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Myocardial Contractile Function in the Region of the Left Ventricular Pacing Lead Predicts the Response to Cardiac Resynchronization Therapy Assessed by Two-Dimensional Speckle Tracking Echocardiography

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ABSTRACT

Objective: Our objective was to test the impact of the posterolateral myocardial systolic function on response to cardiac resynchronization therapy (CRT).

Methods: We studied 40 patients before and 4 ± 2 months after CRT. Dyssynchrony was defined as anteroseptal-to-posterior wall delay (≥ 130 ms) caused by speckle-tracking radial strain. Average longitudinal strain in four posterior and lateral segments (**ε**-pl) where the left ventricular pacing lead was positioned was calculated by automated functional imaging. Response to CRT was defined as a ≥ 15% decrease in end-systolic volume.

Results: The negative value of **ε**-pl in responders was significantly higher than that in non-responders at baseline (-7.8±6.9% vs. -2.1±4.9%; $p<0.01$). Combining dyssynchrony with **ε**-pl < -7.8% was more effective for predicting response to CRT than dyssynchrony parameters alone (92% vs. 75%).

Conclusion: Addition of posterolateral myocardial systolic function to measurement of dyssynchrony appears to be of value for predicting response to CRT.

Cardiac resynchronization therapy (CRT) is an established therapeutic option for patients with advanced heart failure (HF). Previous studies have demonstrated that CRT improves acute and chronic hemodynamics, HF symptoms, exercise capacity, quality of life, survival, and left ventricular (LV) systolic function[1-7]. Randomized clinical trials have demonstrated, however, that up to one third of HF patients do not favorably respond to CRT with standard clinical selection criteria, including the electrocardiographic QRS width[1, 3, 4, 7]. Accordingly, the quantification of LV mechanical dyssynchrony by echocardiography has emerged as an important option for predicting response to CRT. Although LV mechanical dyssynchrony has been associated with response to CRT, some patients with LV mechanical dyssynchrony assessed by echocardiography do not respond to CRT. Other factors, such as LV lead position or scar burden, may also influence response to CRT, regardless of the presence of dyssynchrony. Previous investigators have reported that myocardial viability or scar tissue is an important marker for response to CRT[8-10]. However, the impact of regional myocardial systolic function assessed by echocardiography in the posterolateral wall where the LV pacing lead is positioned for response to CRT is not known. Automated function imaging (AFI), based on 2-dimensional speckle tracking imaging, can be used for assessment of regional longitudinal strain of the 17-LV segment as a bull's eye map[11, 12].

Our objective was thus to test the impact of the posterolateral myocardial systolic function assessed by AFI on response to CRT. Furthermore, we evaluated the hypothesis that the addition of posterolateral myocardial systolic function to LV dyssynchrony assessed by echocardiography will further improve the ability to predict response to CRT.

METHODS

Study Population

We studied 47 consecutive HF patients who underwent CRT. The selection criteria for CRT included chronic severe HF (New York Heart Association functional class III or IV), LV ejection fraction (EF) ≤ 35%, and QRS duration ≥ 120ms. Seven patients were excluded from subsequent analysis because their echocardiographic images were technically of unsatisfactory. Accordingly, the patient study group consisted of 40 HF patients, 28 (70%) New York Heart Association functional class III and 12 (30%) class IV at the initial evaluation. The group

mean age was 67 ± 12 years, 10 (25 %) were female, mean EF was 25 ± 8%, mean QRS duration was 163 ± 25 ms and nine patients (23%) had ischemic cardiomyopathy (Table 1). Twenty-four patients were diagnosed with sinus rhythm and six with atrial fibrillation, while 10 had previously undergone implantation of permanent right ventricular pacing at least 1 year before enrollment and they were predominantly right ventricular paced, which was defined as ≥ 90% paced when the device was interrogated at the time of enrollment. All patients were on optimal pharmacological therapy, if tolerated. Written informed consent to participate in the study was obtained from all patients.

Echocardiography

All echocardiographic studies were performed with a commercially available echocardiography system (Vivid 7, GE Vingmed, Milwaukee, WI). Patients were studied before and 4 ± 2 months after CRT. Echocardiographic images were obtained in the left lateral decubitus position with a 3.5-MHz transducer. Mean frame rates were 65 ± 15 frames/s for grayscale imaging used for speckle tracking analysis. Sector width was optimized for complete myocardial visualization while maximizing the frame rate. Gain settings were adjusted for routine grayscale 2-dimensional imaging to optimize endocardial definition. Pulsed-wave Doppler of the LV outflow tract was obtained to determine LV ejection phase. End-diastolic wall thickness of the posterior wall was measured by using routine grayscale 2-dimensional imaging. LV end-diastolic volume, LV end-systolic volume (ESV), and EF were calculated from the apical 2- and 4-chamber images with the biplane Simpson's technique[13]. For patients with atrial fibrillation, measurements of standard echocardiographic and speckle tracking parameters were obtained as the averages of at least three consecutive cardiac cycles. Response to CRT was defined as reverse remodeling detected by a relative decrease in ESV ≥ 15% from baseline[14, 15]. Patients were defined as non-responders if they did not show the above pre-specified echocardiographic changes. Mitral regurgitation was visually assessed on the basis of the ratio of regurgitant jet area to left atrial area as none (grade 0), mild (grade 1), moderate (grade 2), severe (grade 3).

LV Dyssynchrony Analysis

Speckle tracking of routine grayscale mid-LV short-axis images was performed as previously described to

assess LV dyssynchrony[16-18]. The measurements were performed offline using dedicated software (EchoPAC version BTO6, GE-Vingmed, Milwaukee, WI). Briefly, an end-systolic circular region of interest was traced on the endocardial cavity, using a point-and-click approach with special care taken to adjust tracking of all endocardial segments. A second and larger concentric circle was then automatically generated and manually adjusted near the epicardium. Speckle tracking automatically analyzed frame-by-frame movement of the stable patterns of natural acoustic markers, or speckles, over the cardiac cycle. Significant LV dyssynchrony was defined as a time difference $\geq$ 130 ms between the anteroseptal and posterior wall peak strain [16-18] (Figure 1).

Regional Myocardial Functional Analysis

Regional myocardial function was quantified using AFI. The measurements were performed offline using dedicated software (EchoPAC version BTO6, GE-Vingmed, Milwaukee, WI). This technique was based on 2-dimensional speckle tracking imaging that can be used for assessment of regional longitudinal strain of the LV and was performed as previously described in detail[11, 12, 19]. Briefly, the mitral annulus and LV apex with 3 index points in the standard 3 apical views were defined at end-systole. The LV end-systolic frame was defined in the apical long-axis view, and the closure of the aortic valve was marked. The time interval between the R wave and aortic valve closure was used as a reference for the 4-chamber and 2-chamber view loops[19]. The software then automatically detected the endocardium, and tracked myocardial motion during the entire cardiac cycle. The LV was automatically divided into six segments for each apical view and the peak systolic longitudinal strain was displayed for each plane, after which the results for all 3 images were combined into a single bull's-eye summary using a 17-segment model (Figure 2) which was automatically translated from the 18-segment model (Figure 3A). Myocardial lengthening (positive value) is color-coded as red and shortening (negative value) as blue (Figure 2). Inadequately tracked segments determined by a tracking score obtained with the speckle tracking algorithm were automatically excluded from analysis. If the tracking by AFI was poor, the region of interest was manually fine-tuned using visual assessment during the cine loop play to ensure that all segmental wall motions were included throughout the cardiac cycle. In this study, two different types of regional myocardial functional indices were determined by AFI. ε-global was calculated as the average of all 17-segment, and ε-pl as the average of four

posterior and lateral segments where the LV pacing lead was positioned (Figure 3B). In normals, longitudinal strain values are generally negative, with a larger negative value indicating a greater longitudinal strain. The peak longitudinal strain was used for regional myocardial functional analysis by AFI. In case of segments with positive or biphasic strain curves, a peak-positive or a larger peak strain was used, respectively.

Pacemaker Implantation and LV Pacing Lead Position

The LV pacing lead was inserted transvenously via the subclavian route in 38 patients and the epicardial surgical approach was used for remaining two patients. The LV pacing lead was positioned in the lateral or posterolateral vein, corresponding to segments 1 to 4 in the left ventricular 17-segment model (Figure 3B). Device implantation was successful in all patients without major complications. After implantation, the atrio-ventricular interval was optimized for maximal diastolic filling by using Doppler echocardiography[20].

Statistical Analysis

All parametric data are expressed as mean ± SD. Group comparisons between before and after CRT were performed with the paired *t* test, and group comparisons between responders and non-responders with the unpaired *t* test. Proportional differences were evaluated using Fisher's exact test or the χ^2 test as appropriate. Correlation analysis was performed using linear regression and expressed as a Pearson correlation coefficient. Analysis of the receiver-operating characteristic (ROC) curve was used to assess the optimal cut-off values to predict response to CRT. For all tests, p value < 0.05 was considered statistically significant.

RESULTS

Patient Characteristics

Thirty patients (75%) were considered responders 4 ± 2 months after CRT according to the predefined criteria and the remaining 10 patients (25%) were classified as non-responders. Baseline echocardiographic characteristics of responders and non-responders were similar (Table 1). Compared with non-responders, responders tended to have smaller LV volumes and larger dyssynchrony, although the difference was not statistically significant (Table 1). Of the six patients with atrial fibrillation, two underwent atrioventricular junction ablation at the same time as CRT and two were defibrillated first and their atrial fibrillation disappeared after CRT.

All six patients with atrial fibrillation received digoxin, beta-blockers, and amiodarone for rate control before CRT. The LV lead position was assessed from a chest X-ray using the frontal and lateral views[21]. The LV pacing lead was positioned mid-lateral (n=21), basal-lateral (n=2), mid-posterior (n=13), and basal posterior (n=4). These lead positions corresponded to segments 1, 2, 3, and 4, respectively in Figure 3B. Overall, speckle tracking analysis by AFI was possible for 97% of the 1,360 segments from 40 subjects (baseline and follow-up) with technically adequate images subjected to the analysis, so that only 3% had to be excluded. Interobserver and intraobserver variability was 8.4% and 4.9% for ε-global, 5.4% and 6.9% for ε-pl, and 4.2% and 1.8% for LV dyssynchrony, respectively.

Impact of Regional Myocardial Function on Response to CRT

ε-global in both responders and non-responders was similar (-6.7±3.0% vs. -5.1±2.4%, NS), but the negative value of **ε**-pl in responders was significantly higher than that in non-responders at baseline (-7.8±6.9% vs. -2.1±4.9%, $p<0.01$, Figure 4). After CRT, the negative value of **ε**-global increased significantly in responders from -6.7±3.0% to -11.4±3.8% ($p<0.01$ vs. baseline), but remained virtually unchanged in non-responders from -5.1±2.4% to -6.6±1.6% (Figure 5). Figure 6 shows representative images of the bull's eye map produced by AFI for responders and non-responders before and after CRT. ROC curve analysis was performed to obtain the optimal cut-off value of **ε**-pl for predicting response to CRT. **ε**-pl of -7.8% had a sensitivity of 90% and a specificity of 60% for prediction of response to CRT. Twenty-eight patients (70%) showed evidence of LV dyssynchrony at baseline, defined as a time difference $\geq$ 130 ms between the anteroseptal and posterior wall peak strain. The response rate after CRT for patients with dyssynchrony was 75%. Furthermore, patients with both significant dyssynchrony and **ε**-pl < -7.8% determined by ROC curve analysis, were associated with a high incidence of LV functional improvement with a response rate of 92%.

Relationship between LVEF and LV Longitudinal Strain

ε-global correlated significantly with EF at baseline ($r=-0.34$, $p<0.05$, Figure 7A). Furthermore, an even closer correlation was found between **ε**-global and EF after CRT ($r=-0.84$, $p<0.0001$, Figure 7B).

Changes in LV Dyssynchrony after CRT

After CRT, LV dyssynchrony improved in responders from 272±154 ms to 53±39 ms ($p<0.001$), but remained virtually unchanged in non-responders, from 216±151ms to 168±66 ms (Table 1). The improvement in LV dyssynchrony correlated with a relative increase in EF after CRT (Figure 8).

DISCUSSION

This study demonstrates that regional myocardial systolic function in the posterolateral wall where the LV pacing lead was positioned was associated with response to CRT. Importantly, combining LV mechanical dyssynchrony with posterolateral myocardial systolic function assessed by AFI was more useful for predicting response to CRT than dyssynchrony parameters alone.

CRT is an established therapeutic option for patients with advanced HF. Previous studies have demonstrated that CRT improves acute and chronic hemodynamics, HF symptoms, exercise capacity, quality of life, survival, and LV systolic function[1-7, 22]. Randomized clinical trials have shown that up to one third of HF patients do not favorably respond to CRT when standard clinical selection criteria are used, including the electrocardiographic QRS width[1, 3, 4, 7]. Accordingly, the quantification of LV mechanical dyssynchrony by echocardiography has emerged as an important options for predicting response to CRT.

Assessment of LV Dyssynchrony

This study focused on radial thickening resulting from speckle tracking radial strain to assess LV dyssynchrony. The largest body of published studies on LV dyssynchrony and prediction of response to CRT reports their results in terms of LV longitudinal shortening velocities using tissue Doppler imaging from the apical views[14, 23-25]. However, the recent PROSPECT (Predictors of Responders to Cardiac Resynchronization Therapy) study used several echocardiographic dyssynchrony indices including tissue Doppler imaging and suggested that dyssynchrony indices based on tissue Doppler velocity could not replace routine selection criteria for CRT[26]. Speckle tracking echocardiography, on the other hand, may be applied to routine gray-scale images is not limited by Doppler angle of incidence. As a result, speckle tracking radial strain analysis allows for an accurate quantification of regional wall thickening. Suffoletto et al[18] have demonstrated that baseline speckle tracking radial dyssynchrony, defined as a time difference ≥ 130 ms between the anteroseptal and posterior wall peak strain, predicted chronic EF

response to CRT (8 ± 5 months after CRT) with 89% sensitivity and 83% specificity. Furthermore, several investigators have also demonstrated the utility of speckle tracking radial strain for predicting response to CRT[16, 17, 27].

Impact of Myocardial Function on Response to CRT

Although LV mechanical dyssynchrony has been associated with response to CRT, some patients with LV mechanical dyssynchrony identified by echocardiography do not respond to CRT. Other factors, such as LV lead position or scar burden, may influence response to CRT, regardless of LV dyssynchrony. Previous investigators have reported that myocardial viability or scar tissue is an important marker for the response to CRT[8-10]. In this study, we showed that the posterolateral systolic function where the LV pacing lead was positioned in responders was significantly higher than that in non-responders (-7.8±6.9% vs. -2.1±4.9%). This was recently corroborated by Bleeker[8] et al who demonstrated that patients with transmural scar in the posterolateral region assessed by contrast-enhanced MRI did not respond to CRT, whereas 81% of the patients without posterolateral scar responded well to CRT. In addition, Hummel et al[9] using contrast echocardiography to identify myocardial viability, reported similar findings for 21 patients with ischemic cardiomyopathy; viability in the posterior and lateral regions correlated with improvement in LVEF after 6 months of CRT. Furthermore, Ypenburg et al[10] using SPECT with technetium-99m tetrofosmin to identify posterolateral myocardial viability, reported similar findings for 51 patients with ischemic cardiomyopathy. In addition, we observed that combining speckle tracking radial dyssynchrony ≥ 130ms with posterolateral myocardial systolic function assessed by AFI < -7.8% was more useful for predicting response to CRT than speckle tracking radial dyssynchrony parameters alone (92% vs. 75%). With this method, we observed significant differences between responders and non-responders in myocardial systolic function assessed by AFI in the LV pacing target region. These data provide further support for the need for assessment of myocardial systolic function in the region of the LV pacing lead in addition to LV dyssynchrony only when selecting patients for CRT.

Impact of LV Lead Location

Although the LV lead is routinely positioned in a posterior or lateral epicardial vein through the coronary sinus, previous investigators have inferred that LV lead position impacts patient response to CRT. Ansalone et al[28]

demonstrated that LV lead placement at the most delayed segment resulted in the greatest immediate improvements after CRT. They also showed that the LV segment with the greatest delay in activation was most commonly the posterior or lateral wall. Becker et al, using 2-dimensional speckle tracking circumferential strain[29] or real-time 3-dimentional echocardiography[30], found that patients who had the LV lead tip position concordant with the site of the latest mechanical activation had a greater degree of EF increase after CRT than the patients with discordant LV lead positioning.

Automated Function Imaging

AFI is based on 2-dimensional speckle tracking imaging, which is applied to routine grayscale images and is not limited by Doppler angle of incidence[11, 12, 19]. Therefore, speckle tracking strain analysis allows for accurate quantification of regional myocardial function. Since AFI can assess regional longitudinal strain from 17-LV segments as a bull's-eye map, this technique facilitates a rapid visual assessment of regional myocardial systolic function.

Relationship between Two Indices of Global LV Systolic Function

Several authors have demonstrated the relationship between regional and global systolic function[19, 27, 31]. Delgado et al reported that regional systolic function assessed by AFI was linearly related to biplane EF. We previously reported regional myocardial systolic function assessed by tissue Doppler strain rate imaging was closely correlated to biplane EF in patients with coronary artery disease[27]. In this study, **ε**-global was found to correlate with EF at baseline and an even closer correlation was observed after CRT. Time to peak systolic strain of each of the segments was dispersed at baseline in the presence of LV dyssynchrony, so that correlation of EF and **ε**-global may not be so close before CRT. Our results suggest that **ε**-global correlated closely with EF if no substantial LV dyssynchrony was present.

Study Limitations

This study included a small number of patients, and future larger studies are needed to further elucidate the role of regional myocardial systolic function for predicting response to CRT. Another limitation is that only 23% of the study population consisted of patients with ischemic cardiomyopathy so that the beneficial response to CRT is

somewhat higher than in previous studies. While the exact reason remains unknown, one possible reason might be the difference of the etiology between patients with chronic severe HF in Japan and other countries, especially the US and Europe. Osada et al[32] reported 80% of patients with chronic severe HF among 284 applicants for heart transplantation in Japan were diagnosed with idiopathic dilated cardiomyopathy.

This study population is not homogeneous because patients with sinus rhythm (24 patients), atrial fibrillation (6 patients) and previous implantation of permanent right ventricular pacing (10 patients) were included. This heterogeneity may have affected the baseline data or response to CRT. Although current criteria for consideration of CRT do not include HF patients with previous implantation of permanent right ventricular pacing, upgrading of right ventricular pacing systems to CRT devices has become routine in many centers. Moreover, several investigators have reported that such upgrading was associated with long-term effects on mortality and morbidity similar to those for HF patients undergoing de novo CRT[33-35].

Because this was a 2-dimensional study, it was not possible to acquire simultaneously three different apical views for assessment of regional myocardial function by AFI. However, the R-R interval was similar (variation < 10%) and the frame rate was the same for each of the three different apical view in all patients. A newly developed 3-dimensional speckle tracking system appears to be a possible solution for this problem.

Although several authors have suggested that scar burden or scar location might impact the response to CRT[8-10, 36] , in this study we could not quantify myocardial scar burden or scar location by means of magnetic resonance imaging or myocardial perfusion imaging.

CONCLUSIONS

The reduced myocardial systolic function assessed by AFI in the region of the LV pacing lead was associated with inadequate LV resynchronization and resulted in non-response to CRT. Addition of posterolateral myocardial systolic function to measurement of dyssynchrony appears to be of value for predicting response to CRT and has potential clinical applications.

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FIGURE LEGENDS

Figure 1 An example of a two-dimensional mid-ventricular short axis image demonstrating radial time strain curves in a heart failure patient with left bundle-branch block. Dyssynchrony is shown as the time difference (arrow) between the peak strain in the anterior septum (yellow curve) and in the posterior wall (purple curve).

Figure 2 An example of a bull's eye map generated by automated functional imaging from three standard apical views. Myocardial lengthening is color-coded as red and shortening as blue.

Figure 3 A) Method for translation from the 18-segment model into the 17-segment model showing apical-left ventricular short axis images. **B)** The left ventricular pacing lead was positioned in the lateral or posterolateral vein, corresponding to segments 1 to 4 in the left ventricular 17-segment model.

Figure 4 Bar graphs of mean **ε**-global and **ε**-pl values for responders and non-responders at baseline. **ε**-global for both responders and non-responders was similar, but the negative value of **ε**-pl was significantly higher for responders than that for non-responders. **ε**-global, average longitudinal strain in all 17 left ventricular segments; **ε**-pl, average longitudinal strain in four posterior and lateral segments where the left ventricular pacing lead was positioned.

Figure 5 Bar graphs of mean **ε**-global values for responders and non-responders at baseline and after cardiac resynchronization therapy (CRT). The negative value of **ε**-global increased significantly in responders, but did not increase in non-responders. **ε**-global, average longitudinal peak systolic strain in all 17 left ventricular segments.

Figure 6 Left ventricular 17-segment bull's eye map presentation of regional strain before and after cardiac resynchronization therapy (CRT) in representative cases of responder (A), and non-responder (B).

Figure 7 (A) Scatter plots showing the correlations between **ε**-global and ejection fraction before cardiac resynchronization therapy (CRT), demonstrating significant correlation. **(B)** Scatter plots showing the correlations between **ε**-global and ejection fraction after CRT, demonstrating closer correlation than before CRT. **ε**-global, average longitudinal strain in all 17 left ventricular segments.

Figure 8 Scatter plots showing the correlation between change in left ventricular dyssynchrony and relative increase in left ventricular ejection fraction, demonstrating significant correlation.

TABLE

Table 1. Baseline Characteristics of Patients and Their Response to Cardiac Resynchronization Therapy

	All patients (n=40)	Responders (n=30)	Non-responders (n=10)
Age (years)	67±12	68±12	66±10
Gender (M/F)	30/10	22/8	8/2
NYHA class (III/IV)	28/12	22/8	6/4
QRS duration (ms)	163±25	164±25	161±26
Left bundle branch block	22 (55%)	19 (63%)	3 (30%)
Rhythm (SR/AF/Paced)	24/6/10	19/3/8	5/3/2
HR (/min)	73±13	73±13	74±11
PR duration (ms)	188±29	187±28	191±35
Posterior wall thickness (mm)	10±2	10±2	10±2
Mitral regurgitation grade (0/1/2/3)	27/12/1/0	21/9/0/0	6/3/1/0
Etiology (ischemic/non-ischemic)	9/31	6/24	3/7
Medication, n (%)			
Diuretics	34 (85%)	24 (80%)	10 (100%)
ACEI/ARB	37 (93%)	28 (93%)	9 (90%)
β-blockers	33 (83%)	25 (83%)	8 (80%)
Ejection fraction (%)			
Baseline	25±8	25±9	26±6
Follow-up	35±14	39±14*	24±5
End-diastolic volume (ml)			
Baseline	170±77	154±56	217±109
Follow-up	139±80	113±51*	216±104

End-systolic volume (ml)			
Baseline	131±67	119±53	166±95
Follow-up	95±69	72±44*	165±82
Left ventricular dyssynchrony (ms)			
Baseline	258±154	272±154	216±151
Follow-up	81±68	53±39*	168±66

ACEI, angiotensin converting enzyme inhibitor; AF, atrial fibrillation; ARB, angiotensin type1 receptor blocker; NYHA, New York Heart Association; SR, sinus rhythm.

Data are presented as means ± SD or number of patients. * $p<0.05$ vs. baseline.

Figure 1

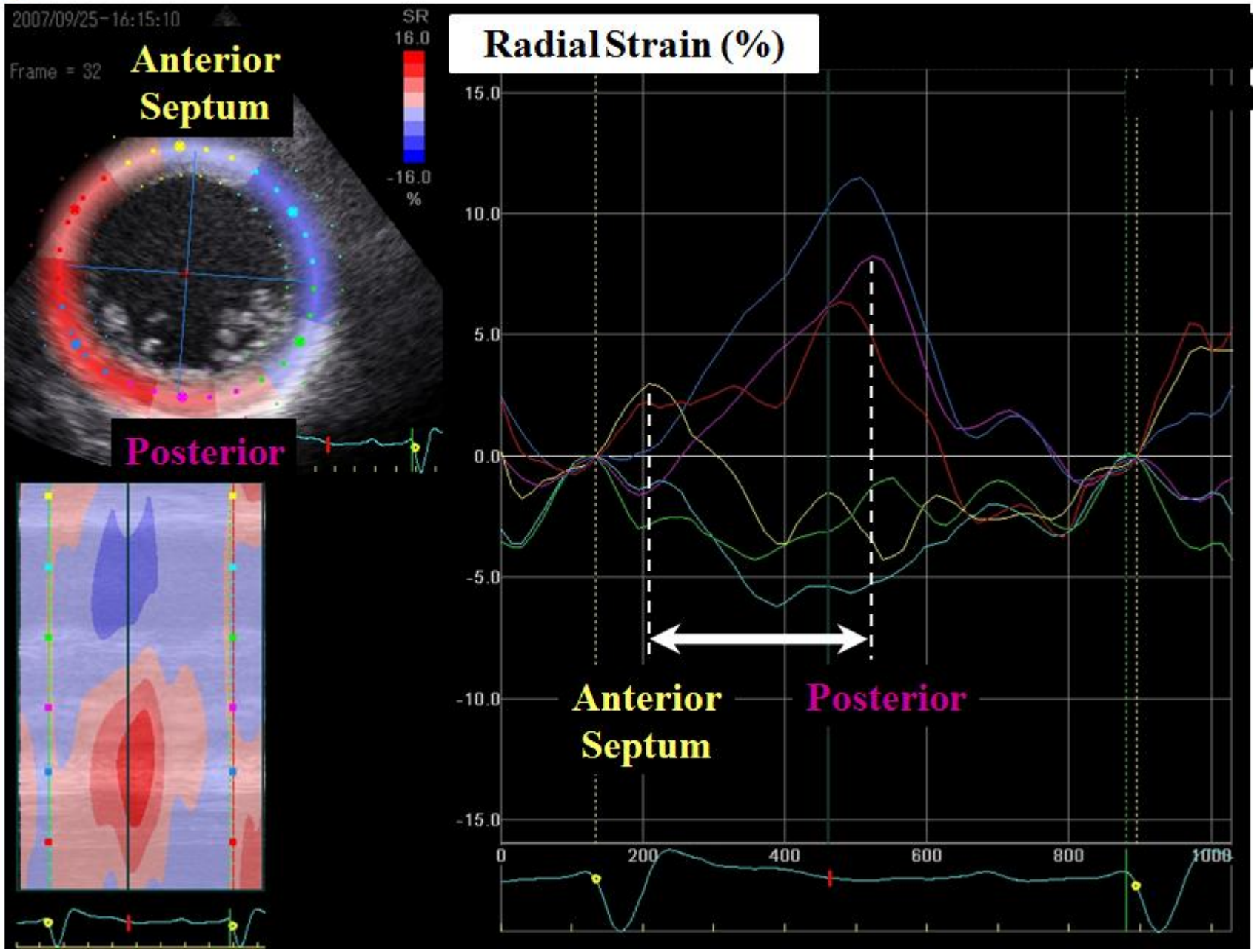

2007/09/25-16:15:10
Frame = 32
Anterior
Septum
SR
16.0
-16.0
%
Posterior
Radial Strain (%)
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
Anterior
Septum
Posterior
0
200
400
600
800
1000

Figure 2

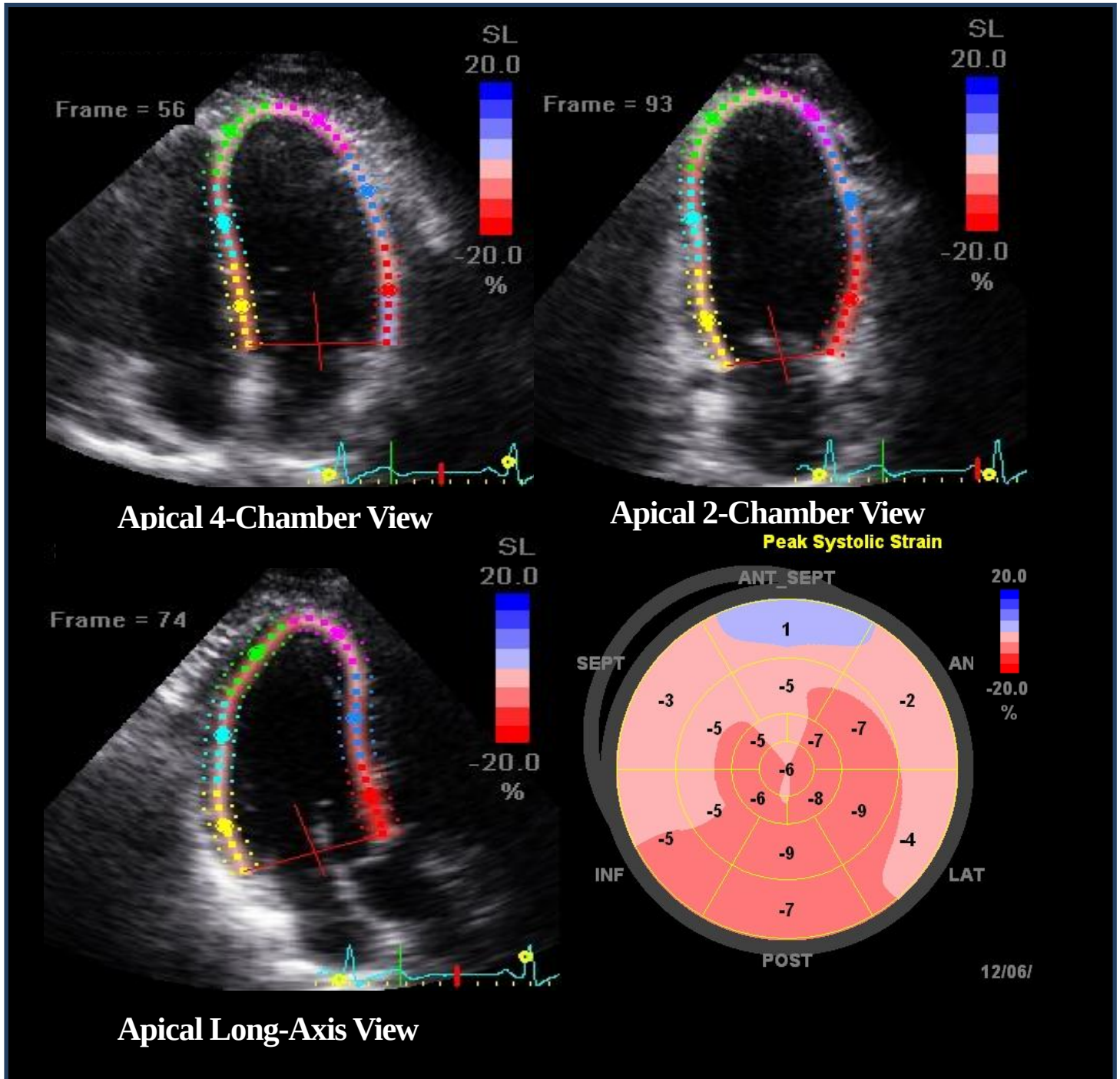
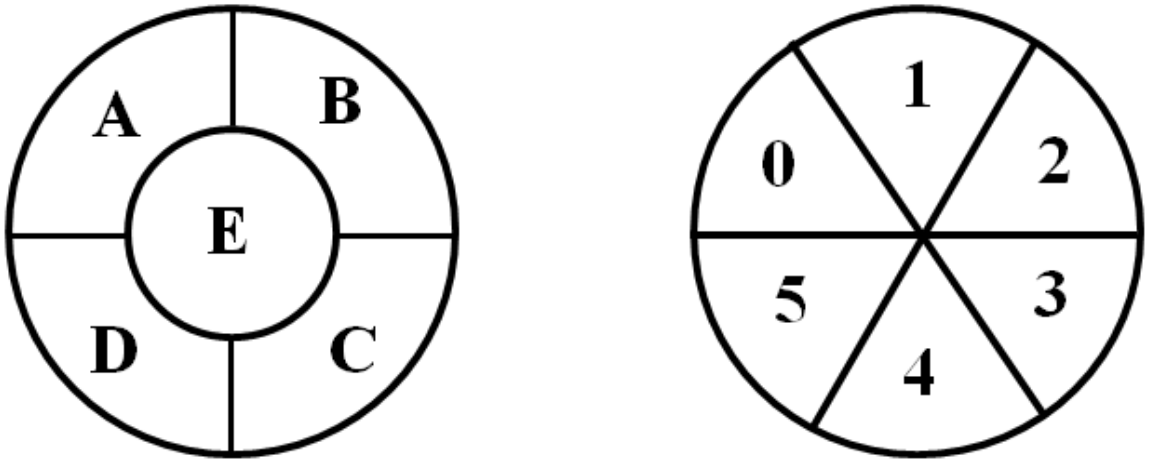

SL
20.0
Frame = 56
-20.0
%
Apical 4-Chamber View
SL
20.0
Frame = 93
-20.0
%
Apical 2-Chamber View
SL
20.0
Frame = 74
-20.0
%
Apical Long-Axis View
Peak Systolic Strain
ANT_SEPT
SEPT
AN
INF
LAT
POST
20.0
-20.0
%
1
-5
-3
-2
-5
-7
-5
-7
-6
-6
-8
-5
-9
-5
-4
-9
-7
12/06/

Figure 3

A) **17-segment model** **18-segment model**



Value (A) = 2/3*[Value (0) + 0.5*Value (1)]
Value (B) = 2/3*[Value (2) + 0.5*Value (1)]
Value (C) = 2/3*[Value (3) + 0.5*Value (4)]
Value (D) = 2/3*[Value (5) + 0.5*Value (4)]
Value (E) = 1/6*[Value (0) + Value (1) + Value (2) + Value (3) + Value (4) + Value (5)

B)

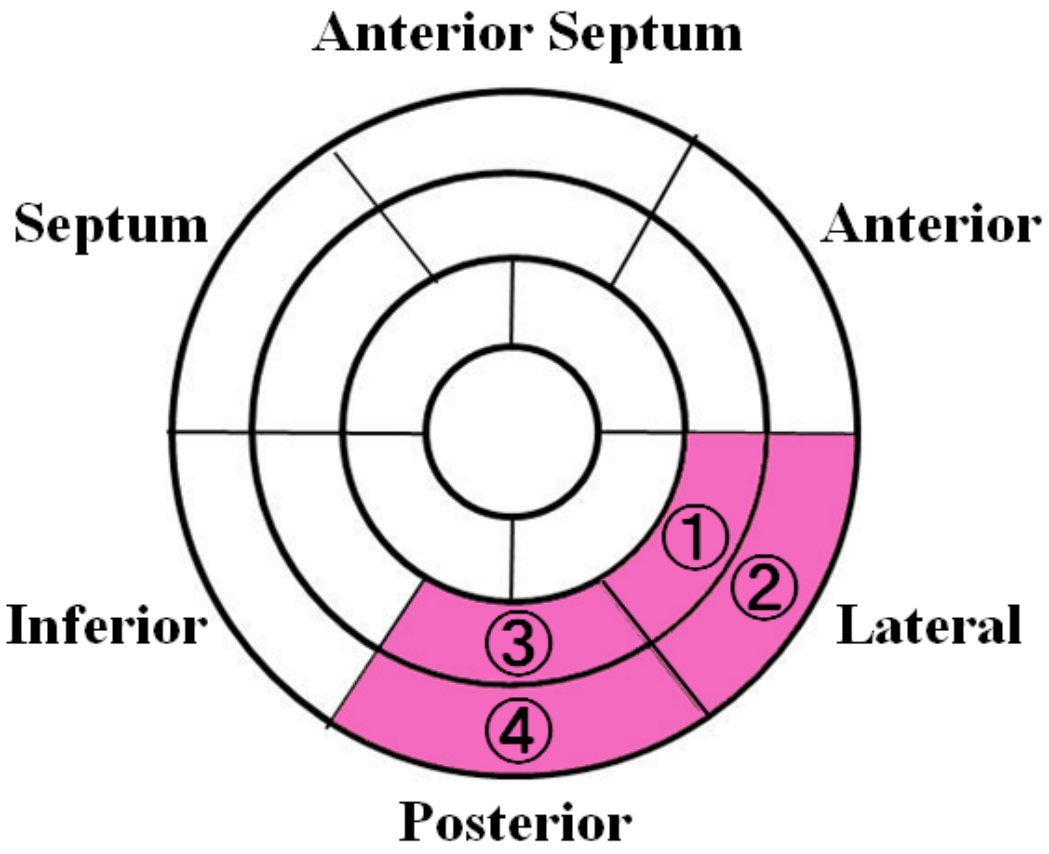


Figure 4

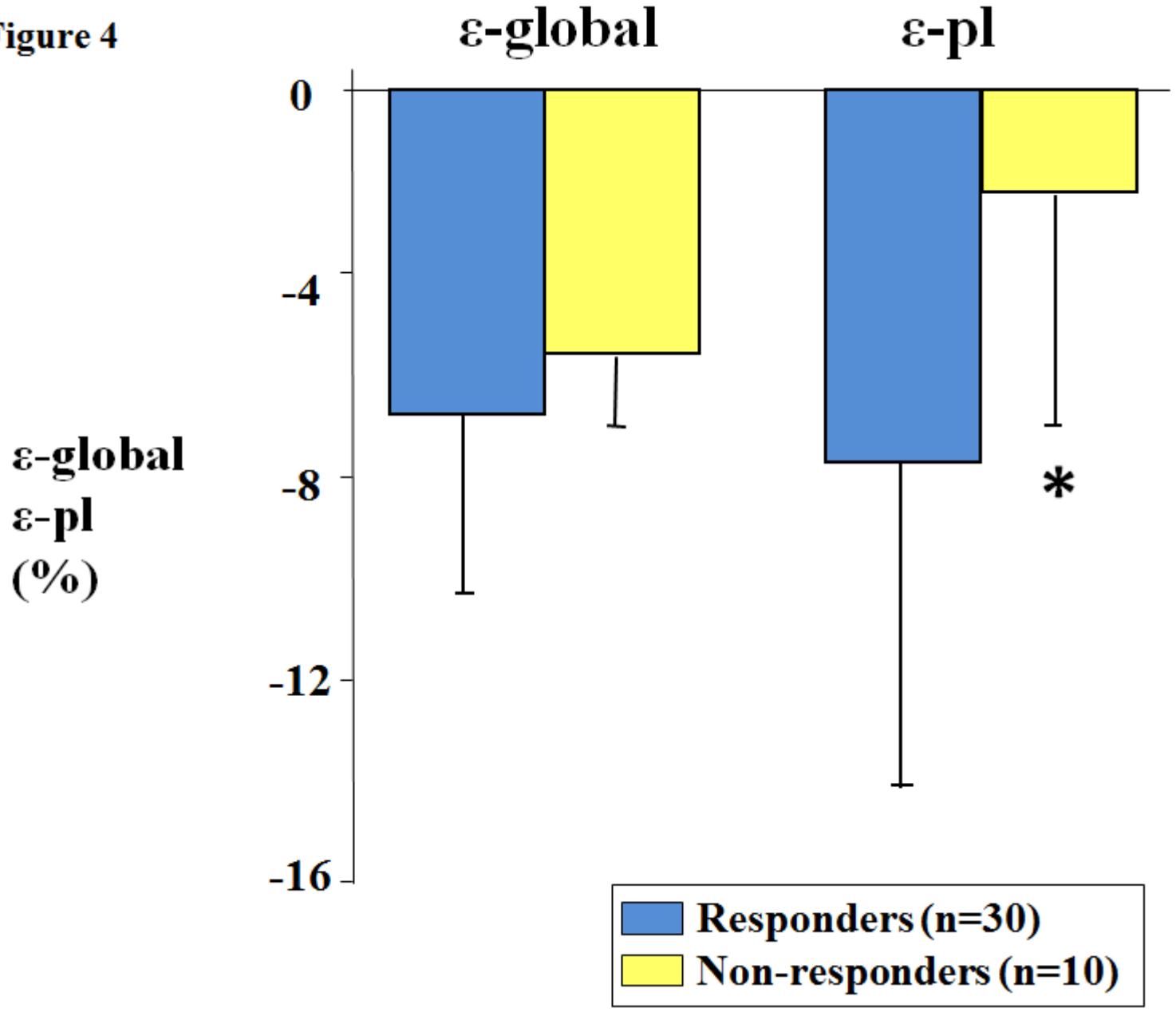

ε-global
ε-pl
0
-4
-8
-12
-16
ε-global
ε-pl
(%)
*
Responders (n=30)
Non-responders (n=10)

Figure 5

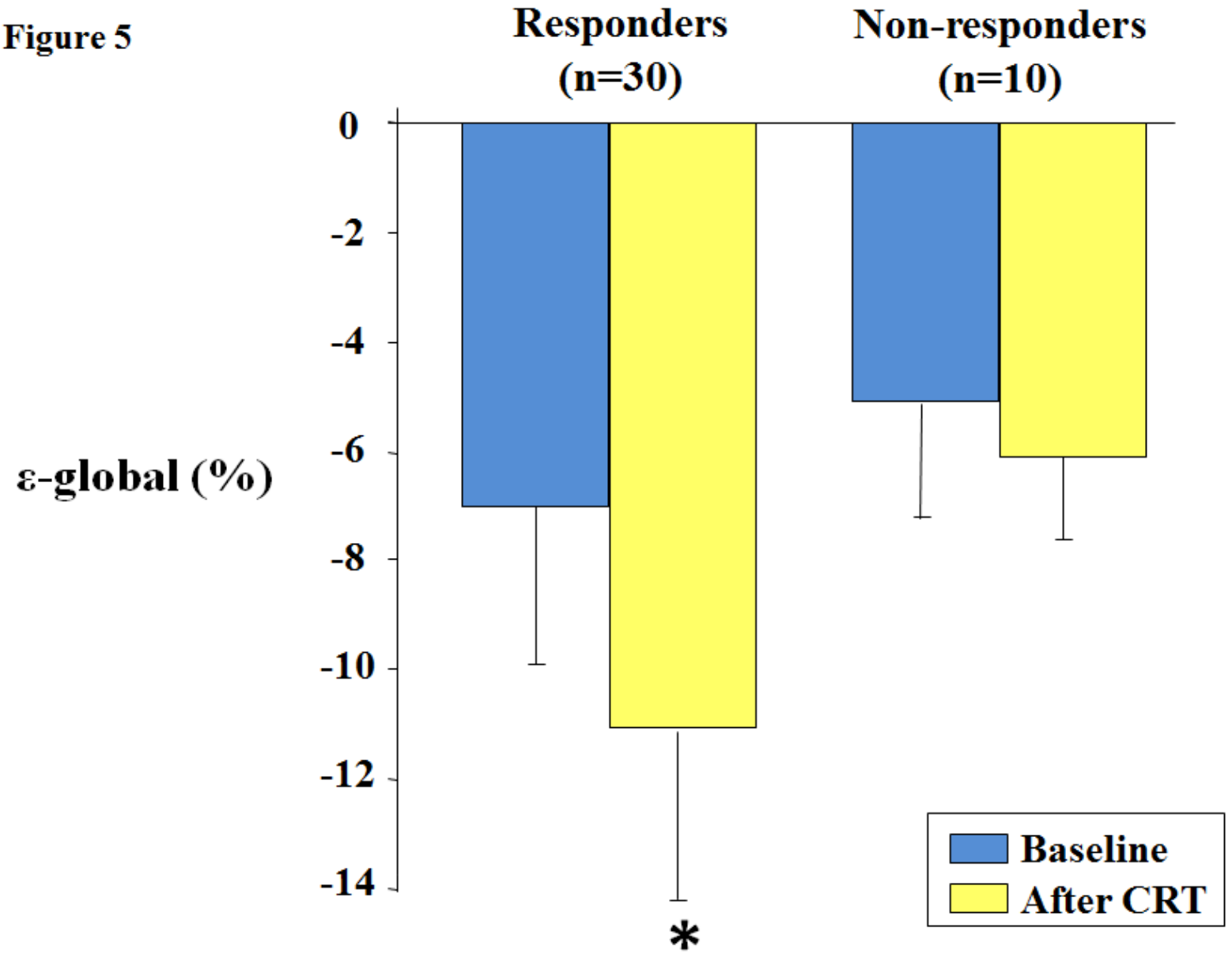

Responders
(n=30)
Non-responders
(n=10)
ε-global (%)
0
-2
-4
-6
-8
-10
-12
-14
*
Baseline
After CRT

Figure 6

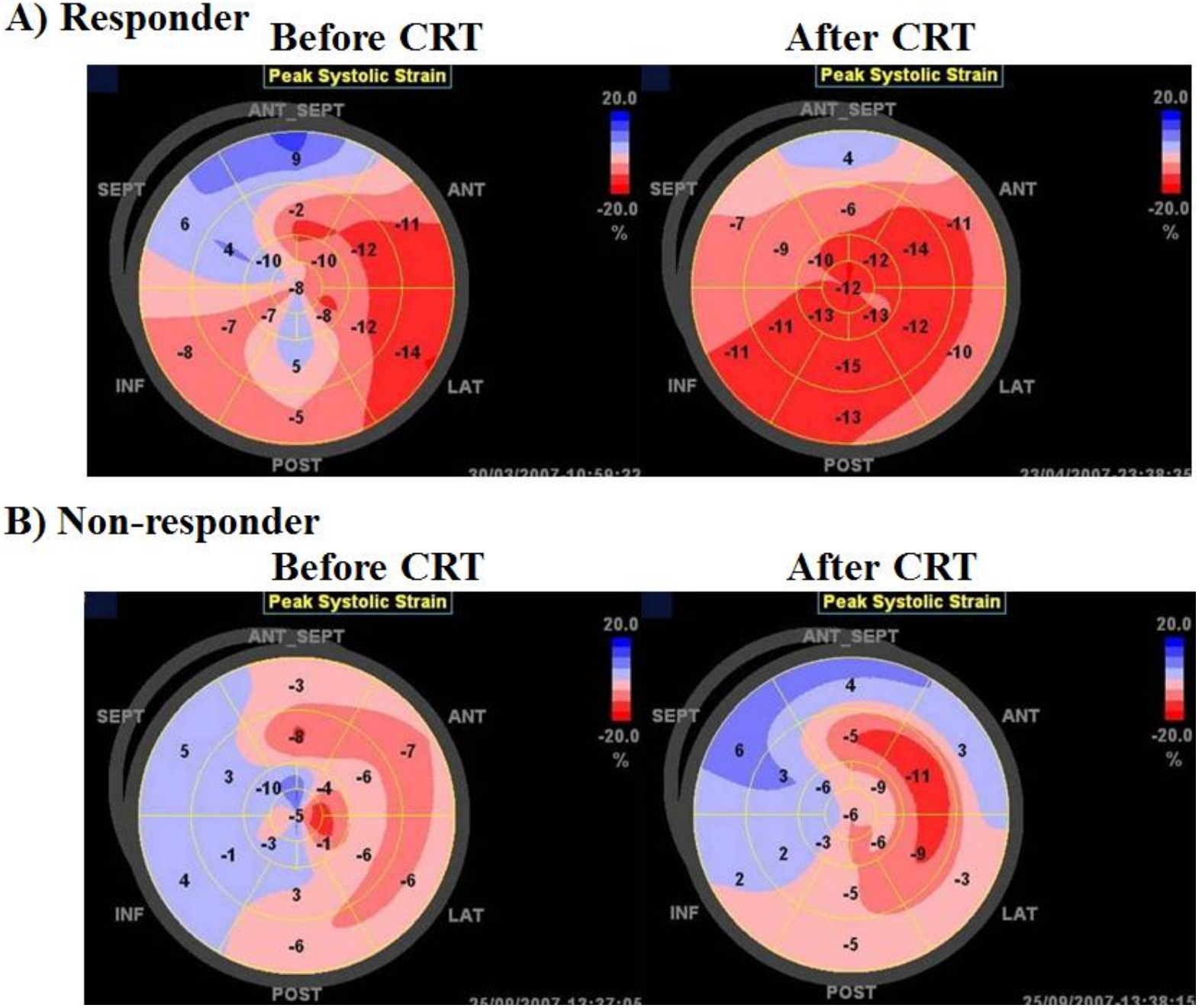

A) Responder
Before CRT
After CRT
Peak Systolic Strain
ANT_SEPT
SEPT
ANT
INF
LAT
POST
20.0
-20.0
%
B) Non-responder
Before CRT
After CRT
Peak Systolic Strain

Figure 7

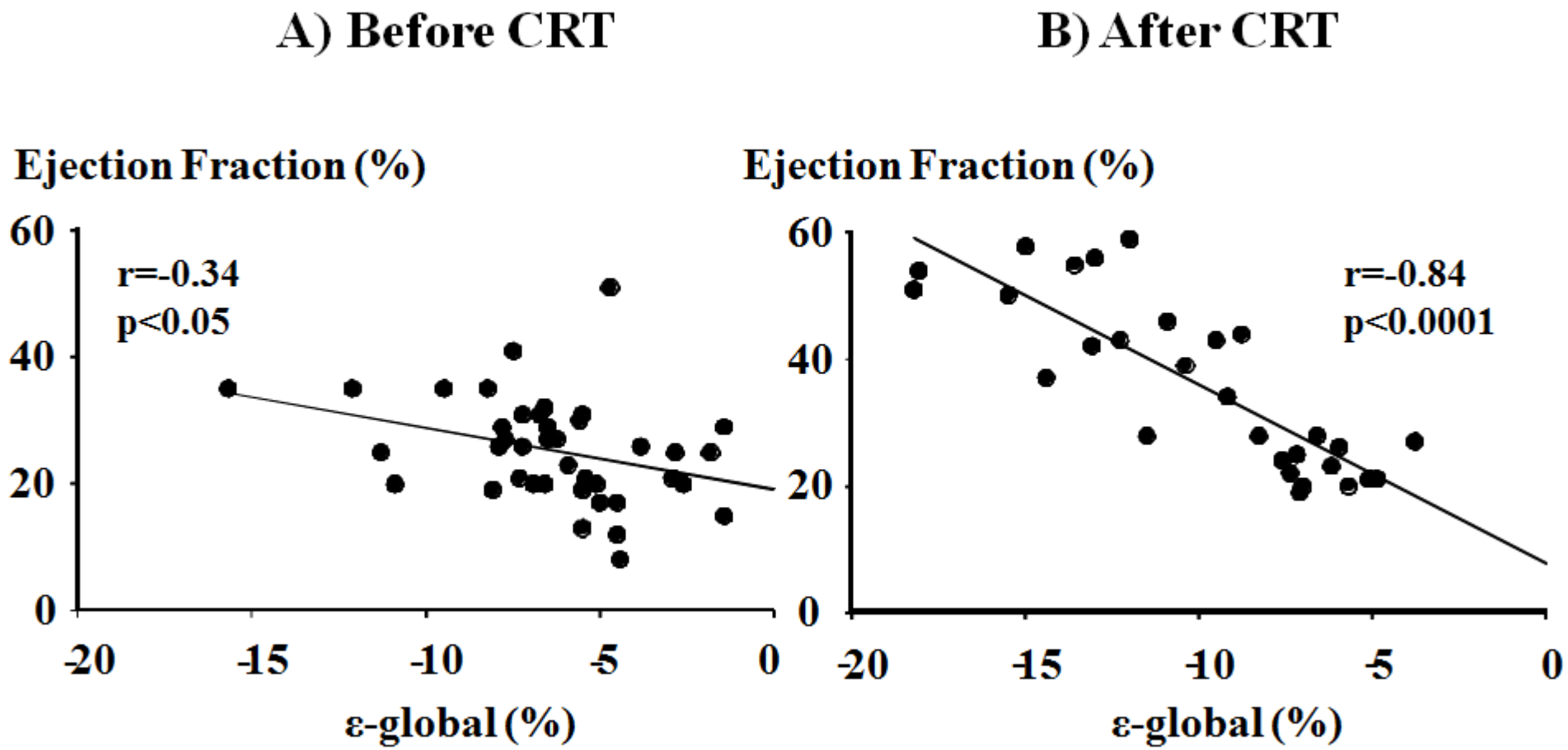
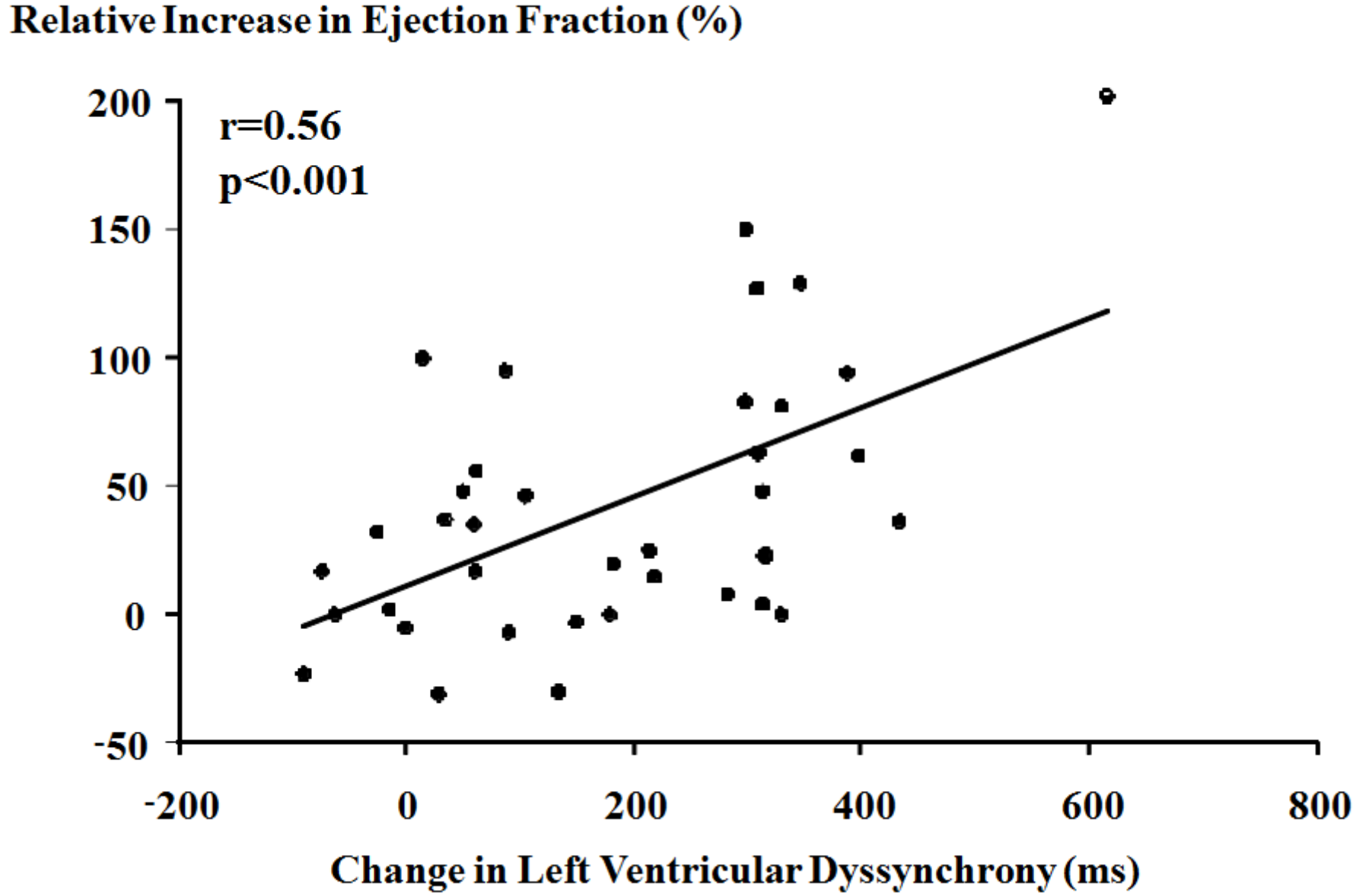

A) Before CRT
B) After CRT
Ejection Fraction (%)
Ejection Fraction (%)
r=-0.34
p<0.05
r=-0.84
p<0.0001
60
40
20
0
-20
-15
-10
-5
0
ε-global (%)
ε-global (%)

Figure 8


Relative Increase in Ejection Fraction (%)
r=0.56
p<0.001
200
150
100
50
0
-50
-200
0
200
400
600
800
Change in Left Ventricular Dyssynchrony (ms)