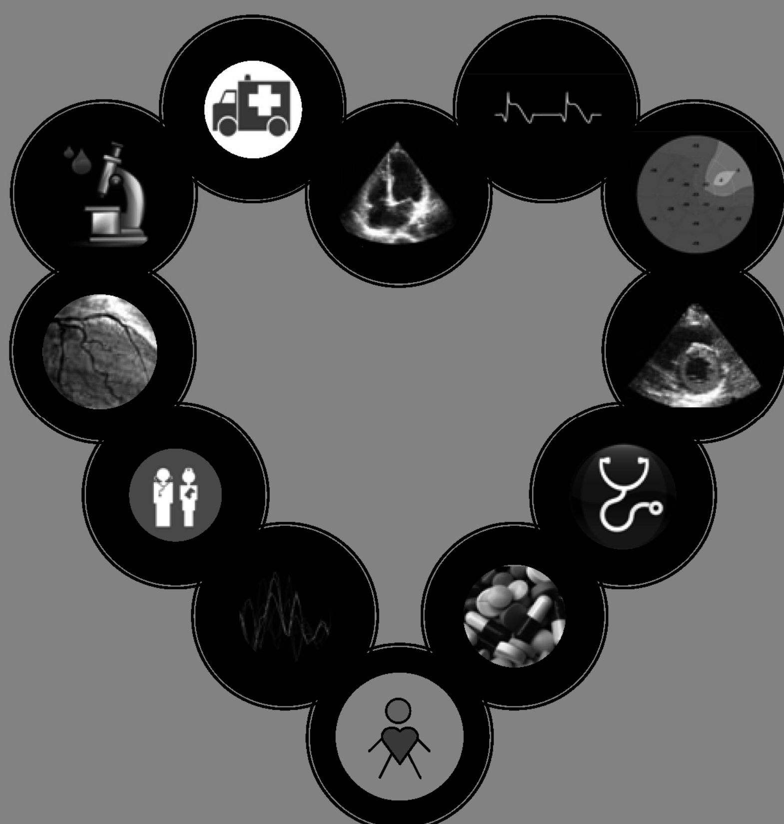
Improving risk stratification after acute myocardial infarction : focus on emerging applications of echocardiography

Antoni, M.L.



Chapter 16

The Effect of Cardiac Resynchronization Therapy on Left Ventricular Diastolic Function Assessed with Speckle Tracking Echocardiography

M. Louisa Antoni, Miriam Shanks, Ulas Hoke, Matteo Bertini,
Arnold C.T. Ng, Dominique Auger, Nina Ajmone Marsan,
Lieselot van Erven, Eduard R. Holman, Martin J. Schalij,
Jeroen J. Bax, Victoria Delgado

Eur J Heart Failure 2011; 13; 1133-1139

Abstract

Objectives

Changes in left ventricular (LV) diastolic function after cardiac resynchronization therapy (CRT) in relation to LV reverse remodeling and heart failure etiology have not been extensively characterized. The aims of the study were to evaluate changes in LV diastolic function with speckle-tracking echocardiography in relation to: 1) CRT response (LV remodeling) and 2) heart failure etiology.

Methods and results

A total of 192 heart failure patients undergoing CRT implantation were evaluated. Speckle-tracking echocardiography was performed before and 6 months after implantation and reliable analysis was obtained in 188 patients. LV diastolic function was assessed by measuring diastolic strain rate during the isovolumic relaxation period (SR_{IVR}) and by calculating the ratio of peak transmitral E-wave to SR_{IVR} (E/SR_{IVR}). Changes in LV diastolic parameters were evaluated in responders and non-responders and in patients with ischemic and non-ischemic cardiomyopathy. Response to CRT was defined as ≥15% reduction in LV end-systolic volume at 6 months follow-up. One-hundred nine patients (58%) were defined as responders. Significant improvements in LV diastolic performance were observed in responders with improvement in SR_{IVR} (from 0.14 ± 0.08 to 0.18 ± 0.12s^{-1}, p = 0.001) and E/SR_{IVR} (from 834 ± 840 to 641 ± 612, p = 0.04). In addition, LV relaxation improved in patients with non-ischemic etiology ($SR_{IVR:}$ from 0.15±0.08 to 0.19±0.13s^{-1}, p=0.004). In contrast, LV relaxation did not improve in non-responders and in patients with ischemic heart disease.

Conclusions

Novel diastolic strain rate indices are useful for evaluating changes in LV diastolic function after CRT. Improvement in diastolic function was only observed in responders to CRT and patients with non-ischemic etiology.

Introduction

Despite the well demonstrated beneficial effects of cardiac resynchronization therapy (CRT) on left ventricular (LV) systolic function parameters, there are conflicting data about the effects of CRT on LV diastolic function.[1-3] In addition, diastolic function has been frequently measured by means of Doppler echocardiography, including tissue Doppler imaging (TDI). The ratio of mitral early diastolic velocity to mitral annulus early diastolic velocity (E/E') is clinically useful to evaluate LV filling pressures. However, a more recent study has demonstrated its limitations to accurately characterize global LV relaxation.[4] The assessment of global load-independent LV relaxation properties with two-dimensional (2D) speckle-tracking imaging has been shown to overcome the limitations of E/E' ratio and to accurately predict cardiac events in several cardiac conditions.[4, 5] In heart failure patients treated with CRT, assessment of LV diastolic function with 2D speckle-tracking imaging may be of interest in order to better understand the effect of CRT on myocardial relaxation and refine the clinical management of these patients. The present study evaluated the effect of CRT on LV diastolic function in responder and non-responder patients to CRT, focusing on the changes in the novel global load-independent indices of LV relaxation as assessed by 2D speckle-tracking imaging. In addition, changes in LV diastolic function after 6 months of CRT were evaluated in relation to underlying heart failure etiology.

Methods

Patient population and data collection

A total of 192 heart failure patients treated with CRT were evaluated.[6] All patients fulfilled current inclusion criteria for CRT (moderate or severe heart failure symptoms despite optimal medical treatment, LV ejection fraction $\leq$ 35%, and QRS duration $\geq$ 120 ms).[7] Diagnosis of ischemic etiology was based on history of myocardial infarction or objective evidence of coronary artery disease as assessed with coronary angiography. Patients in atrial fibrillation or with echocardiographic data of insufficient quality to perform reliable speckle tracking analysis were excluded. The feasibility of 2-dimensional speckle tracking analysis was 98%. Therefore, out of the initial 192 patients, 4 patients were excluded due to poor window and, accordingly, the patient population included 188 patients.

According to the institutional protocol, clinical characteristics were evaluated at baseline and 6 months follow-up. Evaluation of functional status included assessment of the New York Heart Association (NYHA) functional class, quality-of-life score (using the Minnesota Living with Heart Failure Questionnaire), and distance covered in the 6-minute walk test. In addition, all patients underwent transthoracic echocardiography at baseline and at 6 months after CRT implantation, for assessment of LV volumes, LV systolic function and LV systolic dyssynchrony. Furthermore, extensive echocardiographic evaluation of LV diastolic function was performed, including LV relaxation and filling pressures as assessed with tissue Doppler imaging (TDI) and 2D speckle-tracking imaging. Changes in LV diastolic parameters were related to CRT response, defined as ≥15% reduction in LV end-systolic volume at 6 months follow-up, and to the underlying etiology of heart failure. Clinical and echocardiographic data were prospectively entered in the departmental Cardiology Information System (EPD-Vision®, Leiden University Medical Center, Leiden, the Netherlands) and retrospectively analyzed.

Echocardiography data analysis

LV end-systolic volume and LV end-diastolic volume were measured in the LV apical 4- and 2-chamber views using the Simpson's biplane method.[1,2] Severity and grade of mitral regurgitation was determined using semi-quantitative and quantitative color Doppler-based parameters.[3] LV dyssynchrony was assessed with color-coded TDI.[10] Significant LV dyssynchrony was defined as ≥ 65 ms of systolic mechanical delay among 4 opposing walls.[10] Evaluation of LV diastolic function included LV filling dynamics, TDI-derived measures of LV filling pressures and novel 2D speckle tracking strain parameters of LV relaxation. Transmitral early (E) and late (A) diastolic velocities, and the E-wave deceleration time were measured. Left atrial volumes were calculated using the ellipsoid model and indexed to body surface area.[4] Using TDI, the peak early diastolic myocardial velocities were measured in 4 basal LV segments and averaged to calculate the mean early diastolic myocardial velocities (E'). The E/E' ratio was then derived as a measure of LV filling pressures.[5] Finally, 2D speckle-tracking diastolic strain rate parameters were measured during the isovolumic relaxation period. From the LV apical views (2- and 4-chamber and long-axis views), individual global longitudinal strain and strain rate curves were obtained with dedicated software (EchoPac version 108.1.5, GE-Vingmed). Peak global strain rate during the isovolumic relaxation period and during early diastole were measured and averaged from the 3 apical views (Figure 1).[4] In summary, the following indices of LV diastolic function were obtained from 2D speckle tracking:[4] 1) early diastolic strain rate (SR_E); 2) strain rate during the isovolumic relaxation period (SR_{IVR}); 3) and, the ratio of peak transmitral E wave to SR_{IVR} (E/SR_{IVR}). As previously reported,[5] mean intra-observer differences were: 0.019 ± 0.054 s^{-1} for SR_{IVR} and 0.044 ± 0.149 s^{-1} for SR_e. Mean inter-observer differences were: 0.013 ± 0.062 s^{-1} for SR_{IVR} and 0.064 ± 0.135 s^{-1} for SR_e. Intraclass correlation coefficients for intra-observer comparisons were 0.862 for SR_{IVR} and 0.980 for SR_e. Similarly, inter-observer agreements were good with intraclass correlation coefficients of 0.921 for SR_{IVR} and 0.980 for SR_e

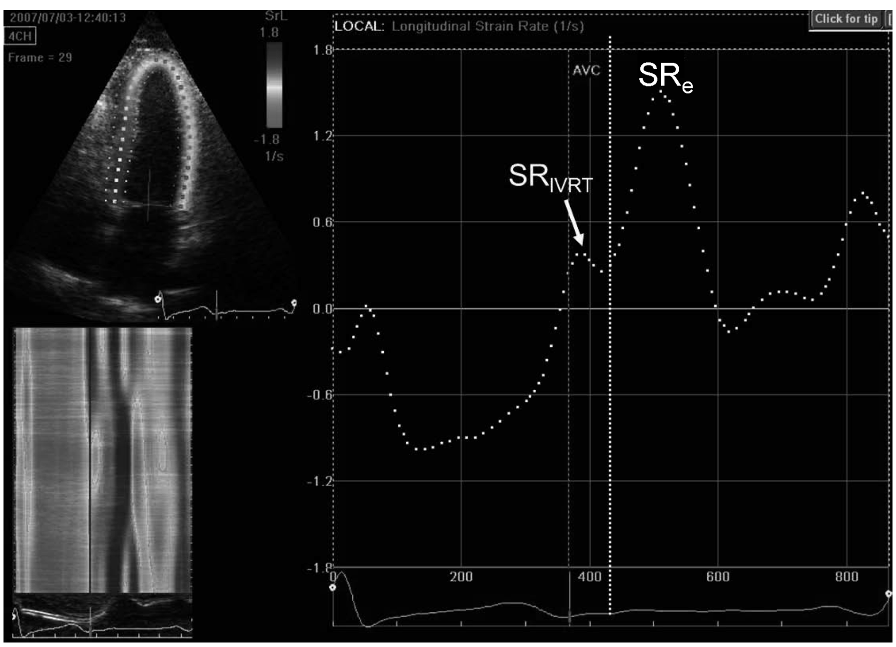


Figure 1.

Assessment of SR_{IVR} and SR_e with 2-dimensional speckle tracking imaging.

After defining the isovolumic relaxation time interval, the longitudinal peak strain rate within this interval is identified as the SR_{IVR}. After this interval, the early peak diastolic E-wave is identified and measured (SR_e). Finally E/ SR_{IVR} is then calculated.

Pacemaker implantation

All patients received a biventricular pacemaker (Contak Renewal 4RF, TR or CD, Boston Scientific St. Paul, Minnesota; or InSync Sentry or III, Medtronic Inc. Minneapolis, Minnesota; Lumax 340 HF-T, Biotronik, Berlin). All pacemaker-implantation procedures were performed under local anesthesia. Pacemaker leads were inserted through the right- or left-sided cephalic or subclavian veins. The right atrial and ventricular leads were positioned conventionally. A coronary sinus venogram was obtained using a balloon catheter, followed by the insertion of the LV pacing lead. An 8-F guiding catheter was used to place the LV lead (Easytrak, Boston Scientific; or Attain-SD, Medtronic; or Corox OTW Biotronik) in the coronary sinus. The LV lead position was targeted to the lateral coronary vein; if unavailable, the posterolateral coronary vein or anterior vein was used.

Statistical analysis

For reasons of uniformity, summary statistics for all continuous variables are presented as mean and standard deviation. Categorical data are presented as frequencies and percentages. The chi-square test was used to compare categorical variables. The student's t test and Mann-Whitney U test were used to compare 2 groups of unpaired data of Gaussian and non-Gaussian distribution, respectively. A comparison of the clinical and echocardiographic variables prior to and after CRT was performed using paired Student *t* test for the continuous variables and McNemar test for the categorical variables. Statistical significance was determined as a two-tailed P value of <0.05. All statistical analyses were performed using SPSS for Windows (SPSS Inc, Chicago), version 16.

Results

Baseline clinical and echocardiographic characteristics

The baseline clinical characteristics of the patients (65 ± 10 years old, 74% men) are described in Table 1. Overall, all patients had moderate or severe heart failure symptoms despite optimized medical therapy and 59% of patients had ischemic heart failure. Mean QRS duration was 152 ± 32 ms.

Baseline echocardiographic characteristics are summarized in Table 2. Mean LV ejection fraction was 27 ± 7%, mean LV dyssynchrony as assessed with TDI was 77±47 ms and moderate to severe mitral regurgitation was observed in 27 (14%) patients. Conventional parameters of LV diastolic function included a mean E/A ratio of 1.9±1.6, mean deceleration time of the E-wave of 185 ± 70 ms and mean left atrial indexed volume of 42 ± 15 ml/m^2. The mean E/E' ratio was 19 ± 10, which reflects increased LV filling pressures. Finally, the novel diastolic indices based on 2D speckle tracking analysis confirmed a significant impaired LV relaxation, as reflected by reduced SR_{IVR} (0.13 ± 0.08 s^{-1}) and SR_E (0.49 ± 0.20 s^{-1}), and increased dimensionless E/SR_{IVR} (910 ± 995).

Table 1. Baseline clinical characteristics of the patients.

	All patients (N = 188)	*Responders (N = 109)*	*Non-responders (N = 79)*	*P*
Age (years)	65 ± 10	66 ± 10	63 ± 10	0.07
Male gender	139 (74%)	78 (71%)	61 (77%)	0.49
Etiology of heart failure				0.005
Ischemic	111 (59%)	55 (51%)	56 (71%)	
Non-ischemic	77 (41%)	54 (49%)	23 (29%)	
QRS duration (ms)	152 ± 32	156 ± 31	147 ± 33	0.08
Serum creatinine level (µmol/L)	104 ± 43	104 ± 50	103 ± 31	0.48
NYHA class	2.8 ± 0.5	2.9 ±0.5	2.8 ± 0.5	0.44
Quality of life score	28 ± 17	30 ± 18	27 ± 17	0.41
Six minute walking test (m)	333 ± 96	330 ± 102	339 ± 88	0.76
Medications (%)				
ACE-inhibitors	172 (92%)	103 (95%)	69 (87%)	0.08
Beta blockers	146 (78%)	89 (92%)	57 (72%)	0.12
Diuretics	147 (78%)	85 (78%)	62 (79%)	0.94

ACE: Angiotensin-converting enzyme; NYHA: New York Heart Association.

Changes in clinical and echocardiographic parameters during follow-up

At 6 months follow-up, there was a significant improvement in NYHA functional class (from 2.8 ± 0.5 to 2.2 ± 0.7, p <0.001), quality-of-life score (from 28 ± 17 to 21 ± 19, p <0.001), and distance walked in 6 minutes (from 333±96 to 371±105, p <0.001) in the overall population. Echocardiographic evaluation demonstrated significant improvements

in LV end-systolic volume (from 141 ± 59 ml to 123 ± 66 ml, p <0.001), end-diastolic volume (from 191 ± 69 ml to 179 ± 77 ml, p <0.001), LV ejection fraction (from 27 ± 7 % to 33 ± 10 %, p <0.001) and mitral regurgitation grade (from 1.6 ± 0.9 to 1.4 ± 0.9, p = 0.001). Among conventional and novel diastolic indices, E-wave deceleration time (from 185 ± 70 ms to 209 ± 67 ms, p <0.001) and SR_{IVR} (from 0.14 ± 0.08 s^{-1} to 0.16 ± 0.11 s^{-1}, p = 0.003) changed significantly at follow-up.
A total of 109 patients (58%) were classified as responders based on the presence of LV reverse remodeling (≥15% decrease in LV end-systolic volume) at 6 months follow-up. No significant differences were observed in baseline clinical characteristics between responder and non-responder patients except for the etiology of LV systolic dysfunction.

Table 2a. Echocardiographic characteristics of responders.

Responders (N = 109)	*Baseline*	*6 Months*	*P*
LV end-systolic volume(ml)	143 ± 54	100 ± 43	<0.001
LV end-diastolic volume(ml)	192 ± 63	157 ± 57	<0.001
LV ejection fraction (%)	26 ± 7	37 ± 9	<0.001
Mitral regurgitation grade	1.6 ± 0.9	1.4 ± 0.9	0.001
Left atrial volume (ml/m^2)	41 ± 13	38 ± 14	0.04
E-wave (m/s)	0.71 ± 0.31	0.76 ± 0.32	0.099
E/A ratio	1.8 ± 1.7	1.6 ± 1.2	0.09
Deceleration time (ms)	185 ± 71	213 ± 68	<0.001
E/E’ ratio	19 ± 10	19 ± 11	0.99
LV dyssynchrony (ms)	86 ± 48	40 ± 33	<0.001
SR_{IVR} (s^{-1})	0.14 ± 0.08	0.18 ± 0.12	0.001
SRe (s^{-1})	0.48 ± 0.21	0.49 ± 0.22	0.49
E/ SR_{IVR}	834 ± 840	641 ± 612	0.04

Table 2b. **Echocardiographic characteristics of non-responders.**

Non-responders (N = 79)	*Baseline*	*6 Months*	*P*
LV end-systolic volume(ml)	139 ± 66	155 ± 78	<0.001
LV end-diastolic volume(ml)	189 ± 78	209 ± 89	<0.001
LV ejection fraction (%)	28 ± 7	27 ± 9	0.66
Mitral regurgitation grade	1.4 ± 0.9	1.4 ± 0.9	0.59
Left atrial volume (ml/m^2)	44 ± 17	43 ± 17	0.47
E-wave (m/s)	0.78 ± 0.36	0.82 ± 0.34	0.26
E/A ratio	2.1 ± 1.6	1.8 ± 1.4	0.22
Deceleration time (ms)	186 ± 69	203 ± 67	0.03
E/E' ratio	19 ± 10	20 ± 11	0.68
LV dyssynchrony (ms)	64 ± 42	56 ± 40	0.23
SR_{IVR} (s^{-1})	0.13 ± 0.08	0.14 ± 0.08	0.74
SRe (s^{-1})	0.50 ± 0.17	0.46 ± 0.23	0.07
E/ SR_{IVR}	1012 ± 1168	879 ± 821	0.51

A: mitral inflow peak late velocity; E: mitral inflow peak early velocity; E': mitral annular peak early velocity; LV: left ventricular; SRe: early diastolic strain rate; SRivr: strain rate during the isovolumic relaxation period.

Responders were more likely to have a non-ischemic etiology compared to non-responders (49% vs. 29%, p = 0.005). Among the baseline echocardiographic characteristics, responder patients had significantly more pronounced LV dyssynchrony compared to non-responders (86 ± 48 ms vs. 64 ± 42 ms, p = 0.001). At 6 months follow-up, responder patients showed a significant reduction in LV volumes and improvement in LV ejection fraction and severity of mitral regurgitation. In contrast, non-responder patients showed progressive LV remodeling with larger LV volumes and non-significant changes in LV ejection fraction and mitral regurgitation (Table 2). Furthermore, a significant improvement in LV dyssynchrony was observed in responder patients (from 86 ± 48 ms to 40 ± 33 ms, p <0.001), whereas no significant changes were observed in non-responder patients (from 64 ± 42 ms to 56 ± 40 ms, p = 0.23).

Changes in LV diastolic function in relation to CRT response

Based on conventional pulsed-wave Doppler echocardiography, both responder and non-responder patients demonstrated a significant increase in E-wave deceleration time (from 185 ± 71 ms to 213 ± 68 ms, $p < 0.001$ and from 186 ± 69 ms to 203 ± 67 ms, $p = 0.03$, respectively). In contrast, there were no significant changes in other conventional parameters of LV diastolic function. When comparing the changes in novel speckle tracking-derived diastolic indices between responder and non-responder patients, only responder patients demonstrated improvement in diastolic function between baseline and 6 months follow-up (Table 2). LV myocardial relaxation as assessed with SR_{IVR} improved from 0.14 ± 0.08 s^{-1} to 0.18 ± 0.12 s^{-1}, $p = 0.001$ and LV filling pressures derived from E/SR_{IVR} improved from 834 ± 840 to 641 ± 612, $p = 0.04$). In contrast, non-responder patients did not show any significant improvement in novel LV diastolic indices.

Changes in diastolic function in patients with ischemic versus non-ischemic heart failure etiology

Table 3 describes the changes in diastolic function as assessed with conventional and novel echocardiographic parameters in patients with ischemic and non-ischemic heart failure etiology. Non-ischemic heart failure patients showed a significant improvement in E/A (from 2.2 ± 1.8 to 1.7 ± 1.4, $p = 0.01$) and in SR_{IVR} (from 0.15 ± 0.08 to 0.19 ± 0.13 s^{-1}, $p = 0.004$), while no changes were observed in patients with ischemic etiology.

Table 3. Diastolic indices in ischemic versus non-ischemic cardiomyopathy.

	Ischemic etiology (N = 111)		***P***	***Non-ischemic etiology (N = 77)***		***P***
	Baseline	***6 Months***		***Baseline***	***6 Months***	
E-wave (m/s)	0.75 ± 0.33	0.79 ± 0.33	0.17	0.73 ± 0.34	0.78 ± 0.33	0.15
E/A ratio	1.7 ± 1.5	1.6 ± 1.2	0.65	2.2 ± 1.8	1.7 ± 1.4	0.01
DT (ms)	182 ± 62	198 ± 61	0.01	191 ± 81	225 ± 73	0.001
E/E’ ratio	18 ± 9	19 ± 10	0.41	21 ± 10	20 ± 13	0.65
SR_{IVR} (s^{-1})	0.13 ± 0.08	0.14 ± 0.09	0.19	0.15 ± 0.08	0.19 ± 0.13	0.004
SRe (s^{-1})	0.48 ± 0.18	0.46 ± 0.23	0.33	0.49 ± 0.23	0.49 ± 0.21	0.90
E/ SR_{IVR}	1024 ± 1152	792 ± 745	0.12	751 ± 697	665 ± 666	0.32

A: mitral inflow peak late velocity; DT: deceleration time; E: mitral inflow peak early velocity; E': mitral annular peak early velocity; LV: left ventricular; SRe: early diastolic strain rate; SRivr: strain rate during the isovolumic relaxation period.

Discussion

The current study evaluated the effect of CRT on LV diastolic function with conventional and novel echocardiographic indices. Based on 2D speckle tracking analysis, CRT exerted a beneficial effect on LV diastolic performance in patients who showed response to CRT and non-ischemic heart failure patients. In contrast, these diastolic parameters did not improve in non-responder patients to CRT and in ischemic heart failure etiology.

Effects of CRT on LV diastolic function: responders versus non-responders

In contrast to the well described effects of CRT on LV systolic function, changes in LV diastolic function after CRT have not been extensively described and are still debated.[1-3] Two studies have described that LV diastolic function improves, but only in patients who demonstrated an improvement in LV systolic function. Waggoner et al. evaluated the short-term effects of CRT on LV diastolic function with conventional echocardiographic measurements in a cohort of 50 heart failure patients.[2] At 4 months follow-up, 28 patients showed an increase in LV ejection fraction >5% and were considered responders to CRT. Pulsed-wave derived diastolic parameters and the E/E' ratio significantly improved in the group of responder patients, whereas the non-responder patients did not show any significant improvement in these parameters. In contrast, load-independent LV diastolic parameters, such as TDI-derived E' and transmitral flow propagation velocity, remained unchanged in responders and non-responders.[2] Therefore, the authors concluded that CRT exerts a beneficial effect on LV filling pressures but does not affect LV relaxation properties. Probably, the relative short-term follow-up (4 months) precluded the authors to observe significant recovery of LV relaxation. These results were extended by Jansen et al. who performed serial echocardiograms before CRT implantation and at 3 and 12 months follow-up in a cohort of 52 patients.[1] CRT response was defined at 12 months follow-up by a reduction in LV end-systolic volume ≥15%. LV diastolic function improved significantly in patients who showed response to CRT and interestingly, significant improvements in E/E' ratio and in the ratio between E-wave and transmitral flow propagation velocity were observed. Therefore, a significant reduction in LV volumes and improvement in LV systolic performance were associated with significant improvements in LV relaxation and LV filling pressures.[1] The results of the current evaluation confirm these previous reports. Particularly, the use of novel echocardiographic parameters based on 2D speckle tracking analysis could demonstrate that in responder patients, significant improvement in LV diastolic performance was observed. A significant improvement in SR_{IVR} and E/ SR_{IVR} was observed whereas SR_e remained unchanged. SR_{IVR} is measured during isovolumic relaxation period (before mitral valve opens), therefore reflecting the rate of myocardial expansion that is least influenced by LV loading conditions. On the other hand, SR_e occurs during the period of early diastolic filling therefore it is affected by the final balance of LV relaxation and left atrial pressure. As SR_{IVR} and SR_e are measured in different parts of cardiac cycle, they are not identical and changes in one parameter may not be accompanied by similar changes in the other parameter.

Effects of CRT on LV diastolic function: ischemic versus nonischemic etiology

Ischemic heart failure patients show less improvement in LV ejection fraction and LV reverse remodeling after CRT than patients with nonischemic heart failure.[12] The presence of extensive areas of myocardial scar has been proposed as one of the mechanisms underlying this reduced efficacy of CRT in ischemic heart failure patients. It may be hypothesized that, the myocardial scar may reduce as well the beneficial effects of CRT on LV relaxation and LV filling pressures. Waggoner et al demonstrated that LV diastolic function and LV filling pressures, as estimated with the E/E' and E/flow propagation ratios, improved after CRT in patients with non-ischemic heart failure.[13] In line with those findings, the current evaluation demonstrated that LV filling pressures or LV relaxation as assessed with novel speckle-tracking imaging did not improve in patients with ischemic cardiomyopathy whereas patients with non-ischemic cardiomyopathy did improve in LV myocardial relaxation as assessed by SR_{IVR}.

Clinical implications and future directions

The number of CRT device implantations has increased significantly in the last decade.[14] The results of the MADIT-CRT and the REVERSE trials have demonstrated that patients with NYHA functional class II heart failure symptoms and QRS duration ≥150 ms benefit from CRT and, consequently, current European Society of Cardiology guidelines have included CRT as class I indication for this subgroup of patients.[7, 15, 16] Ongoing trials may further expand the indications of CRT to subpopulations that do not fulfill the inclusion criteria of current guidelines (i.e. narrow QRS complex, heart failure patients with preserved LV ejection fraction).[17-19] Particularly, the group of patients with heart failure and preserved LV ejection fraction include patients with diastolic dysfunction. Evaluation of diastolic LV mechanics with novel indices may help to understand the potential beneficial effects of CRT in this subgroup of patients. The novel indices of LV diastolic function that were used in the current study are derived from LV longitudinal strain rate curves assessed with speckle-tracking imaging. Speckle-tracking imaging is a relatively novel technique that allows angle- and load-independent assessment of myocardial deformation. Importantly, recent studies have validated these novel indices with invasive measurements of LV diastolic function.[4, 20] Wang et al. demonstrated that SR_{IVR} correlated good with tau ($r = -0.74$, $p < 0.001$) and E/ SR_{IVR} showed a good correlation with pulmonary capillary wedge pressure ($r = 0.79$, $p < 0.001$).[4] In addition, E/SR_{IVR} was superior to conventional E/E' ratio for the prediction of an increased LV filling pressure. The assessment of LV diastolic function with 2-dimensional speckle tracking echocardiography has several advantages over the assessment of E/E' ratio: it represents the performance of all myocardial segments, accounts for the initial LV size and it is not affected by tethering or translation effects. In addition, the ability to assess LV diastolic function with load-independent measurements is especially important in patients with heart failure, where loading conditions may vary considerably during the follow-up.[21]

Conclusions

Novel diastolic strain rate indices are useful for evaluation of changes in LV diastolic performance after CRT. Improvement in diastolic function was only observed in the responders to CRT and in patients with non-ischemic cardiomyopathy suggesting that presence of viable myocardium is pertinent not only for improvement in systolic function but also diastolic function with CRT.

References

1. Jansen AH, van Dantzig J, Bracke F, et al. Improvement in diastolic function and left ventricular filling pressure induced by cardiac resynchronization therapy. *Am Heart J* 2007;**153**:843-9.
2. Waggoner AD, Faddis MN, Gleva MJ, et al. Improvements in left ventricular diastolic function after cardiac resynchronization therapy are coupled to response in systolic performance. *J Am Coll Cardiol* 2005;**46**:2244-9.
3. Yu CM, Zhang Q, Yip GW, et al. Are left ventricular diastolic function and diastolic asynchrony important determinants of response to cardiac resynchronization therapy? *Am J Cardiol* 2006;**98**:1083-7.
4. Wang J, Khoury DS, Thohan V, et al. Global diastolic strain rate for the assessment of left ventricular relaxation and filling pressures. *Circulation* 2007;**115**:1376-83.
5. Shanks M, Ng AC, van de Veire NR, et al. Incremental prognostic value of novel left ventricular diastolic indexes for prediction of clinical outcome in patients with ST-elevation myocardial infarction. *Am J Cardiol* 2010;**105**:592-7.
6. Van Bommel RJ, Mollema SA, Borleffs CJ, et al. Impaired renal function is associated with echocardiographic nonresponse and poor prognosis after cardiac resynchronization therapy. *J Am Coll Cardiol* 2011;**57**:549-55.
7. Dickstein K, Vardas PE, Auricchio A, et al. 2010 focused update of ESC Guidelines on device therapy in heart failure: an update of the 2008 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure and the 2007 ESC Guidelines for cardiac and resynchronization therapy. Developed with the special contribution of the Heart Failure Association and the European Heart Rhythm Association. *Eur J Heart Fail* 2010;**12**:1143-53.
8. Lang RM, Bierig M, Devereux RB, Flachskampf FA, et al. Recommendations for chamber quantification. *Eur J Echocardiogr* 2006;**7**:79-108.
9. Zoghbi WA, Enriquez-Sarano M, Foster E, et al. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. *J Am Soc Echocardiogr* 2003;**16**:777-802.
10. Bax JJ, Bleeker GB, Marwick TH, et al. Left ventricular dyssynchrony predicts response and prognosis after cardiac resynchronization therapy. *J Am Coll Cardiol* 2004;**44**:1834-40.
11. Nagueh SF, Appleton CP, Gillebert TC, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *Eur J Echocardiogr* 2009;**10**:165-93.
12. Marsan NA, Bleeker GB, Van Bommel RJ, et al. Comparison of time course of response to cardiac resynchronization therapy in patients with ischemic versus nonischemic cardiomyopathy. *Am J Cardiol* 2009;**103**:690-4.
13. Waggoner AD, Rovner A, de las Fuentes L, et al. Clinical outcomes after cardiac resynchronization therapy: importance of left ventricular diastolic function and origin of heart failure. *J Am Soc Echocardiogr* 2006;**19**:307-13.
14. Van Veldhuisen DJ, Maass AH, Priori SG, et al. Implementation of device therapy (cardiac resynchronization therapy and implantable cardioverter defibrillator) for patients with heart failure in Europe: changes from 2004 to 2008. *Eur J Heart Fail* 2009;**11**:1143-51.

15. Linde C, Abraham WT, Gold MR, et al. Randomized trial of cardiac resynchronization in mildly symptomatic heart failure patients and in asymptomatic patients with left ventricular dysfunction and previous heart failure symptoms. *J Am Coll Cardiol* 2008;**52**:1834-43.
16. Moss AJ, Hall WJ, Cannom DS, et al. Cardiac-resynchronization therapy for the prevention of heart-failure events. *N Engl J Med* 2009;**361**:1329-38.
17. Chung ES, Katra RP, Ghio S, et al. Cardiac resynchronization therapy may benefit patients with left ventricular ejection fraction >35%: a PROSPECT trial substudy. *Eur J Heart Fail* 2010;**12**:581-7.
18. Holzmeister J, Hurlimann D, Steffel J, et al. Cardiac resynchronization therapy in patients with a narrow QRS. *Curr Heart Fail Rep* 2009;**6**:49-56.
19. Maass AH, Van Veldhuisen DJ. Device therapy in patients with heart failure and preserved ejection fraction (HFPEF): a new frontier? *Eur J Heart Fail* 2010;**12**:527-9.
20. Dokainish H, Sengupta R, Pillai M, et al. Usefulness of new diastolic strain and strain rate indexes for the estimation of left ventricular filling pressure. *Am J Cardiol* 2008;**101**:1504-9.
21. Wang J, Nagueh SF. Echocardiographic assessment of left ventricular filling pressures. *Heart Fail Clin* 2008;**4**:57-70.