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Chapter 3.4

High-temporal velocity-encoded MRI for the assessment of left ventricular inflow propagation velocity: comparison with color M-mode echocardiography

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ABSTRACT

Purpose

Left ventricular (LV) inflow propagation velocity (Vp) is considered a useful parameter in the complex assessment of LV diastolic function and is measured by Color M-mode echocardiography. The aim of current study was to develop an alternative method for Vp-assessment using high-temporal velocity-encoded magnetic resonance imaging (VE-MRI).

Methods

A total of 43 patients diagnosed with ischemic heart failure (61 ± 11 years) and 22 healthy volunteers (29 ± 13 years) underwent Color M-mode echocardiography and VE-MRI to assess the inflow velocity through the mitral valve (mean inter-examination time 14 days). (Temporal resolution of VE-MRI was 10.8–11.8 ms) Local LV inflow velocity was sampled along a 4 cm line starting from the tip of the mitral leaflets and for consecutive sample points the point-in-time was assessed when local velocity exceeded 30 cm/s. From the position-time relation, Vp was calculated by both the difference quotient (Vp-MRI-DQ) as well as from linear regression (Vp-MRI-LR).

Results

Good correlation was found between Vp-echo and both Vp-MRI-DQ ($r=0.83$ $p<0.001$) and Vp-MRI-LR ($r=0.84$ $p<0.001$). Vp-MRI showed a significant but small underestimation as compared to Vp measured by echocardiography (Vp-MRI-DQ: 5.5 ± 16.2 cm/s, $p=0.008$; Vp-MRI-LR: 9.9 ± 15.2 cm/s, $p<0.001$). Applying age-related cut-off values for Vp to identify LV impaired relaxation, Kappa-agreement with echocardiography was 0.72 ($p<0.001$) for Vp-MRI-DQ and 0.69 ($p<0.001$) for Vp-MRI-LR.

Conclusion

High-temporal VE-MRI represents a novel approach to assess Vp showing good correlation with Color M-mode echocardiography. In healthy subjects and patients with ischemic heart failure, this new methods demonstrated good agreement with echocardiography to identify LV impaired relaxation.

INTRODUCTION

Despite improvements in the treatment of cardiac diseases, the prevalence of systolic and diastolic heart failure (HF) continues to rise [1]. Particularly, presence of LV diastolic dysfunction, with or without a concomitant LV systolic dysfunction, is associated with increased morbidity and portends poor prognosis [2,3]. Furthermore, subclinical LV diastolic dysfunction has been shown to be related to a high risk of progression to symptomatic HF and therefore an early detection of LV impaired relaxation might have important clinical implications for patient management [1].

LV diastolic function is influenced by several factors, such as LV geometry and myocardial relaxation properties, left atrial function, pericardial restraint, heart rate and rhythm [4]. Direct measurement of the LV pressure-volume relation is considered the gold standard for diagnosis of diastolic function [5,6], but such assessment is invasive and not available for most patients. Current recommendations for the evaluation of LV diastolic function consider echocardiography the method of choice for a non-invasive evaluation in clinical practice and a combination of various parameters is proposed [7]. A useful marker for the assessment of LV diastolic function with echocardiography is the LV inflow propagation velocity (V_p), a relatively load-independent parameter that records velocity information along a scan line from the mitral valve into the ventricle during early LV filling [8-11]. V_p can be measured with Color M-mode echocardiography, which allows a high temporal resolution. It has been shown that the ratio of peak early filling velocity to V_p is directly proportional to LA pressure and therefore can be used to identify impaired LV relaxation by itself [12,13] or in combination with the isovolumic relaxation time [14]. Furthermore, while a $V_p > 50$ m/sec is considered normal, in patients > 30 year-old a V_p less than 45 cm/s has been suggested to identify LV impaired relaxation; in patients < 30 year-old, this cut-off value is raised to 55 cm/s [10].

Recently, magnetic resonance imaging with high-temporal time-resolved velocity encoding (VE-MRI) has been also proposed for V_p evaluation [15], allowing for the assessment of the intra-cardiac blood flow velocities. The aim of the current study was to develop a high-temporal VE-MRI approach to measure V_p and to compare this method with Color M-mode echocardiography in patients with ischemic HF and healthy volunteers.

MATERIAL AND METHODS

Subjects

Forty-three patients with ischemic HF consecutively referred for cardiac MRI and 22 healthy volunteers were included in this study. Valvular stenosis or a repaired/replaced valve was an exclusion criterion. Data on New York Heart Association (NYHA) classification and percentage of LV scarring based on delayed contrast enhancement MRI [16] were obtained by patient status review. To allow evaluation of a wide range of LV diastolic function, the mean age of the

healthy volunteers was substantially younger as compared to patients. Mean inter-examination time between echocardiography and VE-MRI was 14 days. The study was approved by the local ethical committee and written informed consent was obtained from all patients and volunteers. Data of this patient population has been published before [17-21] however none was related to Vp-evaluation.

Echocardiography

Transthoracic echocardiography images were acquired in the left lateral decubitus position using a commercially available system equipped with a 3.5 MHz or M5S transducer (Vivid 7-9, GE-Vingmed Ultrasound, Horton, Norway). Vp was measured as described by Garcia et al. [10] by a cardiologist with 10 years of experience, (NA) blinded with regard to the MRI results. In the apical 4-chamber view, with the use of Color Doppler, the M-mode cursor was aligned along the mitral inflow stream to record the early flow propagation velocity into the LV. Baseline shift was performed as needed to obtain a distinct border of the propagation velocity into the LV cavity (usually Nyquist limit around 30-40 cm/sec). During off-line analysis, the slope of the first 'aliasing' velocity (red to blue) was traced from the mitral valve plane to 4 cm distal in the LV (Vp in cm/sec) (Figure 1). In some cases, the slope of the aliasing area in the M-mode image flattens towards the top. In such cases, the measurement line was positioned along the steepest part of the area of aliasing. For each subject, Vp-echo was calculated from an average of three measurements.

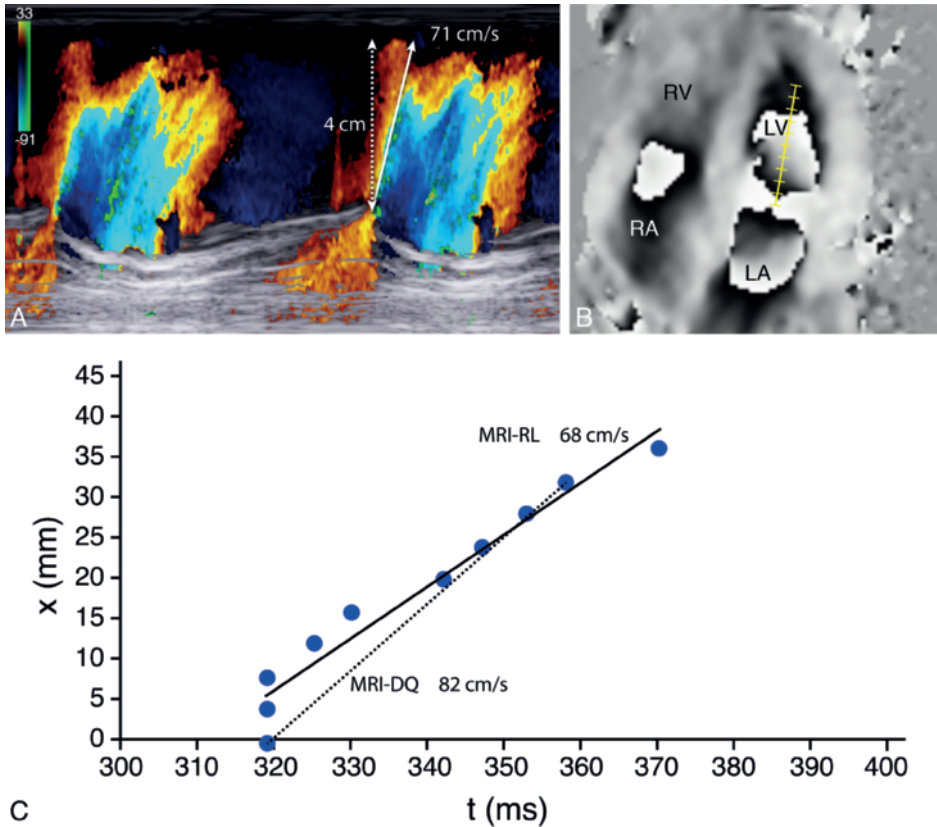
MRI acquisition

MRI patient data was collected using a 1.5 Tesla (T) MRI system (Intera, release 11 and 12; Philips Medical Systems, Best, the Netherlands) with 33 mT/m maximal gradient amplitude and 100 mT/m/ms slew rate. A five-element cardiac coil placed on the chest was used for signal reception. A series of survey scans which included cine 2- and 4-chamber views and a multi-slice multi-phase short-axis set were acquired to measure LV volume and compute the ejection fraction ($LV\ EF = (LV\ end-diastolic\ volume - LV\ end-systolic\ volume) / LV\ end-diastolic\ volume$) with a steady-state free-precession sequence with typical imaging parameters: slice thickness = 8 mm, field-of-view = 400×320 mm², spatial resolution voxel size of 1.8×2.0×8.0 mm³, flip angle = 50°, echo time (TE) = 1.7 ms, repetition time (TR) = 3.4 ms, one number of signal averages (NSA) and no parallel imaging. Each slice was acquired using breath-holding in end-expiration. Retrospective gating was used, with 10% arrhythmia rejection, and for each slice, 1 average heart beat was reconstructed into 30 phases. Image analysis with manual contour segmentation for LV volume calculation was performed using in-house developed MASS software.

Subsequent non-segmented VE-MRI was performed in a 4-chamber view with single-directional in-plane velocity encoding in phase encoding direction. This direction was visually angulated parallel to the LV inflow direction (i.e. parallel to the line from the opened mitral valve leaflets to the apex). The following typical imaging parameters were used: slice thickness = 8 mm, field-of-view = 370×320 mm², spatial resolution voxel size of 2.8×2.5×8.0 mm³, flip angle =

10°, TE = 3.4 ms, TR = 5.4 ms, NSA = 4 and no parallel imaging was used. Velocity sensitivity was set to 20 cm/s and retrospective gating was used. Acquisition was performed with free breathing. The maximal number of phases was reconstructed, yielding an effective temporal resolution of approximately 6 ms (i.e., the true temporal resolution equals $2 \times \text{TR} = 10.8$ ms).

Figure 1. Schematic representation of velocity propagation assessment with Color M-mode echo and velocity-encoded MRI.



During offline analysis of echocardiography (panel A), the slope of the first 'aliasing' velocity (red to blue) is traced from the mitral valve plane to position 4 cm distal into the LV. On the velocity encoded MRI scan (panel B), a 4 cm scan line is defined starting from the position of the valve leaflets and in the direction of the LV inflow. 11 sample points (4 mm apart) are defined on this scan line and the point-in-time was recorded, starting from the onset of LV filling, when aliasing was reached for each consecutive sample point. The time points where aliasing occurs, are then displayed in a position-time graph (panel C). The slope of the line of the position-time relation, representing Vp, is calculated by two definitions: Vp-MRI-Difference Quotient (Vp-MRI-DQ), using the difference quotient (i.e. the slope of the straight line between the first point and the final recording that represents the inflow wave), and Vp-MRI-Linear Regression (Vp-MRI-LR), using the slope which was calculated by linear regression from all included sample points along the scan line. Since the slope of the x-t relation flattens towards the top in this example, only measurement points along the steepest part of line are included and the last sample point most distally in the LV is disregarded. Due to the limited temporal resolution, consecutive sample points may present equal recorded times of aliasing in case of fast propagation, as is illustrated in the first 8 mm distal to the valve (panel C).

Volunteer data was acquired using a 3.0T MRI system (Ingenia, Philips Medical Systems, The Netherlands) with 45 mT/m maximal gradient amplitude and 200 mT/m/ms slew rate. A combination of FlexCoverage Posterior coil in the table top with a dStream Torso coil was used, providing up to 32 coil elements for signal reception. Similar to the patient data acquisition, a series of survey scans and a multi-slice multi-phase short-axis set were acquired with a steady-state free-precession sequence with typical imaging parameters: slice thickness = 8 mm, field-of-view = 350×350 mm², spatial resolution voxel size of 1.5×1.5×8.0 mm³, flip angle = 45°, TE = 1.5 ms, TR = 3.0 ms, NSA = 3 and parallel imaging with SENSE factor 2. Free breathing was allowed. VE-MRI was performed with typical imaging parameters: slice thickness = 8 mm, field-of-view = 320×260 mm², spatial resolution voxel size of 2.5×2.5×8.0 mm³, flip angle = 10°, TE = 3.8 ms, TR = 5.9 ms (i.e., the true temporal resolution equals 2×TR = 11.8 ms), NSA = 1 and parallel imaging with SENSE factor 2. Velocity sensitivity was set to 30 cm/s and retrospective gating with 10% arrhythmia rejection, was used with maximal number of phases reconstructed and acquisition was performed with free breathing.

VP-QUANTIFICATION BASED ON VE-MRI

The approach of inflow propagation evaluation with MRI has been modelled to the Color M-mode approach, i.e. a position-time (x-t) graph was constructed which displays for each consecutive sample point along the scan line from mitral valve towards the apex, the point in time when local inflow velocity exceeds the aliasing value of 30 cm/s. Similar to Vp-echo assessment from Color M-mode echocardiography, the slope of the straight line constructed from the x-t relation then represents Vp. Therefore, in the 4-chamber view velocity images, a scan line of 4 cm was manually indicated from the tip of the valve leaflets into the LV, parallel to the inflow direction. The velocity scale was set to a maximal inflow velocity of 30 cm/s. For volunteers, this aliasing threshold already has been set at the acquisition. For patient data, however, the maximal velocity sensitivity at acquisition was 20 cm/s. Therefore, using the MASS software, the display range of velocity values was first shifted from -20 cm/s – 20 cm/s into -10 cm/s – 30 cm/s. Equidistantly along the scan line, 11 sample points were defined, 4 mm apart. Starting at the onset of LV filling, the point-in-time was recorded when aliasing was reached for each consecutive sample point along the scan line. These time points were then transported offline into MS Excel (version 2010) and displayed in a position-time graph. The slope of the line of the position-time relation, representing Vp, was calculated by two definitions: Vp-MRI-Difference Quotient (Vp-MRI-DQ), using the difference quotient (i.e., the slope of the straight line between the first point and the final recording that represented the inflow wave), and Vp-MRI-Linear Regression (Vp-MRI-LR), using the slope which was calculated by linear regression from all included sample points along the scan line. Similarly as in Color M-mode echocardiography in cases when the slope of the x-t relation flattens towards the top, only the measurement points along the steepest part of line

were included and sample points more distal in the LV were disregarded, both for Vp-MRI-DQ as well as for Vp-MRI-LR calculation.

Intra- and interobserver variation of MRI-DQ and MRI-LR were tested by repeated analysis in 10 randomly selected controls and 10 patients. Two observers (EC with 2 years of cardiac MRI experience and JW with over 15 years of cardiac MRI experience), performed these analyses blinded for each other and the analyses was performed twice by the initial observer with an inter-examination time of two weeks.

To compare the signal-to-noise ratio (SNR) in patients versus volunteers, one observer (JW) measured SNR in the VE-MRI magnitude images at the moment of end-diastole, by placing circular sampling regions-of-interest of approximately 1 – 1.5 cm² in the left ventricle (at the position of the end of the scan line, 4 cm distal to the mitral valve) and in the air near to the anterior chest wall. SNR was calculated by the ratio between the mean signal intensity sampled in the LV and the standard deviation of the signal intensity measured in air.

Statistical analysis

Continuous data were expressed as mean $\pm$ standard deviation (SD). Vp from VE-MRI was compared with echo Doppler using paired t-test, Pearson correlation and Bland-Altman analysis with 95% limits of agreement. [22] When using the cut-off value for Vp of 45 cm/s for subjects >30 years and 55 cm/s for subject <30 years to classify LV impaired relaxation, a cross-table was constructed to determine weighted kappa agreement (Fleiss-Cohen weighting) between both modalities [23]. Correlation and agreement were classified as excellent (>0.95), strong (0.95 – 0.85), good (0.85 – 0.70), moderate (0.70 – 0.60) or fair (>0.60). Intra- and interobserver variation was determined by the significance of differences between measurements and the intraclass correlation coefficient for absolute agreement and the coefficients of variation. SPSS for Windows version 20 (SPSS Inc., Chicago, Illinois) was used for statistical analysis and P < 0.05 was considered significant.

RESULTS

Characteristics of the patients and healthy volunteers, with parameters for left ventricular volume measurement obtained by standard short-axis MRI evaluation, are presented in Table 1. Delayed enhancement analysis in 42 patients showed a mean infarct size of $23 \pm 16\%$ of the total LV myocardial mass. Mean heart rate $\pm$ SD during VE-MRI for patients was 68 ± 14 bpm (range 45 – 104 bpm), which resulted in mean VE-MRI acquisition time of 4 minutes 7 seconds (range: 2 minutes 43 seconds – 5 minutes 17 seconds). For volunteers, mean heart rate $\pm$ SD during VE-MRI was 68 ± 13 bpm (range 53 – 103 bpm), which resulted in mean VE-MRI acquisition time of 1 minutes 22 seconds (range: 54 seconds – 1 minutes 46 seconds). Heart rates between examinations were very similar and not statistically significantly different: mean heart rate in patients during during

echocardiography 69 ± 15 bpm (for comparison with VE-MRI $p = 0.65$). For controls, mean heart rate during echocardiography 67 ± 13 bpm (for comparison with VE-MRI $p = 0.46$). Heart rates between patients and controls were also not statistically significantly different ($p=0.46$). Analysis time for Vp-assessment from VE-MRI was 1–2 minutes. SNR measured in VE-MRI in patients was 53 ± 36 versus 114 ± 77 in volunteers ($p = 0.002$).

In Figure 2, correlation between Vp-echo and both VE-MRI-assessed markers (Vp-MRI-DQ and Vp-MRI-RL) is presented. Good correlation between both modalities was observed: linear regression analysis between Vp-echo and Vp-MRI-DQ $Y = aX + b$, with regression coefficients $a = 0.81 \pm 0.07$ and $b = 6.1 \pm 4.6$, $r = 0.83$, $p < 0.001$. Linear regression between Vp-echo and Vp-MRI-LR $Y = aX + b$, with regression coefficients $a = 0.70 \pm 0.06$ and $b = 8.3 \pm 3.7$, $r = 0.84$, $p < 0.001$. Comparing both MRI markers, Vp-MRI-DQ showed significant but slightly higher values as compared to Vp-MRI-LR (mean difference 7.1 ± 8.1 cm/s, $p < 0.001$), with excellent correlation: $r = 0.941$ ($p < 0.001$). The agreement between Vp-echo and both VE-MRI markers is presented in Bland-Altman graphs in Figure 3. For both Vp-MRI-DQ and Vp-MRI-LR, a significant but small underestimation compared to Vp-echo was observed (Vp-MRI-DQ: 5.5 ± 16.2 cm/s, $p = 0.008$, 95% limits of agreement -26 to 37 cm/s; Vp-MRI-LR: 9.9 ± 15.2 cm/s, $p < 0.001$, 95% limits of agreement -20 to 40 cm/s). As shown by the Bland-Altman graphs, the bias between Vp-echo and Vp-MRI becomes larger for higher values of Vp.

To identify LV impaired relaxation, age-related cut-off values were used (Vp < 45 cm/s for subjects older than 30 years and Vp < 55 cm/s for subjects younger than 30 years). A 26 year-old female volunteer showed a Vp-echo = 59 cm/s, a Vp-MRI-DQ = 48 cm/s and a Vp-MRI-LR = 45 cm/s. All other volunteers showed Vp > 55 cm/s for Vp-echo as well as for both VE-MRI markers. All patients were older than 30 years. Applying the age-related cut-off values, good agreement was found between Vp-echo and Vp-MRI-DQ: kappa $\pm$ standard error (SE) = 0.72 ± 0.09 , $p < 0.001$;

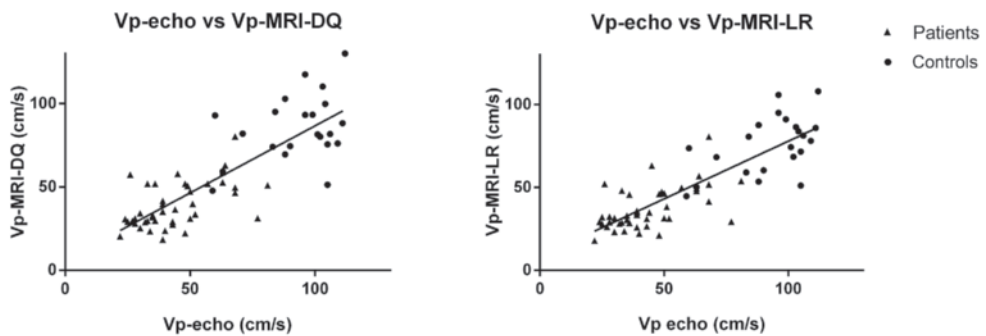
Table 1. Population characteristics. EF: ejection fraction; LV: left ventricle, EDV: end-diastolic volume; ESV: end-systolic volume.

	Healthy volunteers	Patients
N	22	43
Age (years)	29 ± 13	61 ± 11
Weight (kg)	65 ± 15	80 ± 11
Gender	68% male	72% male
Heart rate (bpm)	68 ± 13	68 ± 14
LV EF %	60.9 ± 4.8	29.6 ± 11.4
LV EDV (mL)	161 ± 37	295 ± 85
LV ESV(mL)	63 ± 19	213 ± 82
NYHA class		9% class I 35% class II 47% class III 9% class IV

moderate agreement was found between Vp-echo and Vp-MRI-LR: $\kappa \pm SE = 0.69 \pm 0.09$, $p < 0.001$ (Table 2). When using either VE-MRI measures of Vp to identify LV impaired relaxation, high values for sensitivity (Vp-MRI-DQ 88% with 95%-CI 71 – 96% and Vp-MRI-LR 88% with 95%-CI 71 – 96%) and specificity (Vp-MRI-DQ 85% with 95%-CI 70 – 93% and Vp-MRI-LR 82% with 95%-CI 67 – 91%) were found (Table 3).

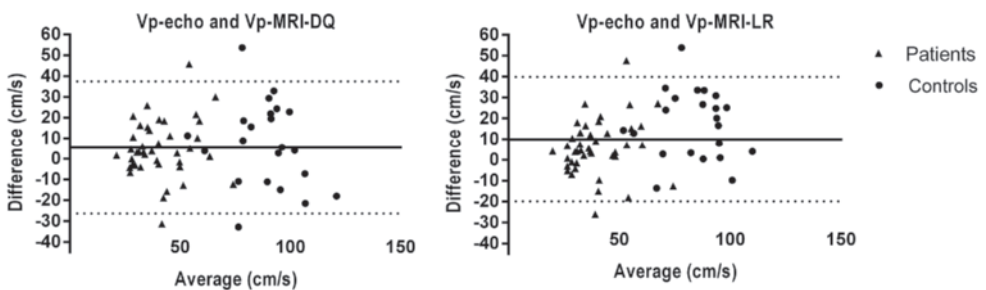
Intra-observer analysis showed excellent intraclass correlation for both MRI-LR and MRI-DQ (0.97) with a coefficient of variation of 15% (Table 3). Mean difference in MRI-LR was -4.5cm/s 95%-CI $-9.0 - -0.6$, $p=0.05$ and in MRI-DQ -3.0cm/s 95%-CI $-7.2 - 1.2$, $p=0.15$. Inter-observer analysis showed strong intraclass correlation for both MRI-LR (0.92) and MRI-DQ (0.95) with a coefficient of variation of 26% for MRI-DQ and 20% for MRI-LR (Table 3). Mean difference in MRI-LR was 2.5cm/s 95%-CI $-5.5 - 10.4$, $p=0.53$ and in MRI-DQ 0.5cm/s 95%-CI $-5.5 - 5.6$, $p=0.99$.

Figure 2. Correlation between velocity propagation.



Measured with Color M-mode echocardiography (Vp-echo) and MRI difference quotient (Vp-MRI-DQ) and MRI linear regression (Vp-MRI-LR).

Figure 3. Agreement between velocity propagation.



Measured with Color M-mode echocardiography (Vp-echo) and MRI difference quotient (Vp-MRI-DQ) and MRI linear regression (Vp-MRI-LR) presented in a Bland-Altman plot.

Table 2. Cross-tables determining weighted kappa agreement (Fleiss-Cohen weighting) between Vp-measurements with Color M-mode echocardiography (Vp-echo) and MRI difference quotient (Vp-MRI-DQ) and MRI linear regression (Vp-MRI-LR).

		Vp-MRI-DQ	
		< 45/55 cm/s	≥ 45/55 cm/s
Vp-echo	< 45/55 cm/s	23	6
	≥ 45/55 cm/s	3	33

		Vp-MRI-LR	
		< 45/55 cm/s	≥ 45/55 cm/s
Vp-echo	< 45/55 cm/s	23	7
	≥ 45/55 cm/s	3	32

Table 3. Intra- and inter-observer variability analysis. Vp-MRI-DQ = Velocity propagation MRI difference quotient, Vp-MRI-LR = Velocity propagation MRI linear regression.

	Intra-observer		Inter-observer	
	Vp-MRI-DQ	Vp-MRI-LR	Vp-MRI-DQ	Vp-MRI-LR
Intraclass correlation coefficient	0.97 (p<0.001)	0.97 (p<0.001)	0.92 (p<0.001)	0.95 (p<0.001)
Mean difference with 95%-CI (cm/s)	-4.5 (-9.0 – -0.6)	-3.0 (-7.2 – 1.2)	2.5 (-5.5 – 10.4)	0.1 (-5.5 – 5.6)
P value	0.05	0.15	0.53	0.99
Absolute difference (cm/s)	7.1 ± 7.9	5.8 ± 7.4	11.9 ± 12.3	8.9 ± 7.5
Coefficient of variation	15%	15%	26%	20%

DISCUSSION

In the current recommendations for LV diastolic function assessment, LV Vp is proposed as a relatively load-independent parameter to identify LV impaired relaxation [8,10,11] and is reproducibly measured by Color M-mode echocardiography [12]. Even when multiple echocardiographic tests of LV diastolic function may be available, Vp-assessment may be useful in the identification of impaired LV relaxation in case other Doppler indices appear to be inconclusive [24].

In the present study, a high-temporal VE-MRI method has been introduced to assess Vp and compared to Color M-mode echocardiography. More specifically, two different approaches of Vp measurement by VE-MRI were assessed; one based on the difference quotient, calculated from the LV inflow wave propagation between two measurement points; and one based on the slope determined with linear regression from the wave propagation along multiple measurement positions. The first approach reflects more closely the analysis by Color M-mode echocardiography, whereas the second approach has been tested as potentially less noise-sensitive. We chose to model the method for MRI-Vp-assessment on the Color M-mode echocardiography approach, rather than evaluating wave propagation similar to arterial pulse wave propagation approaches [25,26] as the short intra-ventricular distance that is covered and the limited spatial and temporal

resolution do not allow such evaluation. Vp-values obtained by both MRI approaches showed good correlation and agreement with Color M-mode echocardiography. However, Vp based on difference quotient calculation showed slightly better agreement and smaller bias when compared with echocardiography. This approach could be therefore proposed as a potential alternative method or as further confirmation to echocardiography in the assessment of LV diastolic function and identification of LV impaired relaxation.

Although echocardiography remains the method of choice for the assessment of LV diastolic function considering the high temporal and spatial resolution and the wide availability, VE-MRI could represent a valuable alternative in several patients referred for cardiac MRI for a comprehensive systolic and diastolic function evaluation. In patients with Duchenne muscular dystrophy for example, echocardiographic window may be poor in progressive disease, but Vp has been reported as an early marker of LV diastolic dysfunction [27]. Vp measured by VE-MRI could therefore serve as a useful tool in such cases when the echo measure is difficult to obtain. Similarly, Vp measured with Color M-mode echocardiography may be challenging in patients with dilated cardiomyopathy [13] or patients after atrioventricular valve surgery [28] due to lateral mitral valve inflow; in these patients the MRI acquisition plane can be adjusted to the inflow direction and provide a potentially more accurate assessment. However, MRI is not feasible in all patients: claustrophobia is occasionally a problem, and absolute contraindications include pacemakers, defibrillators, and cerebral clips.

Several limitations of current study should be mentioned. VE-MRI is characterized by a lower temporal resolution as compared to Color M-mode echocardiography. Higher temporal resolution is possible by applying one-directional Fourier encoded M-mode [29], however, this technique was not available on our MRI platform. Especially for fast wave propagation, temporal resolution of VE-MRI may not be adequate to register Vp accurately. This explains the fact that agreement between MRI and Color M-mode echocardiography worsened for higher Vp values. However, around the proposed cut-off values of 45cm/s (>30 year-old) and 55cm/s (<30 year-old), VE-MRI performs well for the identification of impaired LV relaxation with a good kappa agreement and high sensitivity and specificity. With VE-MRI an average heart beat is constructed from several minutes of recording, consequently variety in heart rate might cause errors. The time-resolved imaging approach of MRI is not feasible for detecting small-scale fluctuations in the temporal domain. However, variety in heart rate was minimized during the acquisition by excluding heart beats with more than 10% deviation of the average. Furthermore, due to logistical reasons, patients and volunteers were scanned using different scanners and field strengths, resulting in minor differences among some scan parameters and a more than twofold higher SNR for VE-MRI in volunteers versus patients. However, SNR of VE-MRI in patients was still adequate for Vp-assessment. Furthermore, it is not expected that the method of Vp-assessment will be affected by scanning at different field strengths. Finally, in the current study, only patients with ischemic heart failure were included. Vp-assessment with VE-MRI should also be evaluated further in healthy controls to provide reference values and in different patient populations

such as heart failure patients with preserved ejection fraction, non-ischemic cardiomyopathy or congenital heart disease.

CONCLUSION

This study showed the feasibility of a high-temporal VE-MRI approach for Vp-assessment, with a direct comparison to Color M-mode echocardiography. Good correlation and agreement was found especially for lower Vp-values which are related to impaired LV relaxation. VE-MRI represents therefore a potential valuable approach in the assessment of LV diastolic function.

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