kolejnych pacjentów z HCM (12 mężczyzn, średnia wieku 47 ± 19 lat). Odkształcenie podłużne i okrężne oraz SR lewej komory zmierzono w CMR przy natężeniu pola magnetycznego 1,5 tesli. Oceniono również TTE i zmienność zależną od obserwatora.

Wyniki: Pomiar FT był możliwy u wszystkich badanych. Stwierdzono dużą zgodność między całkowitym LV-LS mierzonym przy użyciu CMR (grupa kontrolna: 20,8 ± 3,0; HCM: 17,6 ± 3,8) i za pomocą TTE (grupa kontrolna: 19,4 ± 2,1; HCM: 16,6 ± 2,9), natomiast pomiary odkształcenia okrężnego i wszystkie pomiary SR charakteryzowały się mniejszą zgodnością. Powtarzalność wyników dotyczących lewej i prawej komory uzyskiwanych przez różnych obserwatorów była większa w przypadku pomiarów odkształceń w porównaniu z SR. Najniższe współczynniki zmienności stwierdzono w przypadku pomiarów LV-LS (13,2%) metodą CMR.

Wnioski: Analiza FT, będącego nową metodą oceny odkształceń mięśnia sercowego oraz SR opartą na badaniu CMR, jest prosta i dobrze koreluje z pomiarami echokardiograficznymi. Ze względu na to, że na CMR nie ma wpływu niewłaściwe okno akustyczne, FT może być atrakcyjną alternatywą dla badania echokardiograficznego w ocenie bardzo ważnych parametrów deformacji miokardium.

Słowa kluczowe: śledzenie cech obrazów ruchomych, odkształcenie, rezonans magnetyczny serca, echokardiografia, przerost lewej komory

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