Echocardiography-Guided Left Ventricular Lead Placement for Cardiac Resynchronization Therapy: Results of the Speckle Tracking Assisted Resynchronization Therapy for Electrode Region (STARTER) Trial

Saba et al: Echo-Guided LV Lead Placement in CRT

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Abstract

Background—Cardiac resynchronization therapy (CRT) improves mortality and morbidity in heart failure (HF) patients with wide QRS complex and diminished left ventricular (LV) function, but response is variable.

Methods and Results—The Speckle Tracking Assisted Resynchronization Therapy for Electrode Region (STARTER) was a prospective, double-blind, randomized controlled trial testing the hypothesis that an incremental benefit to CRT would be gained by echo-guided (EG) transvenous LV lead placement versus a routine fluoroscopic approach. EG LV lead placement was attempted at the site of latest time-to-peak radial strain by speckle tracking echocardiography. The pre-specified primary endpoint was first HF hospitalization or death. Of 187 New York Heart Association class II-IV HF patients (62% ischemic, EF 26±6%, QRS 159±27ms), 110 were randomized to EG and 77 to routine strategies. Primary events included 30 deaths and 37 HF hospitalizations over 1.8 years. Using intention-to-treat, patients randomized to an EG strategy had a significantly more favorable event-free survival (hazard ratio (HR) = 0.48, 95% confidence interval (CI) = 0.28-0.82, p=0.006). Exact or adjacent concordance of LV lead with latest site could be achieved in 85% of the EG group and occurred fortuitously in 66% of controls (p=0.010), and was associated with an improvement in event-free survival (HR=0.40, 95% CI=0.22-0.71, p=0.002).

Conclusions—A strategy of EG LV lead placement for CRT improved patient outcomes by reducing the combined risk of death or HF hospitalizations and has implications for delivery of CRT.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifier: NCT00156390.

Key Words: cardiac resynchronization therapy; speckle tracking echocardiography; LV lead position; death; heart failure hospitalization
Cardiac resynchronization therapy (CRT) has become an integral treatment modality for patients with heart failure (HF), diminished left ventricular (LV) ejection fraction (EF), and a wide QRS complex, conferring symptomatic relief, functional improvement, and survival benefit to the majority of recipients\textsuperscript{1-4}. Despite these benefits, approximately one third of patients do not respond to CRT\textsuperscript{1}, and much resultant attention has focused on attempts to improve response. Although several reasons have been implicated in non-response, such as degree of LV scar burden\textsuperscript{5-7} and lack of mechanical dyssynchrony\textsuperscript{6,8-12}, the position of the LV pacing electrode with respect to the site of latest LV mechanical activation appears to be of increasing importance as a factor related to CRT response\textsuperscript{13-16}. We therefore prospectively tested the hypothesis that an incremental clinical benefit of CRT would be gained by echocardiography-guided (EG) transvenous LV lead placement targeting the site of latest LV mechanical activation compared to the routine approach by performing a prospective, randomized, double-blinded study.

\textbf{Methods}

The Speckle Tracking Assisted Resynchronization Therapy for Electrode Region (STARTER) was a prospective, single center, double-blinded, randomized trial comparing the EG LV lead positioning through the transvenous approach during CRT implantation to a routine approach without imaging guidance. Patients were enrolled and implanted at the University of Pittsburgh Medical Center (UPMC) between June, 2005 and March, 2011. Patients and health care providers were blinded to their treatment assignment, except for the implanting physician.

\textit{Enrolled Patients}

STARTER enrolled patients who were at least 18 years of age, New York Heart Association (NYHA) class II, III, or IV symptoms on optimal medical therapy LV ejection fraction.
fraction (EF) ≤35%, and QRS width ≥120 ms. The study received Institutional Review Board approval and all patients gave written informed consent. Patients who had persistent atrial arrhythmias (n=44) were included as long as they underwent atrioventricular nodal ablation at the same time as the CRT device implantation or their ventricular response rate was slow enough to allow a high percentage (>90%) of biventricular pacing. Also, patients with chronic right ventricular pacing undergoing upgrade to a CRT device were eligible for this study (n=40). All patients received CRT-defibrillators except for 4 patients (2 in each study arm) who received CRT-pacemakers. Eligible patients were randomized to EG treatment arm versus routine control arm in a 3 to 2 ratio.

Echocardiography
All echocardiographic studies (GE Vivid 7 system, Horten, Norway) were analyzed by the core lab at UPMC Presbyterian. LV volumes were assessed by biplane Simpson rule using manual tracing of digital images. For speckle tracking radial strain, digital grayscale 2-D cine loop images were acquired at end-expiratory apnea from basal and mid-LV short axis views with frame rates of 60-90Hz for off-line analysis (GE EchoPac BT08-BT11). Briefly, circular regions of interest were placed on the endocardial and epicardial borders and manually adjusted for optima time-strain curves. The times to peak strain from 8 free wall segments (4 from each view) were determined from a minimum of 3 consecutive beats and averaged. The site of latest activation was determined as the segment with latest peak strain (Figure 1A). Patients whose latest peak strain occurred equivalently in more than one segment were reported as such. No cases were encountered where septal or anteroseptal regions coincided with the latest site of mechanical activation. Dyssynchrony was determined as the time difference between peak strain in the anterospetal segment to peak strain in the posterior wall, as previously described.
Using this approach, our intraobserver variability in time to peak strain analysis from the identical digital cineloops was 6±6% and the interobserver variability was 8±7%. Although a formal quantitative exclusion of scar with a predetermined cutoff was not performed\textsuperscript{16, 22}, segments with likely scar (thin wall ≤ 0.5 mm and an abnormal increase in acoustic reflectance)\textsuperscript{23} that had very low amplitude strain curves with significant noise were handled as missing data, and therefore were not selected as a site of latest mechanical activation.

The labeling of the 4 free wall segments from basal and mid LV levels were anterolateral, lateral, posterolateral, or posterior to correspond to the regions of the coronary venous anatomy (Figure 1B). The corresponding naming of segments by the speckle tracking software was as shown in Figure 1B and as follows: (with speckle tracking software labels listed first): Anterior = Anterolateral, Lateral = Lateral, Posterior = Posterolateral, and Inferior = Posterior. A pictorial report of site of latest mechanical activation was given to the implanting physician only for patients randomized to the EG group.

Device Implantation Procedure

CRT was carried out using a transvenous approach with the right ventricular lead placed in or near the right ventricular apex. A right atrial lead was placed in all but 19 patients who had persistent atrial arrhythmias. Coronary venography was performed in left anterior oblique (LAO) projection in all patients. The fluoroscopic images were divided into corresponding anatomical regions described above in the LAO view (Figure 1B) and into equal thirds in the right anterior oblique (RAO) view: basal, mid LV, and apical regions for documentation of LV lead position. Patients randomized to the EG study group had their LV lead placement attempted in the latest LV mechanical activation site as reported by speckle tracking echocardiography, described...
above. Patients who were randomized to control had their LV leads placed in the routine manner, targeting posterior or lateral LV regions.

**Determination of LV Lead Concordance**

Polar maps using a 16-segment model of the time to peak strain in relation to LV lead position were constructed after device implantation. Exact concordance was defined as when the LV lead was positioned in the same segment of latest mechanical activation. Adjacent segments were defined as segments that were immediately adjacent to the latest activation site, including touching diagonally using the 10 free-wall segments of the 16-segment model\textsuperscript{24}. Timing of apical segments was not determined prospectively, so patients with apical lead positioning could only be classified as adjacent or remote.

**Follow-Up Echocardiography**

LV volumes and LVEF were determined from follow-up echocardiography obtained 6-12 months after CRT as pre-specified in our protocol. Dyssynchrony after CRT was determined by speckle tracking as before CRT. To demonstrate the effects of CRT on resynchronization of the LV, dyssynchrony was assessed post hoc in patients with existing follow-up echocardiographic dyssynchrony data.

**Follow-Up for Clinical Endpoints**

The predefined primary endpoint was a composite of death or first HF hospitalization after CRT. Clinical events were adjudicated independently by two investigators not involved in patient care. Pre-defined secondary endpoints included a composite of death, heart transplantation, or LV assist device implantation, change in LVEF, and change in LV end-systolic volumes (LVESV). In addition, response to CRT was predefined as a $\geq15\%$ relative reduction in LVESV on follow-up echocardiography and no primary endpoint or as a $\geq5\%$ absolute increase in LVEF (EF units)
and no primary endpoint. All analyses were performed by intention-to-treat according to the randomization status as well as by lead concordance status. The study was terminated on April 25, 2012 after an interim analysis indicated that the pre-specified primary endpoint was reached in more than 30% of enrolled patients and that there was a significant difference in event rates between the two study groups.

Sample Size and Statistical Analysis

The sample size calculation was based on the two-sided primary hypothesis. It assumed a 67% 1-year survival free from HF hospitalization in the control group. In order to demonstrate 80% event-free survival rate in the echo-guided group, a total of 195 patients are needed in both groups, assuming a type I error of 10% and a power of 5%.

All analyses were performed according to the intention-to-treat principle. All continuous variables were expressed as mean ± standard deviation and were compared using the Student T-test or analysis of variance, as appropriate. Continuous pre-defined subgroups were dichotomized around their mean value. Discrete variables were expressed as percentages and compared using the chi square test. Time to events were calculated according to the Kaplan–Meier method and compared using the log-rank test. The effect of treatment assignment on the primary endpoint in pre-defined subgroups was analyzed using the Cox proportional hazards model. All analyses were conducted using the IBM PASW software version 19 (Armonk, NY). P values ≤0.05 were considered statistically significant.
Results

Patient Population and Procedural Data

A total of 187 (110 EG and 77 routine) patients were randomized in STARTER. Baseline characteristics were similar between the two study groups (Table 1). The majority of patients in both study groups belonged to NYHA class III and a high percentage of subjects were receiving β-blockers (88%) and Angiotensin converting enzyme inhibitors or Angiotensin receptor blockers (82%). There were 165 patients with complete baseline data. Ninety-six (87%) were in the EG group (6 excluded due to poor echocardiographic images, 7 had LV lead placement failure, and 1 had procedure cancellation) and 69 patients (90%) were in the routine group (2 were excluded due to poor echocardiographic images, 3 had LV lead placement failure, and 3 had procedure cancellation). The total procedural time (130±60 minutes versus 134±52 minutes, p=0.662) and fluoroscopic time (35±27 minutes versus 32±21 minutes, p=0.482) were similar between the two study groups.

There were a total of 15 complications related to CRT implantation. These included device infection requiring explantation (n=3), pneumothorax (n=1); LV lead dislodgement (n=4), atrial lead dislodgement (n=1), coronary sinus staining during venography (n=2), and diaphragmatic stimulation from LV pacing requiring device reprogramming (n=4). These complications were not influenced by the treatment assignment.

As expected after CRT, patients overall had significant improvement in NYHA class (2.9±0.5 at baseline versus 2.0±0.8), LVEF (27±6% at baseline versus 37±12%), LV end-diastolic volume (187±73 ml at baseline versus 155±67 ml) and LV end-systolic volume (140±61 ml at baseline versus 102±59 ml; p<0.001 for all).
Treatment Effects on Primary Endpoints

During a mean follow-up 1.8±1.3 years, 67 (36%) patients reached the primary endpoint. There were 30 deaths (15 in EG and 15 in routine arms, p=0.19) and 37 HF hospitalizations (16 in EG and 21 in routine arms, p=0.049). Six patients (3 in each arm) who were hospitalized for HF underwent the implantation of a LV assist device, and 2 (1 in each arm) underwent heart transplantation. The event-free survival was significantly improved in the EG compared to the routine control group (Hazard Ratio [HR] = 0.48, 95% confidence interval (CI) = 0.28-0.82, p=0.006, Figure 2). The 2-year event-free survival was 77% in the EG versus 57% in the routine control group, indicating a 26% reduction in event rates.

The favorable treatment effect of EG group was retained when all the following pre-defined subgroups were tested for potential differences in CRT response: age, gender, type of cardiomyopathy, baseline LVEF, LVESV, LV end-diastolic volume. When dichotomizing the cohort around the mean of QRS width (159 ms), an effect of treatment assignment on the primary endpoint was demonstrated with a more pronounced advantage of the EG over routine strategy in patients with narrower QRS complexes (HR=0.35, 95% CI = 0.17 – 0.72, p=0.004 for QRS≤159 ms compared to HR=0.59, 95% CI = 0.26 – 1.33, p=0.200 for QRS>159 ms).

LV Lead Position and Concordance with the Site of Latest Mechanical Activation

The site of latest mechanical activation among the 8 free-wall segments was: basal anterolateral (4%), basal lateral (12%), basal posterolateral (20%), basal posterior (11%), mid anterolateral (3%), mid lateral (15%), mid posterolateral (25%), and mid posterior (10%). The distribution of LV lead position in LAO and RAO fluoroscopy is shown in Table 2. Of note, the implanting physician targeted the site of the latest mechanical activation in the EG group regardless of being non-posterolateral or lateral when feasible by coronary venous anatomy and lead stability.
Twenty-three of EG patients (24%) had LV leads in non-posterolateral or lateral positions. Exact concordance between the segment of latest mechanical activation by speckle tracking echocardiography and LV lead position was achieved in 30% of patients in the EG study group and occurred fortuitously in 12% of controls (p=0.011). When expanding to include segments immediately adjacent to site of latest activation, LV lead position was either exactly concordant or adjacent in 85% of patients in the EG study group while this occurred fortuitously in 66% of controls (p=0.010). Pacing at LV regions concordant or adjacent to the site of latest mechanical activation conferred a significantly higher event-free survival compared to pacing at remote sites (HR = 0.40, 95% CI = 0.22-0.71, p=0.002, Figure 3, upper panel). The 2-year event-free survival was 73% in concordant or adjacent versus 46% in remote LV lead positions, indicating a 37% reduction in event rates. Patients with either exact concordant or adjacent leads were grouped together because when analyzed separately outcomes in these subgroups were similar. Concordance of LV lead position with latest activation was also significantly associated with the composite secondary endpoint of death, LV assist device implantation, or heart transplantation (HR = 0.31, 95% CI = 0.15-0.67, p=0.002, Figure 3, lower panel). The 2-year survival was 87% in concordant or adjacent versus 63% in remote LV lead positions, indicating a 27% reduction in event rates.

There were 121 patients with follow-up echocardiograms available, due to either death occurring before the follow-up echocardiogram or failure to return for imaging. Significantly greater reverse remodeling demonstrated by LVESV decrease was seen in the EG versus routine arm and in concordant or adjacent versus remote lead locations (Table 3). Although the increase in LVEF was not significantly different between the EG versus routine patients, it was significantly greater in concordant or adjacent versus remote lead locations (Table 3). Using
echocardiographic and clinical data (n=149), EG patients had significantly higher response rates defined by either $\geq 15\%$ relative decrease in LVESV or $\geq 5\%$ absolute increase in LVEF from baseline and no primary event (Table 3). Similarly, patients with LV leads concordant or adjacent to site of latest activation had significantly higher CRT response rates (Table 3).

Effect of Resynchronization after CRT

Baseline dyssynchrony and resynchronization post hoc for mechanistic support of the effect of LV lead position in the 127 patients with repeat echocardiography after CRT. Resynchronization was defined as a 50% decrease in radial dyssynchrony (difference in time to peak anteroseptal to posterior wall strain) from before to after CRT, providing that they had at least 95 ms dyssynchrony measure at baseline. This cut-off of 95 ms was based on a subgroup analysis of the MADIT-CRT4 trial (abstract attached as supplement). Reduction in dyssynchrony was significantly greater in the EG versus the routine groups group ($-158\pm179$ ms in EG group versus $-91\pm173$ ms in routine group, p=0.038, Figures 4A and 4B). Resynchronization was achieved in 61% of patients (70% in EG group versus 48% in routine group, p=0.021). It was significantly associated with freedom from HF hospitalization or death (HR = 0.28, 95% CI=0.14-0.56, p<0.001, Figure 4C) as well as freedom from death, LV assist device implantation or heart transplantation (HR = 0.30, 95% CI = 0.11-0.80, p=0.011).

Discussion

This randomized clinical trial of two different CRT delivery strategies demonstrated that LV lead placement directed toward the site of latest mechanical activation by speckle tracking echocardiography reduced the composite endpoint of HF hospitalization or death compared with routine fluoroscopic lead placement. The benefits of the EG approach were achieved without
any increase in the duration of the implantation, radiation exposure, or procedural complications. Furthermore, patients in whom exact or adjacent concordance was achieved had an even more pronounced reduction in the primary endpoint, as well as in the important secondary endpoint of death, heart transplant, or LVAD. We also observed a greater benefit in LV reverse remodeling with the EG strategy, and higher CRT response rates compared with the routine approach. Finally, achieving resynchronization of radial strain was associated with more favorable clinical outcomes providing mechanistic support for our findings.

The importance of the site of LV lead pacing during CRT has been previously demonstrated by our group and others with consistent results supporting the benefit of pacing the LV at the site of latest mechanical activation. Delgado et al showed an incremental benefit of LV lead positioning at the site of latest mechanical activation over the presence of dyssynchrony and absence of scar in a large series of CRT recipients with ischemic heart disease. Recently, the TARGET trial, which prospectively randomized patients to a targeted LV lead placement at or close to the site of latest mechanical activation versus non-targeted approach demonstrated superiority of the targeted approach for the primary endpoint of LVESV reduction. Conceived independently, STARTER examined a similar hypothesis and demonstrated the superiority of a strategy of echocardiographic guidance during LV lead placement for CRT for the primary endpoint of death or HF hospitalization. Furthermore, STARTER extended these previous findings by adding resynchronization data to provide mechanistic support for our outcomes. The similar findings between TARGET and STARTER as well as their consistency with the results of several previous retrospective studies combine to support the importance of the LV pacing site for CRT.
The incremental benefit seen in the EG group is supported by a higher percentage of concordance between the LV pacing site and the site of latest mechanical activation, which in turn was associated with a higher rate of mechanical resynchronization. Pacing the latest site of mechanical activation is likely to reduce the total LV electromechanical activation time to a greater extent compared to pacing at other sites. Response to CRT has been shown to be multifactorial, with likely determinants including the presence of myocardial scar versus viable tissue\(^5\). Nevertheless, our results demonstrate that given a non-selected population of CRT recipients, a strategy of echocardiographic guidance is associated with improved clinical and echocardiographic outcomes compared to routine strategy. Although exact concordance could be achieved in only 30% of patients in EG group and fortuitously occurred in 12% of the routine group, adjacent concordance was achieved in the majority of patients in the EG group (85%) and conferred clinical and echocardiographic benefits. These results suggest that there is a relatively large ‘sweet spot’ for optimal LV pacing as previously suggested by animal studies\(^3\), but emphasize that a EG approach has a measurable clinical benefit.

The favorable results after CRT in our patient population are in keeping with the results of published large randomized clinical trials\(^2, 3\). The one-year event free survival in our routine control group was comparable to the event rate of death or cardiovascular hospitalization in the treatment arms of both the COMPANION\(^2\) and CARE-HF\(^3\) trials. Our present data therefore demonstrate an incremental benefit of the EG strategy beyond the expected benefits previously reported with routine CRT therapy. Achieving higher success rates of delivering the LV lead to its intended ‘optimal’ pacing site beyond the constraints of the coronary venous anatomy could possibly be achieved in the future using minimally invasive epicardial\(^32\) or even transeptal...
endocardial approaches. Whether the higher LV lead concordance rates using these techniques would translate into additional improvement in outcomes after CRT remains to be demonstrated.

The present study has limitations. It was a single center trial limited to 3 affiliated hospitals and 5 different implanting physicians. However, the clinical demographics of patients enrolled in STARTER were very similar to those enrolled in other large, randomized CRT trials. Still, the results of this study may need to be replicated in a multi-center setting. Although the number of patients enrolled in STARTER was relatively small, this study was powered to detect differences by treatment strategy in the primary endpoint of death or first HF hospitalization as well as in a number of pre-specified secondary endpoints. Furthermore, the consistency between our results and those of the TARGET trial support the validity of these findings. The number of patients included in the follow-up echocardiographic analyses represents about 2/3 of the randomized patients. This is primarily driven by the fact that patients who had events prior to their follow-up echocardiogram could not be included in these analyses, although clinical outcomes were available. There are technical limitations to speckle tracking echocardiography, which requires adequate image quality for off-line analysis. Our laboratory which is experienced in this method, had intraobserver and interobserver variability averaging <10% for time to peak strain measurements, although no test-retest variability was performed in this study. The TARGET study further supports that this method may be utilized successfully by others. Another limitation is that we did not prospectively evaluate and exclude regional scar for LV lead placement. The incremental value of avoiding scar in addition to targeting the site of latest LV mechanical activation is worthy of future study.

In conclusion, we found that a strategy of echocardiographic guidance to LV lead placement was superior to a routine approach in CRT device implantation in patients with LV
dysfunction and mild, moderate, or severe heart failure symptoms for the primary endpoint of death or heart failure hospitalization. The strategy of echocardiographic guidance was also associated with improved echocardiographic response to CRT. This approach has practical implications for improving patient care for CRT recipients.

Sources of Funding

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Disclosures

Dr. Saba receives research grant support from Medtronic, Boston Scientific and St. Jude Medical; Dr. Schwartzman receives research grant support from Medtronic and Boston Scientific; Dr. Jain receives research grant support from Medtronic; Dr. Adelstein receives research grant support from St. Jude Medical; Dr. Gorcsan receives research grant support from Biotronik, GE, Toshiba, Medtronic, and St. Jude Medical; All other authors have no conflict of interest disclosures.

References


Table 1. Baseline Characteristics of Patient Population by Treatment Assignment

<table>
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<tr>
<th>Characteristic</th>
<th>Echocardiographic-Guided CRT N=110</th>
<th>Routine Control CRT N=77</th>
<th>P-Value</th>
</tr>
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<tbody>
<tr>
<td>Age (years)</td>
<td>66±11</td>
<td>67±13</td>
<td>0.61</td>
</tr>
<tr>
<td>Male Gender (%)</td>
<td>70%</td>
<td>78%</td>
<td>0.29</td>
</tr>
<tr>
<td>NYHA HF Class II/III/IV (%)</td>
<td>16/64/20 (%)</td>
<td>8/71/21 (%)</td>
<td>0.21</td>
</tr>
<tr>
<td>Ischemic Heart Disease (%)</td>
<td>58%</td>
<td>67%</td>
<td>0.27</td>
</tr>
<tr>
<td>Diabetes Mellitus (%)</td>
<td>37%</td>
<td>36%</td>
<td>0.98</td>
</tr>
<tr>
<td>LVEF</td>
<td>26±6</td>
<td>26±7</td>
<td>0.80</td>
</tr>
<tr>
<td>LVESV (ml)</td>
<td>140±59</td>
<td>144±63</td>
<td>0.57</td>
</tr>
<tr>
<td>LVEDV (ml)</td>
<td>186±68</td>
<td>192±73</td>
<td>0.73</td>
</tr>
<tr>
<td>QRS duration (ms)</td>
<td>157±27</td>
<td>162±27</td>
<td>0.27</td>
</tr>
<tr>
<td>RV pacing (%)</td>
<td>20%</td>
<td>23%</td>
<td>0.77</td>
</tr>
<tr>
<td>Atrial Arrhythmias (%)</td>
<td>25%</td>
<td>27%</td>
<td>0.89</td>
</tr>
<tr>
<td>Serum Creatinine (mg/dL)</td>
<td>1.2±0.4</td>
<td>1.3±0.6</td>
<td>0.20</td>
</tr>
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NYHA = New York Heart Association class of heart failure; LVEF = left ventricular ejection fraction; LVESV = left ventricular end-systolic volume; LVEDV = left ventricular end-Diastolic volume
Table 2. Left ventricular Lead Location by Fluoroscopy and Relationship to site of Latest Mechanical Activation

<table>
<thead>
<tr>
<th></th>
<th>Echocardiographic-Guided CRT (n=96)</th>
<th>Routine Control CRT (n=69)</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distribution of LV Lead Location</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAO Projection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Anterolateral</td>
<td>17%</td>
<td>15%</td>
<td>0.867</td>
</tr>
<tr>
<td>o Lateral</td>
<td>40%</td>
<td>46%</td>
<td></td>
</tr>
<tr>
<td>o Posterolateral</td>
<td>36%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>o Posterior</td>
<td>7%</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>RAO Projection</td>
<td></td>
<td></td>
<td>0.114</td>
</tr>
<tr>
<td>o Basal</td>
<td>39%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>o Mid Ventricular</td>
<td>39%</td>
<td>43%</td>
<td></td>
</tr>
<tr>
<td>o Apical</td>
<td>23%</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td><strong>Relationship of LV Lead Location to Site of Latest Mechanical Activation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exact Concordance</td>
<td>30%</td>
<td>12%</td>
<td>0.011</td>
</tr>
<tr>
<td>Concordant or Adjacent</td>
<td>85%</td>
<td>66%</td>
<td>0.010</td>
</tr>
<tr>
<td>Remote</td>
<td>15%</td>
<td>33%</td>
<td>0.010</td>
</tr>
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LAO = left anterior oblique; RAO = right anterior oblique; LV = left ventricle
Table 3. Volumes, Ejection Fractions, and Response Rates after CRT

<table>
<thead>
<tr>
<th></th>
<th>Echo Guided (n=73)</th>
<th>Routine (n=48)</th>
<th>Concordant or Adjacent Lead (n=85)</th>
<th>Remote Lead (n=23)</th>
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<tr>
<td>Relative Change in ESV (%)</td>
<td>-30±29*</td>
<td>-20±25</td>
<td>-30±26#</td>
<td>-11±32</td>
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<tr>
<td>Absolute Change in EF (%)</td>
<td>12±11</td>
<td>9±10</td>
<td>13±11#</td>
<td>6±10</td>
</tr>
<tr>
<td></td>
<td>Echo Guided (n=87)</td>
<td>Routine (n=62)</td>
<td>Concordant or Adjacent Lead (n=101)</td>
<td>Remote Lead (n=31)</td>
</tr>
<tr>
<td>ESV Decrease &gt; 15% and No Primary Event</td>
<td>57%*</td>
<td>35%</td>
<td>54%#</td>
<td>26%</td>
</tr>
<tr>
<td>EF Increase &gt; 5% and No Primary Event</td>
<td>59%*</td>
<td>39%</td>
<td>57%#</td>
<td>26%</td>
</tr>
</tbody>
</table>

(*) p<0.05 vs. Routine; (＃) p<0.05 vs. Remote; CRT = cardiac resynchronization therapy; ESV = end-systolic volume, EF = ejection fraction.
Figure Legends

Figure 1. A. Top Panels: Short-axis echocardiographic speckle tracking images at basal and mid left ventricular (LV) levels with six color-coded time-strain curves per image to the left. Site of latest mechanical activation (arrows right top panel) was determined to be basal lateral (left top panel). B. Bottom Panels: Segmentation of mid-LV short axis view on left for co-registration with coronary venous anatomy from the left anterior oblique projection on right. A clock-face analogy with the great cardiac vein at 12 o’clock and the middle cardiac vein at 6 o’clock. The LV free wall was divided into four segments according to coronary venous anatomy (with corresponding speckle tracking software labels listed first): Anterior = Anterolateral, Lateral = Lateral, Posterior = Posterolateral, and Inferior = Posterior. Also, LV length was divided into thirds from the right anterior oblique fluoroscopic projection. LV = left ventricle, RV = right ventricle

Figure 2. Kaplan-Meier plots of the results of the primary end point of freedom from heart failure hospitalization or death after cardiac resynchronization therapy (CRT) including all randomized patients with intention to treat analysis. Patients randomized to echocardiographic guided left ventricular (LV) lead positioning strategy had a significantly more favorable clinical outcome in comparison to routinely treated patients.

Figure 3. Kaplan-Meier plots of clinical outcome results after cardiac resynchronization therapy (CRT) in patients with left ventricular (LV) leads concordant or adjacent to the segment of latest mechanical activation by speckle tracking echo versus remote LV lead location. Patients with concordant or adjacent LV leads had a significantly improved survival free from heart failure
hospitalization or death (top panel) as well as free from death, heart transplant, or left ventricular assist device (bottom panel).

**Figure 4.** Representative images from two patients in this study before and after cardiac resynchronization therapy (CRT). Patient **A** (top panels) had a significant septal to posterior wall strain delay by speckle tracking echocardiography that resynchronized after CRT with a concordant left ventricular (LV) lead position. Patient **B** (middle panels) had significant dyssynchrony that failed to resynchronize after CRT with a remote LV lead position. **C.** A Kaplan-Meier plots of clinical outcomes after CRT in patients who were resynchronized compared to patients who were not resynchronized. Resynchronization was defined as having dyssynchrony at baseline (>95 ms anterior to septal radial strain delay) and a >50% reduction in dyssynchrony after CRT. Resynchronized patients had a significantly survival free from heart failure hospitalization or death.
LV Lead Positioning

Echo Guided*

Routine

Freedom From Heart Failure
Hospitalization or Death

% 100

n = 187
all patients

Time (years) after CRT

Echo Guided 110
92 83 68 56

Routine 77
52 48 39 32

*p = 0.006
Echocardiography-Guided Left Ventricular Lead Placement for Cardiac Resynchronization Therapy: Results of the Speckle Tracking Assisted Resynchronization Therapy for Electrode Region (STARTER) Trial
Samir Saba, Josef Marek, David Schwartzman, Sandeep Jain, Evan Adelstein, Pamela White, Olusegun A. Oyenuga, Tetsuari Onishi, Prem Soman and John Gorcsan III

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