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ORIGINAL INVESTIGATIONS

Usefulness and Limitation of Dobutamine Stress Echocardiography to Predict Acute Response to Cardiac Resynchronization Therapy

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*Background: It has been hypothesized that a long-term response to cardiac resynchronization therapy (CRT) could correlate with myocardial viability in patients with left ventricular (LV) dysfunction. Contractile reserve and viability in the region of the pacing lead have not been investigated in regard to acute response after CRT. Methods: Fifty-one consecutive patients with advanced heart failure, LV ejection fraction ≤ 35%, QRS duration > 120 ms, and intraventricular asynchronism ≥ 50 ms were prospectively included. The week before CRT implantation, the presence of viability was evaluated using dobutamine stress echocardiography. Acute responders were defined as a ≥15% increase in LV stroke volume. Results: The average of viable segments was 5.8 ± 1.9 in responders and 3.9 ± 3 in nonresponders (P = 0.03). Viability in the region of the pacing lead had an excellent sensitivity (96%), but a low specificity (56%) to predict acute response to CRT. Mitral regurgitation (MR) was reduced in 21 patients (84%) with acute response. The presence of MR was a poor predictor of response (sensibility 93% and specificity 17%). However, combining the presence of MR and viability in the region of the pacing lead yields a sensibility (89%) and a specificity (70%) to predict acute response to CRT. Conclusion: Myocardial viability is an important factor influencing acute hemodynamic response to CRT. In acute responders, significant MR reduction is frequent. The combined presence of MR and viability in the region of the pacing lead predicts acute response to CRT with the best accuracy. (ECHOCARDIOGRAPHY, Volume **, ******** ****)*

dobutamine stress echocardiography, *resynchronization therapy*, *ventricular dyssynchrony*, *heart failure*, *myocardial viability*, *mitral regurgitation*

Cardiac resynchronization therapy (CRT) improves ventricular dyssynchrony, and in term is associated with an improvement in symptoms and prognosis in patients with severe heart failure.[1–6] Echocardiographic assessment of the acute hemodynamic response to CRT predicts long-term clinical outcome in both ischemic and nonischemic cardiomyopathy.[7] After CRT, about 50% of patients have an acute increase in stroke volume ≥15% and are identified as acute responders.[8] An acute increase in stroke volume is related to reduction of left ventricle (LV) dyssynchrony and corresponding stress–strain disparities and inefficient contraction of the ventricle.[9] Resynchronization of the LV improved coordinated timing of the mechanical activation of papillary muscles and appears to be the main mechanistic contributor to immediate MR reduction and increase in stroke volume.[10–17] Response to CRT might

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be modulated by the presence of functional mitral regurgitation before implantation. In the CARE-HF study, it was shown that patients whose conditions did not improve were likely to have no significant mitral regurgitation as compared with responders.[18] However, the presence of MR seems not to predict acute response to CRT.[8] To date, the main approach identifying CRT candidates has been QRS duration and mechanical dyssynchrony.[19–21] However, between 30% and 40% of patients with congestive heart failure and QRS >120 ms do not clinically improve after CRT.[6,22] Moreover, even in patients with QRS >120 ms and significant intraventricular asynchronism response to CRT may not occur,[23] CRT nonresponse is likely a diverse phenomenon. Contractile reserve may represent a key element in the resynchronization process. Because electrical conduction and regional wall thickening are influenced by the extent of myocardial fibrosis, it has been hypothesized that a long-term response to CRT could correlate with myocardial viability in patients with LV dysfunction. Using nuclear[5,6] myocardial perfusion imaging (2C1Ti),[24,25] magnetic resonance imaging (MRI),[23,26] or dobutamine stress echocardiography (DSE),[27–31] studies have demonstrated the importance of LV viability in predicting response to CRT. Furthermore, scar tissue in the LV pacing lead region may prohibit response to CRT.[32] However, contractile reserve and viability in the region of the pacing lead have not been investigated in regard to acute response after CRT. We therefore hypothesized that the combined presence of viability in the region of the pacing lead and MR is the best echocardiographic parameter to predict acute response following CRT.

Methods

From May 2005 to March 2008, 51 patients (mean age 66 ± 11 years, 35 (67%) male) provided informed consent and were prospectively enrolled. Inclusion criteria were as follows: (1) NYHA functional classes III and IV heart failure, (2) QRS duration ≥120 ms, (3) chronic LV systolic dysfunction (LV ejection fraction ≤ 35%), (4) basal LV dyssynchrony ≥50 ms, (5) optimal medical treatment for heart failure including angiotensin-converting enzyme inhibitors or AT1 receptor antagonists diuretics, beta-receptor blockers and spironolactone when tolerated, and (6) sinus rhythm. Patients with recent myocardial infarction, with coronary revascularization (<6 months), and presenting standard contraindications to DSE were excluded. All patients underwent coronary angiograms before implantation to exclude treatable ischemic heart disease. Etiology was considered ischemic in the presence of significant coronary artery disease (≥50% stenosis in one or more of the major epicardial coronary arteries) and/or a history of myocardial infarction or prior revascularization. All patients provided informed consent, and the study protocol was approved by local ethics committee.

Study Design

The patients underwent a clinical examination, a 12-lead electrocardiography (ECG), and a resting and DSE, within the week before CRT implantation. Resting echocardiography was also performed within 24 hours following device placement. Acute responders to CRT were defined as a ≥15% increase in LV stroke volume.[8]

Echocardiographic Assessment

Echocardiographic measurements were performed by two observers blinded to patients' status using Philips Sonos 5500 or 7500 instrument with a 2.5-MHz transducer (Philips Medical Systems, Amsterdam, The Netherlands). LV volumes and ejection fraction were measured using the modified biplane Simpson's rule. LV stroke volume was calculated by multiplying the LV outflow tract area by the LV outflow tract velocity–time integral measured by pulsed-wave Doppler.

The proximal isovelocity surface area (PISA) was used to assess the MR severity and to measure the effective regurgitant orifice (ERO) area and regurgitant volume.[33] Aortic and pulmonary Doppler flows were recorded in the pulsed mode from the apical four-chamber view and parasternal short-axis view, respectively. Aortic and pulmonary ejection delays were defined as the delay between the onset of the QRS complex on the surface ECG and the onset of the aortic and pulmonary waves. The interventricular delay was defined as the time difference between the aortic and pulmonary electromechanical delay.[34]

Intraventricular Asynchronism Measurement

Tissue Doppler imaging (TDI) was performed in the pulsed-wave Doppler mode from apical

views to assess longitudinal myocardial regional function, analyzing the septal, inferior, lateral, anterior, and posterior walls.[34] Velocity profiles were recorded with a sample volume placed in the middle of the basal segment of each wall. Gain and filters were adjusted as needed to eliminate background noise and to allow for a clear tissue signal. TDI signals were recorded at a sweep of 100 mm/s. The electromechanical delay defined as the delay between the onset of the QRS complex on the surface ECG and the onset of the systolic TDI wave was measured by MS or PG. Intraventricular asynchronism was defined as the time difference between the shortest and longest electromechanical delay among the five LV walls.[34]

Assessment of Contractile Reserve

All patients underwent DSE according to a low-dose infusion protocol. The patients received 5, 10, 15, and 20 μg/kg per minute of dobutamine in a 3-minute stage, with echocardiographic images recorded at each stage.[35,36] Heart rate and blood pressure were monitored during each stage. Criteria for stopping the dobutamine infusion included (1) hypotension (systolic blood pressure < 90 mmHg), (2) angina, (3) significant arrhythmias (atrial fibrillation, bigeminy, ventricular tachycardia), and (4) attainment of 85% maximal predicted heart rate. The regional wall motion was assessed by the 16-segment model recommended by the American Society of Echocardiography.[37] Thus, a normal or hyperkinetic segment was graded as 1, hypokinetic as 2, akinetic as 3, and dyskinetic as 4. The stress images at the dobutamine dose showing the maximum augmentation of wall motion were compared with baseline images. A segment was considered to have contractile reserve if after dobutamine the wall motion improved by one grade. Viability in the region of the LV pacing lead was defined as the presence of viability in two contiguous segments. DSE was interpreted by MS or PG.

CRT Implantation and LV Lead Position

A coronary sinus venogram was obtained using balloon catheter, followed by the insertion of the LV pacing lead (Guidant Corporation, St Paul, NM or Medtronic Inc., Minneapolis, MN, USA) in the coronary sinus. The preferred position was a lateral or posterolateral vein. The right atrial and ventricular leads were positioned conventionally. All leads were connected to a dual-chamber biventricular pacing (Guidant Corporation, or Medtronic Inc., Milwaukee, WI, USA). One day after implantation, the LV lead position was assessed from a chest x-ray. Using the frontal and lateral views (scored anterior, lateral, or posterior), we determined the LV lead locations.[38]

Statistical Analysis

Results are expressed as mean ± SD or percentages unless otherwise specified. The patients were separated into two groups (responders and nonresponders) according to the early post-CRT change in LV stroke volume (>15%).[8] Interobserver and intraobserver variabilities for the measurement of inter- and intraventricular asynchronism as well as for the quantification of the wall motion score index (WMSI) were determined from the analysis of Doppler echocardiographic images of 15 randomly selected patients by two independent observers (MS and PG). The results were compared with a one-way analysis of variance, Pearson's correlation coefficient, and the Bland–Altman method. Baseline data of the responder group versus the nonresponder group were compared for statistical significance using the *t*-test or chi-square test, as appropriate. Baseline and post-CRT MR severity were compared within groups using the paired-*t* test or chi-square test, as appropriate. Sensitivity and specificity for prediction of CRT response were determined for various cutoff values of the echocardiographic parameters using receiver-operating characteristic curves. Linear regression analyses were used to evaluate the relationship between CRT response, assessed as the percentage of change in LV stroke volume, and the percentage of change in echocardiographic data.

Results

Patients

The day after CRT implantation, 28 patients (55%) were responders and compared to nonresponders (n = 23, 45%) there was no significant difference with regards to baseline demographic and clinical characteristics (Table I). However, the patients in the nonresponder group tended to have higher LV stroke volume (46 ± 2 ml vs. 39 ± 12 ml, P = 0.06). The number of akinetic segments in each patient ranged from 1 to 15 segments (mean 9.5 ± 3.3). Device implantation was successful in all patients and one patient developed pneumothorax after

TABLE I

Demographic and Clinical Data

Variables	All Patients (n = 51)	Responders (n = 28, 55%)	Nonresponders (n = 23, 45%)	P-Value
Demographic data				
Age (years)	66 ± 11	67 ± 10	65 ± 13	0.52
Male, n (%)	35 (69)	19 (68)	16 (70)	0.90
CAD, n (%)	35 (69)	18 (65)	17 (74)	0.46
Clinical data				
QRS duration (ms)	161 ± 30	159 ± 27	163 ± 33	0.67
LBBB, n (%)	32 (63)	20 (71)	12 (52)	0.16
RBBB, n (%)	3 (6)	2 (7)	1 (4)	0.67
IVCD, n (%)	8 (17)	3 (12)	5 (22)	0.36
PR (ms)	184 ± 41	176 ± 32	194 ± 49	0.14
Pre-CRT pacing, n (%)	8 (16)	3 (11)	5 (22)	0.28
NYHA III/IV, n (%)	35 (69)/16 (31)	21 (75)/7 (25)	14 (60)/9 (39)	0.28
Medication				
Diuretic, n (%)	48 (94)	26 (93)	22 (96)	0.67
β-blockers, n (%)	48 (94)	26 (94)	22 (96)	0.67
ACEi, n (%)	35 (69)	19 (68)	16 (70)	0.90
AR blockers, n (%)	15 (30)	9 (33)	6 (26)	0.58
Digoxin, n (%)	14 (27)	5 (18)	9 (39)	0.09
Spironolactone, n (%)	33 (63)	15 (54)	17 (74)	0.14

CAD = coronary arteries disease; LBBB = left bundle branch block; RBBB = right bundle branch block; IVCD = intraventricular conduction defect; ACEi = angiotensin-converting enzyme inhibitors; AR = angiotensin receptors.

CRT implantation. LV pacing threshold was not different between responders and nonresponders (1.18 ± 0.70 vs. 1.75 ± 0.5, P = 0.17). In the subgroup of patients with CAD, no patients experienced angina, electric, or regional wall motion modification at peak stress (20 μg/kg per minute) suggesting ischemia.

Reproducibility of Asynchronism and WMSI

There were excellent correlations ($r \geq 0.96$) between intra- and interobserver analyses of viability in the region of the pacing lead and for WMSI. Intra- and interobserver relative differences were <3% for all parameters. The Bland–Altman method showed excellent agreement between inter- and intraobserver measurements in both low and high values of asynchronism or WMSI.

Contractile Reserve to Predict Response

All patients completed the DSE protocol without complications. During low-dose dobutamine infusion, responders tended to have less akinetic segments (7.7 ± 3 vs. 9 ± 3, P = 0.06) and a significantly higher number of viable segments (5.8 ± 1.94 vs. 3.87 ± 2.99, P = 0.007) than nonresponders. The presence of more than four viable segments and viability in the region of the pacing lead were statistically more frequent in responders (96% vs. 52%, $P < 0.0001$ and 96% vs. 43%, $P < 0.0001$, respectively) (Table II). LV stroke volume changes after CRT were directly related to the improvement in WMSI during dobutamine infusion ($r = 0.45$, P = 0.0012) (Fig. 1A). A similar correlation was also observed between the change in ERO after CRT and the improvement of WMSI during DSE ($r = 0.41$, P = 0.0057) (Fig. 1B).

Global Viability and Local Viability versus Response to CRT

Among patients with local viability (i.e., viability in the region of the pacing lead), 27 (73%) were responders corresponding to 96% of all responders. Conversely, in patients with global viability (i.e., ≥ 4 viable segments) without local viability (n = 4), only one patient (25%) was identified as a responder. In the absence of local and global viabilities, all patients (n = 10, 100%) were nonresponders (Fig. 2).

TABLE II

Echocardiographic Data

Variables	All Patients (n = 51)	Responders (n = 28, 55%)	Nonresponders (n = 23, 45%)	P-Value
LV geometry and function				
LV end-diastolic volume (ml)	214 ± 67	211 ± 69	217 ± 65	0.75
LV end-systolic volume (ml)	178 ± 63	177 ± 67	180 ± 67	0.90
LV end-diastolic diameter (mm)	67 ± 8	66 ± 8	68 ± 8	0.26
LV end-systolic diameter (mm)	59 ± 9	61 ± 9	57 ± 3	0.13
End-systolic SI (%)	63 ± 9	64 ± 9	63 ± 9	0.87
End-diastolic SI (%)	69 ± 9	66 ± 2	65 ± 2	0.82
LV stroke volume (ml)	42 ± 12	39 ± 12	46 ± 2	0.06
LV ejection fraction (%)	19 ± 7	18 ± 8	19 ± 6	0.70
Asynchronism				
Interventricular (ms)	45 ± 27	43 ± 26	47 ± 28	0.63
Intraventricular (ms)	83 ± 25	87 ± 25	79 ± 24	0.23
No. of akinetic segments				
Rest	9.5 ± 3	9.4 ± 3	10 ± 3	0.26
Dobutamine	8.4 ± 3	7.7 ± 3	9 ± 3	0.06
Wall motion score index				
Rest	3.5 ± 0.4	3.41 ± 0.42	3.55 ± 0.25	0.15
Dobutamine	3.1 ± 0.5	2.97 ± 0.41	3.25 ± 0.48	0.03
Viability				
No. of viable segments	4.9 ± 3	5.8 ± 1.94	3.87 ± 2.99	0.007
More than viable segments, n (%)	39 (76)	27 (96)	12 (52)	<0.0001
Viability in the region of the lead, n (%)	37 (73)	27 (96)	10 (43)	<0.0001
Lead placement				
Posterior, n (%)	34 (66)	20 (71)	14 (61)	0.83
Lateral, n (%)	15 (30)	8 (29)	7 (30)	0.87
Anterior, n (%)	2 (4)	–	2 (9)	–

LV = left ventricular; ED = end-diastolic; ES = end-systolic; SI = sphericity index.

Impact of Viability and Mitral Regurgitation on CRT Response

The prevalence of MR between responders and nonresponders was not statistically different before and after CRT (pre-CRT: 93% vs. 83%, P = 0.26, post-CRT: 83% vs. 85%, P = 0.96). Moreover, there was no significant difference in baseline MR severity between groups (Fig. 3A), and whereas in responders ERO and regurgitant volume were significantly reduced following CRT, there was no significant change in nonresponders (Fig. 3A and B). Indeed, in responders, ERO was reduced by 57 ± 24% (from 18 ± 12 mm^2 to 8 ± 8 mm^2, P = < 0.001). The percentage of patients with severe MR (ERO ≥ 20 mm^2) was also not statistically different between groups before CRT (Fig. 3C). Only four responders had no MR before CRT. In receiver-operating characteristics curves, the presence of MR, as well as the presence of viability on the region of the pacing lead, was associated with excellent sensitivity (93% and 96%) but with low specificity (17% and 56%) in predicting acute CRT response. Combining the presence of MR and viability in the region of the pacing lead yield the best combination of sensitivity and specificity (89%, 70%) (Fig. 4).

Discussion

The main finding of the present study showed that for acute benefit in ischemic and nonischemic cardiomyopathies, CRT requires the presence of myocardial viability. A direct relationship between improvement in WMSI as assessed during low-dose dobutamine infusion and the improvement in LV stroke volume and reduction in ERO after CRT was described. This study shows the ability of DSE to predict acute response to CRT in patients with drug-refractory systolic heart dysfunction and significative intraventricular dyssynchrony.

Lastly, the combined presence of viability in the region of the pacing lead defined as viability

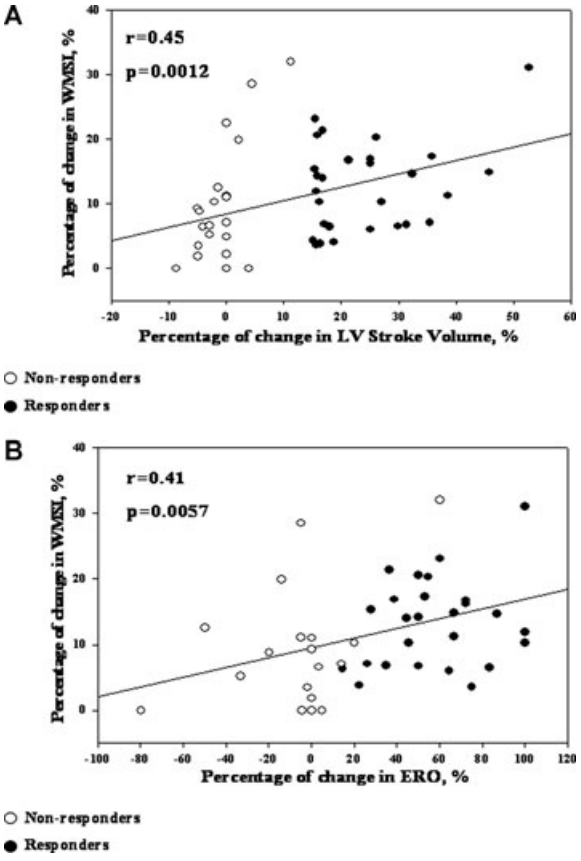

Figure 1. ***A.*** *Correlation between changes in WMSI (rest/dobutamine) and changes in stroke volume after CRT.* ***B.*** *Correlation between changes in WMSI (rest/dobutamine) and changes in ERO after CRT.*

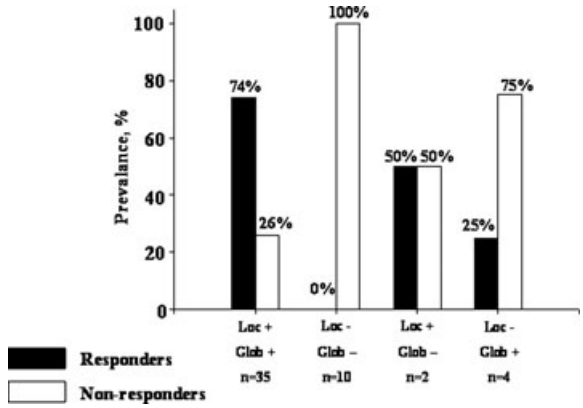

Figure 2. *Percentage of responders to CRT for four different patient categories based on the presence or the absence of viability in the region of the pacing lead (local +/local −) in combination with the presence or the absence of four or more viable segments (global +/global −).*

in two contiguous segments and MR predicts acute response with the best accuracy.

Effect of Global Viability

Wall motion response during dobutamine infusion is useful in predicting functional myocardial recovery in patients with ischemic and nonischemic heart diseases.[35,39–41] The clinical response to treatments such as β-blockade or revascularization in patients with LV systolic dysfunction has been shown to be dependent on the presence and extent of viable myocardium. Although CRT improves cardiac function by other mechanisms than revascularization or by up-regulation of sarcoplasmic reticulum calcium ATPase (beta-blockade), the relationship between viability and CRT benefit still holds.[27–31] When myocytes have been supplanted by replacement fibrosis because of cell death and interstitial remodeling, medical therapy and CRT may not improve LV function. However, studies evaluating the relationship between CRT and myocardial viability are scarce. Ypenburg et al. evaluated and demonstrated that besides the presence of LV dyssynchrony, myocardial contractile reserve (resulting in a $\geq$7.5% increase in LV ejection fraction during dobutamine infusion) predicts LV reverse remodeling and improvement in LV function, 6 months after CRT implantation. Another study in 67 patients (34% ischemic) revealed that the presence of contractile myocardial reserve was an independent predictor of event-free survival after CRT. Using a cutoff value of 25% increase in dobutamine LV ejection fraction exhibits a sensitivity of 70% and a specificity of 62% for predicting major cardiac events.[31] Hummel et al., in 21 CRT patients (100% ischemic), evaluated myocardial viability by myocardial contrast echocardiography.[30] The LV systolic performance was assessed by echocardiography on the day after implantation. In that study, acute improvement in LV stroke volume was significantly correlated with the degree of viability as determined by the perfusion score index.[30] In our study, we related global viability to acute response to CRT. Improvement in LV stroke volume correlated ($r = 0.45$, $P = 0.0012$) with improvement in WMSI during the dobutamine test. Moreover, responders showed a greater number of viable segments (5.8 ± 1.94 vs. 3.87 ± 2.99, $P = 0.007$).

The presence of more than four viable segments predicted acute response to CRT with a high sensitivity but with a low specificity.

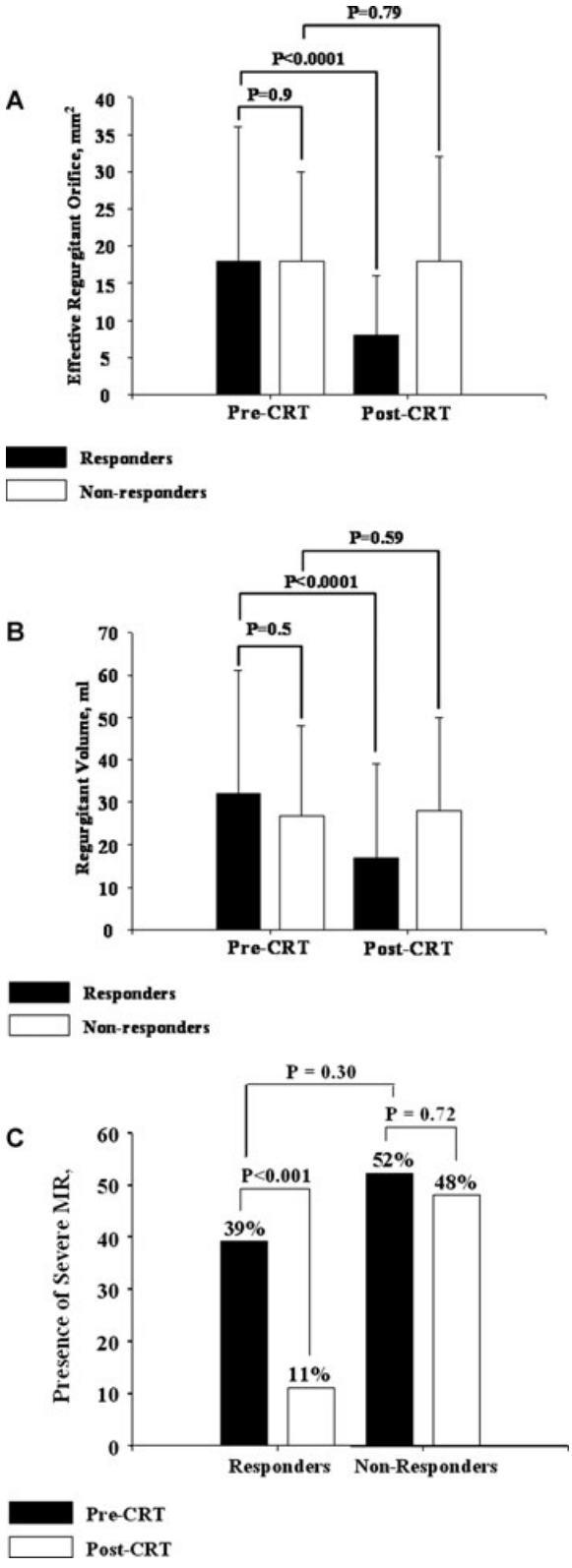

Figure 3. *Quantification of MR in responders and non-responders before and after CRT.* ***A.*** *Changes in ERO;* ***B.*** *Changes in regurgitant volume;* ***C.*** *Changes in the presence of severe MR (≥20 mm²)*

Role of Viability in the Region of the Pacing Lead

Using contrast-enhanced MRI, Bleeker et al. demonstrated in 40 patients (100% ischemic) that CRT did not reduce LV dyssynchrony in patients with transmural scar tissue in the posterolateral LV segments, resulting in clinical and echocardiographic nonresponse to CRT. Only 14% of patients with a posterolateral scar showed response to CRT. Even in the subset of patients with intraventricular asynchrony and postero-lateral scar, the response rate was low (n = 2, 18%).[32] Ypenburg et al. recently observed in 31 CRT patients that responders showed an increase in strain in the region of the LV pacing lead during low-dose dobutamine infusion while nonresponders had no contractile reserve (absence of an increase in strain).[27] Furthermore, Lim et al. demonstrated that only patients (n = 19) with contractile reserve in the LV target site for pacing (lateral, posterolateral) presented a decrease in LV dyssynchrony with CRT.[28] The authors also showed that the mean increase of LV stroke volume was greater in patients with contractile reserve (22% vs. 0%). The number of viable segments in each wall showing viability (i.e., contractile reserve) was however not stated in that study. In line with these results, the present study demonstrated that acute responders to CRT showed viability in the region of the pacing lead

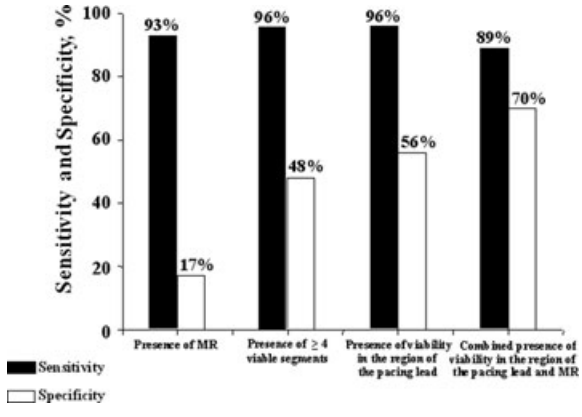

Figure 4. *Performance of viability and MR evaluated before CRT in predicting acute response.*

significantly more often than nonresponders. It appears likely that viability of the paced segments is the crucial factor mediating the influence of viability (local viability vs. global) on response to CRT. Of interest, in the present study, in the absence of viability in the region of the pacing lead, three patients (75%) did not show acute response even if they had more than four viable segments. Moreover, one patient (50%) was a responder in the presence of only three viable segments (i.e., only in the region of the pacing lead). Therefore, it is likely that acute improvement in LV stroke volume after biventricular pacing is driven mainly by viability of the paced myocardial segments. However, viability in the region of the pacing lead predicts acute response with an excellent sensitivity (96%) but with a low specificity (56%). Combining viability in the region of the pacing lead and MR predicts acute response after CRT with the best accuracy suggesting that reduction of MR is almost mandatory in acute responders. The principal mechanism explaining this acute change in LV stroke volume is probably, at least in part, related to the diminution of functional MR. CRT appears to increase mitral closing force, coordinate tethering forces on papillary muscles, and increase the leaflet coaptation surface to reduce MR.[13–15] Previous studies have reported conflicting results regarding the presence and severity of MR and response to CRT. Of interest, none of those studies have evaluated LV viability and its relationship with MR presence or severity and LV remodeling.[42–45] In our study, only four responders did not have MR in pre-CRT. Of interest, those patients had nonischemic cardiomyopathy, viability in the region of the pacing lead, and a mean of 8 viable segments, which suggests that acute response may occur in patients without MR before CRT but only in the presence of substantial viable myocardium.

Clinical Implications

Our present results confirm earlier suggestions that the absence of viability in the region of the LV pacing lead may prohibit response to CRT. This study focuses on acute response and its relationship with viability and MR. Even if acute response after CRT underestimates long-term effects, identification of such patients may be important since acute hemodynamic response to CRT predicts long-term clinical outcome and acute responders may represent more than 70% of all eventual responders.[8] Our results support that the presence of viability in the region of the pacing lead is a better predictor of acute response over the burden of global viability. Also, in the presence of local viability, a decrease of MR seems mandatory in most patients with acute response. Of interest, in our study, the criterion used to define the presence of "significant" viability in the region of the LV pacing lead (presence of viability in two contiguous segments) is simple, rapid, and easily applicable in the context of clinical evaluation before CRT. This underlines the importance of assessing local viability in order to guide LV positioning. The region of myocardium without viability should be avoided as a final resting place for LV lead placement to maximize the possibility of therapeutic benefit.

Study Limitations

These results should be regarded cautiously, and some limitations should be underlined. First, the lack of difference between responders and nonresponders regarding the presence of CAD may be the result of the small number of patients, and results should be confirmed by a larger study. Second, although the difference was not statistically different, more nonresponders took digoxin and spironolactone than responders and showed a higher incidence of class IV NYHA; therefore, because of the sample size ($n = 51$) and the heterogeneity of the population studied, those data should be interpreted cautiously until confirmed by suitably powered clinical trials that are undoubtedly needed. Third, dyssynchrony was defined by longitudinal tissue Doppler imaging using a cutoff value of 50 ms as inclusion criterion. Combining longitudinal and radial dyssynchrony indices as inclusion criteria could have been helpful in choosing a more homogenous population prone to CRT response.[46]

Conclusion

In this study, we demonstrated that myocardial viability is an important factor influencing acute hemodynamic response to CRT. In acute responders, significant MR reduction is frequent. The combined presence of MR and viability in the region of the pacing lead defined as two contiguous viable segments, determined by DSE predicts acute response to CRT with the best accuracy.

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