Impact of QRS Duration on Clinical Event Reduction With Cardiac Resynchronization Therapy

Ilke Sipahi, MD; Thomas P. Carrigan, MD; Douglas Y. Rowland, PhD; Bruce S. Stambler, MD; James C. Fang, MD

Background: Cardiac resynchronization therapy (CRT) is effective in reducing clinical events in patients with heart failure and prolonged QRS interval. Studies using surrogate measures and subgroup analysis of large trials suggest that only patients with severely prolonged QRS benefit from CRT. Our objective was to determine whether the effect of CRT on adverse clinical events (e.g., death, hospitalizations) is different in patients with moderately (i.e., 120-149 milliseconds) vs severely (i.e., ≥150 milliseconds) prolonged QRS duration.

Methods: Searches of MEDLINE, SCOPUS, and Cochrane databases were conducted for randomized controlled CRT trials. Trials reporting clinical events according to different QRS ranges were identified. Five randomized trials fulfilling the inclusion criteria (total patients, n=5813) were included in the meta-analysis.

Results: In patients with severely prolonged QRS, there was a reduction in composite clinical events with CRT (risk ratio, 0.60; 95% confidence interval [CI], 0.53-0.67) (P<.001). In contrast, there was no benefit of CRT in patients with moderately prolonged QRS (RR, 0.95; 95% CI, 0.82-1.10) (P=.49), resulting in a significantly different impact of CRT in the 2 QRS groups (P<.001). There was a significant relationship between baseline QRS duration and risk ratio (P<.001) with benefit of CRT appearing at a QRS of approximately 150 milliseconds and above. The differential response of the 2 QRS groups was evident for all New York Heart Association classes.

Conclusions: Cardiac resynchronization therapy was effective in reducing adverse clinical events in patients with heart failure and a baseline QRS interval of 150 milliseconds or greater, but CRT did not reduce events in patients with a QRS of less than 150 milliseconds. These findings have implications for the selection of patients for CRT.

recognized that one-third to one-half of patients receiving CRT based on the guidelines did not respond to this treatment. The recommendation for the QRS cutoff of 120 milliseconds or greater for implantation of CRT devices was based on the entry criteria of 2 major trials. Recently, the HFSA and ESC guidelines for management of heart failure were revised in response to the MADIT-CRT trial. These new guidelines introduced a new recommendation for CRT in NYHA 1 and/or NYHA 2 systolic heart failure, but this time with a new QRS cutoff of greater than 150 milliseconds for this population. The new cutoff was based on the subgroup analysis of the MADIT-CRT trial, in which patients with a QRS interval shorter than 150 milliseconds had no reduction in heart failure events with CRT. These updated guidelines continued to recommend CRT for patients with NYHA 3 and 4 heart failure with the old QRS cutoff of 120 milliseconds or greater. However, studies using surrogate measures of response (ie, hemodynamics or peak oxygen consumption) suggest that patients with a QRS duration between 120 and 150 milliseconds do not benefit from CRT, regardless of their NYHA functional class. In this context, to our knowledge, the impact of the degree of QRS prolongation on the effect of CRT for reducing adverse clinical events (ie, death and hospitalization) has never been analyzed systematically. Therefore, our objective was to determine whether the impact of CRT on clinical end points is affected by the degree of baseline QRS prolongation by performing a meta-analysis of randomized trials testing CRT in heart failure.

METHODS

LITERATURE SEARCH

Systematic searches were made of MEDLINE, SCOPUS (covering EMBASE), Cochrane Central Register of Controlled Trials, and Cochrane Database of Systematic Reviews databases to retrieve all published randomized controlled trials of CRT that reported clinical events according to baseline QRS duration. The search terms and other search strategies are described in detail for each database in eAppendix. The results of the literature search are depicted in Figure 1.

STUDY SELECTION

To evaluate the efficacy of CRT in relation to QRS duration, we included trials that reported clinical outcomes of subgroups stratified by QRS duration. Studies were excluded if they (1) were not randomized; (2) did not have a non-CRT control group; (3) enabled implantable cardioverter defibrillator (ICD) implantation only in one study arm and not in the other(s) (trials enabling ICD implantation in both arms were eligible); (4) had cross-over study design; (5) did not report the clinical outcomes of interest such as death and hospitalization; and/or (6) reported clinical outcomes without any relation to specific limited QRS ranges.

DATA EXTRACTION

Data from studies meeting the selection criteria were extracted and verified independently by 2 investigators (I.S. and T.P.C.). In cases where the point estimates and the confidence intervals (CIs) for subgroups were not specifically stated, forest plots were used, if available, to extract this information using electronic calculators. Among the included trials, there were slight differences in the cutoffs used for QRS subgroup reporting. In an attempt to standardize the cutoff, we contacted the corresponding authors of the trials that did not report QRS subgroups with the exact 150-millisecond cutoff (ie, COMPANION reporting with 147 milliseconds, REVERSE with 152 milliseconds, and CARE-HF with 159 milliseconds) and asked for the effect sizes with the 150-millisecond cutoff. However, this information was not provided for any of these trials. Thus, we defined the subgroup with a QRS duration of less than 150 milliseconds in most cases as moderately prolonged and those with a QRS duration of greater than 150 milliseconds as severely prolonged. One trial reported 3 subgroups; the “middle” subgroup of this trial (148-168 milliseconds) was included among our severely prolonged QRS subgroups, since the QRS duration was greater than 150 milliseconds for most patients in the subgroup.

STATISTICAL ANALYSIS

We generated funnel plots according to different QRS subgroups to examine the possibility of publication bias. We supplemented testing for publication bias with the Begg Rank Correlation test. Four of the included trials reported hazard ratios (HRs), and 1 trial reported odds ratios (ORs). The values for ORs are similar to those for HRs (ie, instantaneous risk ratio [RR]) when the outcome is uncommon. Given that the outcome in the trial that reported ORs was less than 20%, we were able to combine

Figure 1. Flowchart of cardiac resynchronization therapy (CRT) trials included in the meta-analysis. Web-only material includes an eTable, eAppendix, and eFigure. CARE-HF indicates Cardiac Resynchronization-Heart Failure; COMPANION, Comparison of Medical Therapy, Pacing, and Defibrillation in Heart Failure; CRT, cardiac resynchronization therapy; MADIT-CRT, Multicenter Automatic Defibrillator Implantation Trial–Cardiac Resynchronization Therapy; RAFT, Resynchronization-Defibrillation for Ambulatory Heart Failure Trial; REVERSE, Resynchronization Reverses Remodeling in Systolic Left Ventricular Dysfunction.

©2011 American Medical Association. All rights reserved.
the ORs from this trial with the HRs from the other trials to obtain a meta-analytic RR.23
Statistical heterogeneity was tested by the Cochran Q statistic and reported as I2. Fixed-effect models were used, unless there was evidence of heterogeneity (ie, I2 > 40%) where random-effects models were used. The difference in the meta-analytic effect size in patients with severely vs moderately prolonged QRS intervals was assessed with heterogeneity analysis. A meta-regression analysis was performed to examine the relationship between the QRS duration (ranked according to the degree prolongation among all subgroups) and log-transformed RR. Statistical tests were considered significant if the 2-sided P value was less than .05. Data were analyzed using Comprehensive Meta Analysis software, version 2.2.048 (Biostat Inc, Englewood, New Jersey).

**RESULTS**

The results of the literature search are shown in Figure 1. Of the 412 results, 70 reports without the exclusion criteria were then subjected to a detailed investigation looking for the parameters of interest (ie, reporting of clinical events according to specific baseline QRS ranges). Accordingly, a total of 5 randomized controlled trials enrolling a total of 5813 patients were included in the meta-analysis.

**STUDY CHARACTERISTICS**

The characteristics of the included trials are summarized in Table 1. The COMPANION trial had 3 arms (medical therapy vs CRT only vs CRT-ICD). Data from the medical therapy vs CRT only arms are included in this analysis. In REVERSE, all patients received a CRT device, but the left ventricular lead was turned off in the control arms. The COMPANION trial had 3 arms (CRT, combined CRT and implantable cardioverter defibrillator, and medical therapy). For the purpose of this meta-analysis, only the CRT and the medical therapy arms were included.

The RAFT trial also included 135 patients with baseline right ventricular pacing with a QRS interval of 200 milliseconds or greater, not included in this analysis.

---

**Table 1. Characteristics of Randomized Controlled Trials of Cardiac Resynchronization Therapy That Were Included in the Meta-analysis**

<table>
<thead>
<tr>
<th>Trial (Sponsor)</th>
<th>NYHA Class</th>
<th>EF, %</th>
<th>QRS Duration, ms</th>
<th>Study Intervention</th>
<th>Control</th>
<th>Average Follow-up, mo</th>
<th>Subgroups by QRS Duration, ms</th>
<th>Composite End Point Reported for QRS Subgroup Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPANION (Guidant)</td>
<td>3 or 4</td>
<td>=35</td>
<td>≥120</td>
<td>CRT (n=617)</td>
<td>Medical therapy (n=308)</td>
<td>16.2 (CRT) and 11.9 (medical therapy)</td>
<td>120-147 (n=324)</td>
<td>All-cause mortality or hospitalization</td>
</tr>
<tr>
<td>CARE-HF (Medtronic)</td>
<td>3 or 4</td>
<td>=35</td>
<td>≥120</td>
<td>CRT (n=409)</td>
<td>Medical therapy (n=404)</td>
<td>29.4</td>
<td>120-159 (n=290)</td>
<td>All-cause mortality or hospitalization for major cardiovascular event including heart-failure hospitalization</td>
</tr>
<tr>
<td>CARE-HF (Medtronic)</td>
<td>1 or 2</td>
<td>=40</td>
<td>≥120</td>
<td>CRT on (n=419)</td>
<td>CRT off (n=191)</td>
<td>12</td>
<td>120-151 (n=303)</td>
<td>All-cause mortality or heart-failure hospitalization or worsened heart failure resulting in cross-over or dropout or worsened NYHA class or moderately or markedly worsened heart-failure symptoms</td>
</tr>
<tr>
<td>MADIT-CRT (Boston Scientific)</td>
<td>1 or 2</td>
<td>=30</td>
<td>≥130</td>
<td>CRT (n=1089)</td>
<td>Medical therapy (n=721)</td>
<td>28.8</td>
<td>130-149 (n=645)</td>
<td>All-cause mortality or heart-failure event (heart-failure hospitalization or outpatient intravenous diuretic therapy)</td>
</tr>
<tr>
<td>RAFT (Canadian Institutes of Health Research, Medtronic)</td>
<td>2 or 3</td>
<td>≥30</td>
<td>≥120</td>
<td>CRT (n=894)</td>
<td>No CRT (n=904)</td>
<td>40</td>
<td>120-149 (n=627)</td>
<td>All-cause mortality or heart-failure hospitalization</td>
</tr>
</tbody>
</table>

Abbreviations: CARE-HF, Cardiac Resynchronization-Heart Failure; COMPANION indicates Comparison of Medical Therapy, Pacing, and Defibrillation in Heart Failure; CRT, cardiac resynchronization therapy; EF, ejection fraction; MADIT-CRT, Multicenter Automatic Defibrillator Implantation Trial–Cardiac Resynchronization Therapy; NYHA, New York Heart Association; RAFT, Resynchronization-Defibrillation for Ambulatory Heart Failure Trial; REVERSE, Resynchronization Reverses Remodeling in Systolic Left Ventricular Dysfunction.

---
Table 2. Characteristics of Patients Enrolled in Randomized Controlled Trials of CRT Included in the Meta-analysis

<table>
<thead>
<tr>
<th>Source</th>
<th>Patient Age, Mean or Median, y</th>
<th>Male</th>
<th>Nonischemic Heart Failure</th>
<th>Diabetes</th>
<th>Mean or Median Baseline EF, %</th>
<th>Conduction Anomaly</th>
<th>Mean or Median QRS Duration at Baseline, ms</th>
<th>Treatment at Baseline</th>
<th>ACE Inhibitor or Angiotensin Receptor Blocker</th>
<th>β-Blocker</th>
<th>Spironolactone</th>
<th>CRT Device Implantation During Trials</th>
<th>Control Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPANION</td>
<td>67</td>
<td>66</td>
<td>44</td>
<td>41</td>
<td>21</td>
<td>69</td>
<td>11.0</td>
<td>LBBB</td>
<td>89</td>
<td>67</td>
<td>54</td>
<td>0.20</td>
<td>0.67</td>
</tr>
<tr>
<td>CARE-HF</td>
<td>67</td>
<td>73</td>
<td>62</td>
<td>41</td>
<td>25</td>
<td>90</td>
<td>5.0</td>
<td>RBBB</td>
<td>95</td>
<td>72</td>
<td>56</td>
<td>2.0</td>
<td>5.7</td>
</tr>
<tr>
<td>REVERSE</td>
<td>63</td>
<td>79</td>
<td>46</td>
<td>23</td>
<td>27</td>
<td>NA</td>
<td>153</td>
<td>NA</td>
<td>96</td>
<td>95</td>
<td>NA</td>
<td>82</td>
<td>85</td>
</tr>
<tr>
<td>MADIT-CRT</td>
<td>65</td>
<td>75</td>
<td>45</td>
<td>30</td>
<td>24</td>
<td>70</td>
<td>13.0</td>
<td>NA</td>
<td>98</td>
<td>93</td>
<td>33</td>
<td>99</td>
<td>97.4</td>
</tr>
<tr>
<td>RAFT</td>
<td>66</td>
<td>83</td>
<td>33</td>
<td>34</td>
<td>23</td>
<td>72</td>
<td>9.0</td>
<td>158</td>
<td>97</td>
<td>90</td>
<td>42</td>
<td>99</td>
<td>99</td>
</tr>
</tbody>
</table>

Abbreviations: ACE, angiotensin-converting enzyme; CARE-HF, Cardiac Resynchronization-Heart Failure; COMPANION indicates Comparison of Medical Therapy, Pacing, and Defibrillation in Heart Failure; CRT, cardiac resynchronization therapy; EF, ejection fraction; ICD, implantable cardioverter defibrillator; LBBB, left bundle branch block; MADIT-CRT, Multicenter Automatic Defibrillator Implantation Trial–Cardiac Resynchronization Therapy; NA, not available; NYHA, New York Heart Association; RAFT, Resynchronization-Defibrillation for Ambulatory Heart Failure Trial; RBBB, right bundle branch block; REVERSE, Resynchronization Reverses Remodeling in Systolic Left Ventricular Dysfunction.

All 5 trials were analyzed using intention-to-treat principle. In COMPANION, prior to reaching the primary end point, 13% of patients in the medical therapy group withdrew, and 2% in the CRT group (without ICD) withdrew. In REVERSE, 7.3% of patients crossed over from CRT off to CRT on, and 1.4% patients crossed over from CRT on to CRT off at 12 months. In MADIT-CRT, 1.1% did not receive a device in the CRT-ICD arm, and 2.6% did not receive a device in the ICD only arm. In this trial, 12.4% of patients assigned to ICD only were switched to a CRT-ICD device before study end, whereas in the CRT group, 7.5% of patients crossed over to ICD only. In RAFT, 4% of patients crossed over and received CRT in addition to an ICD, and in the CRT-ICD group, 6.0% did not receive CRT. In this trial, 0.6% and 1.1% either withdrew or were lost to follow-up in the ICD and CRT-ICD arms, respectively. Dropout or cross-over rates were not presented in the CARE-HF trial.

The baseline characteristics of patients enrolled in the trials are listed in Table 2. Within each arm of the included trials, there were no statistically significant differences with regard to age, sex, ejection fraction, functional class, QRS duration, or medication use.

No evidence of publication bias was detected with the Begg Rank Correlation method (P > .50). Funnel plots examining publication bias according to the QRS groups are presented in the eFigure.

QUANTITATIVE FINDINGS

The impact of CRT on clinical events in patients with severely prolonged QRS is shown in Figure 2. For these patients, there was a statistically significant reduction in risk for composite clinical events in each individual trial with the exception of the middle QRS subgroup of COMPANION (ie, the subgroup with the least severely prolonged QRS among the subgroups with severely prolonged QRS), where there was a statistically insignificant benefit (P = .09). On meta-analysis, patients with severely prolonged QRS randomized to CRT had a 40% risk reduction in clinical events (P = .32.1; RR, 0.60 [95% CI, 0.53-0.67]) (P < .001 by fixed-effect model). On the contrary, there was no statistically significant benefit for patients with moderately prolonged QRS in any of the individual trials...
Figure 3. There was a statistically insignificant benefit in the CARE-HF trial, which had the most prolonged QRS interval within the moderately prolonged QRS subgroups (P = .06). On meta-analysis, there was no significant benefit of CRT for reduction in clinical events in this group of patients (P = .06; RR, 0.95 [95% CI, 0.82-1.10]) (P = .49 by fixed-effects model). When directly compared with heterogeneity analysis, the overall effect of CRT on clinical events was significantly different in patients with moderately vs severely prolonged QRS intervals (P < .001).

The relationship between the magnitude of QRS prolongation and the impact of CRT on the risk of composite clinical events assessed by meta-regression analysis is pre-
The findings of the meta-analysis remained robust to sensitivity analysis (Table 3). When the analysis was limited to NYHA 3 and 4 cases (COMPANION\textsuperscript{16} and CARE-HF\textsuperscript{17}), there was still a high significant benefit of CRT in patients with severely prolonged QRS and no statistically significant benefit in patients with moderately prolonged QRS. The same was observed in NYHA 1 and 2 cases. Similarly, when the analysis was limited to trials with nearly universal use of ICDs in both arms of trials, statistically significant benefit with CRT was seen only in patients with severely prolonged QRS and not in those with moderately prolonged QRS. When the analysis was limited to trials without background ICD therapy, again the benefit of CRT was observed only in the patients with severely prolonged QRS. In each sensitivity analysis performed using the 1-study-out method, there remained a significant difference in the impact of CRT on clinical events according to degree of QRS prolongation. When analysis was limited to trials uniformly reporting HRs (ie, when REVERSE\textsuperscript{23} was left out), there was again benefit in patients with severely prolonged QRS and not in patients with moderately prolonged QRS.

### Table 3. Sensitivity Analyses

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$I^2$, %</th>
<th>Model</th>
<th>Risk Ratio (95% CI)</th>
<th>$P$ Value</th>
<th>$P$ Value, Moderately vs Severely Prolonged QRS Subgroups</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYHA 3 and 4 only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.06</td>
</tr>
<tr>
<td>Severe prolonged QRS (n=1106)</td>
<td>0</td>
<td>Fixed effect</td>
<td>0.67 (0.57-0.80)</td>
<td>&lt;.001</td>
<td>.06</td>
</tr>
<tr>
<td>Moderately prolonged QRS (n=614)</td>
<td>50.6</td>
<td>Random effects</td>
<td>0.87 (0.64-1.18)</td>
<td>.38</td>
<td>.001</td>
</tr>
<tr>
<td>NYHA 1 and 2 only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>Severe prolonged QRS (n=1482)</td>
<td>0</td>
<td>Fixed effect</td>
<td>0.47 (0.37-0.60)</td>
<td>&lt;.001</td>
<td>.001</td>
</tr>
<tr>
<td>Moderately prolonged QRS (n=948)</td>
<td>0</td>
<td>Fixed effect</td>
<td>1.06 (0.78-1.44)</td>
<td>.72</td>
<td>.001</td>
</tr>
<tr>
<td>With background ICD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>Severe prolonged QRS (n=2518)</td>
<td>0.2</td>
<td>Fixed effect</td>
<td>0.54 (0.46-0.63)</td>
<td>&lt;.001</td>
<td>.001</td>
</tr>
<tr>
<td>Moderately prolonged QRS (n=1575)</td>
<td>0</td>
<td>Fixed effect</td>
<td>1.02 (0.84-1.23)</td>
<td>.87</td>
<td>.001</td>
</tr>
<tr>
<td>No Background ICD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.06</td>
</tr>
<tr>
<td>Severe prolonged QRS (n=1106)</td>
<td>0</td>
<td>Fixed effect</td>
<td>0.67 (0.57-0.80)</td>
<td>&lt;.001</td>
<td>.001</td>
</tr>
<tr>
<td>Moderately prolonged QRS (n=614)</td>
<td>50.6</td>
<td>Random effects</td>
<td>0.87 (0.64-1.18)</td>
<td>.38</td>
<td>.001</td>
</tr>
</tbody>
</table>

One Study Out

| Abbreviations: CARE-HF, Cardiac Resynchronization-Heart Failure\textsuperscript{17}; CI, confidence interval; COMPANION, Comparison of Medical Therapy, PACing, and Defibrillation In Heart Failure\textsuperscript{16}; ICD, implantable cardiac defibrillator; MADIT-CRT, Multicenter Automatic Defibrillator Implantation Trial–Cardiac Resynchronization Therapy\textsuperscript{20}; NYHA, New York Heart Association; RAFT, Resynchronization-Defibrillation for Ambulatory Heart Failure Trial\textsuperscript{22}; REVERSE, Resynchronization Reverses Remodeling in Systolic Left Ventricular Dysfunction.\textsuperscript{23} |

**COMMENT**

This meta-analysis shows that while CRT was very effective in reducing adverse clinical events in patients with systolic heart failure and a baseline QRS duration of 150 milliseconds or greater, it did not reduce such events in patients with a QRS interval less than 150 milliseconds. The difference in benefit between the 2 QRS groups was statistically significant ($P < .001$). These results were consistent among all the randomized trials included in this meta-analysis, regardless of enrollment criteria for functional class.

The lack of benefit of CRT in patients with QRS durations less than 150 milliseconds has been observed in several hemodynamic and echocardiographic studies, as well as in studies using cardiometabolic stress tests and quality of life measures. Auricchio et al\textsuperscript{3} observed that...
when the QRS duration was less than 150 milliseconds, biventricular pacing did not improve either the maximum left ventricular pressure derivative or aortic pulse pressure, whereas those with longer QRS intervals had increases in both.\(^{1}\) In a more recent randomized study, Auricchio et al\(^{22}\) also showed that peak oxygen consumption as assessed by cardiometabolic stress test did not improve with left ventricular pacing in patients with a QRS duration between 120 and 150 milliseconds. In contrast, both parameters improved significantly in patients with QRS intervals greater than 150 milliseconds. Similarly, distance walked in 6 minutes and quality-of-life score improved only in patients with QRS intervals greater than 150 milliseconds. REVERSE study investigators\(^{26}\) showed that there was no significant reverse remodeling with CRT in patients with moderately prolonged QRS, contrasting with the remarkable reverse remodeling in those with longer QRS durations. Our meta-analysis extends these previous observations of lack of benefit on surrogate measures in patients with QRS interval less than 150 milliseconds to the lack of reduction in clinical events, including death and hospitalizations in such patients, in the setting of randomized controlled clinical trials. On the other hand, it was observed that there was a trend for benefit in the moderately prolonged QRS subgroup (ie, 120-159 milliseconds) in the CARE-HF trial.\(^{17}\) In this context, it should be pointed out that CARE-HF mandated the presence of at least 2 predefined echocardiographic criteria for mechanical dyssynchrony if baseline QRS was between 120 and 149 milliseconds, unlike the other included trials. Of the 290 patients with QRS intervals between 120 and 159 milliseconds in this trial, only 92 of them had a QRS between 120 and 149 (32%), and the remaining 198 had a QRS of 150 milliseconds or greater (68%).\(^{27}\) Therefore, it is not completely clear whether this trend for benefit was driven by the patients with QRS durations between 150 and 159 milliseconds or by the use of echocardiographic criteria in patients with QRS between 120 and 149 milliseconds or both. One recent non-randomized study\(^{28}\) suggests that echocardiographic parameters of dyssynchrony (Yu index, radial strain) may help identify patients with moderately prolonged QRS who might respond to CRT.

The initial guidelines advising on the indication for CRT in heart failure were primarily directed by the two trials that reported significant reductions in clinical events in NYHA III and IV patients.\(^{7-10}\) These two trials used a QRS duration of $\geq 120$ milliseconds as the enrollment criterion. The writing committees subsequently endorsed the same cutoff of $\geq 120$ milliseconds in their guidelines with the strongest level of recommendation (ie, Class I; procedure should be performed).\(^{16,17}\) However this cutoff set forth in these trials appears to be arbitrary in that other clinical trials have used different QRS cutoffs such as 130 or 150 milliseconds.\(^{29-31}\) In contemporary practice, approximately 40% of CRT devices are implanted in patients with a QRS duration $<150$ milliseconds.\(^{32}\) Soon after CRT was approved as a treatment for heart failure, it was recognized that one-third to one-half of patients do not respond to these devices implanted according to the current indications.\(^{33,34}\) This has led to intense research examining the reasons for non-response and led to the creation of special “non-responder clinics” in some institutions.\(^{35}\) Predicting response to CRT is complex and is related to both substrate and procedural factors. Sweeney, et al. recently demonstrated that the probability of LV reverse remodeling is linearly related to baseline left ventricular activation time and is $<50\%$ with a left ventricular activation time $<90$ milliseconds (corresponding to a QRS duration of approximately $<150$ milliseconds according to their regression formula).\(^{34}\) The current meta-analysis of randomized controlled clinical trials that assessed clinical endpoints, along with the previous studies using surrogate outcomes, suggest that a predominant reason for CRT non-response is a suboptimal patient selection criterion for QRS duration.

Very recently treatment guidelines advising on CRT were updated primarily to incorporate the findings of the MADIT-CRT trial and extended the indication for CRT to NYHA I and/or II patients.\(^{18,19}\) For these patients a new QRS cutoff of $\geq 150$ milliseconds was advised given the subgroup analysis of the MADIT-CRT trial showing lack of benefit with a QRS $<150$ milliseconds. However, these guidelines continued to recommend a QRS cutoff of 120 milliseconds for NYHA III and IV patients. Our meta-analysis shows that the lack of benefit in patients with QRS $<150$ milliseconds is a more pervasive phenomenon and is not limited to only NYHA I and II patients but is also observed in NYHA III and IV patients. It appears that the degree of QRS prolongation is more important than the level of functional impairment for selection of patients for CRT. Modification of the current guidelines that reflect these findings can have important consequences for resource utilization. We think that an individual patient level analysis of existing clinical trials to examine whether a subset of patients with moderately prolonged QRS might benefit from CRT (perhaps offset by another subset with increased risk resulting in a net neutral effect in the moderately prolonged QRS group) will be helpful to further specify the new recommendations.

**STUDY LIMITATIONS**

Not all randomized CRT trials reported clinical events according to different QRS subgroups, and these trials could not be included in this meta-analysis. However, all the long-term and large-scale trials could be included. For example, the meta-analysis could incorporate QRS-specific data for more than 85% of the total number of deaths recorded in all the randomized CRT trials reporting on this outcome.\(^{35}\) Therefore, publication bias with regard to reporting according to QRS ranges is highly unlikely to account for the observed differences.

The composite outcome varied across the included trials. However, despite the differences in the inclusion of other events besides all-cause mortality and heart failure hospitalization to the composite outcome, the RR was always lower in the severely prolonged QRS group of all the trials, and there was no statistically significant reduction in any of the composite outcomes in the moderately prolonged QRS subgroup of any trial.
The exactitude of the 150-millisecond cutoff observed in the current analysis for predicting clinical benefit with CRT is likely to be imperfect for the individual patient. Because we did not have access to individual-level patient data, we used the ranges of QRS durations reported in the publications of clinical trials to determine a cutoff. With this approach, an approximate value of 150 milliseconds emerged as a cutoff, below which clinical events were not reduced by CRT. In this context, Varma has recently shown that despite similar QRS durations, patients with left bundle branch block have left ventricular activation times that are on average 36 milliseconds longer than patients with right bundle branch block. Consequently, the QRS duration above which CRT will be beneficial is probably significantly different with different types of conduction abnormalities. Therefore, we believe that a meta-analysis of individual patient-level data of all relevant clinical trials can further refine the QRS cutoffs for different types of conduction abnormalities.

When performing this meta-analysis, we were faced with the problem of dealing with 2 different types of association measures (ie, HR and OR) reported in different trials. We believed that including only the 4 trials that reported HRs and excluding REVERSE reporting ORs would introduce bias and would be less robust. Given the similarities of the 2 measures in many situations, we combined these measures and reported the meta-analytic effect size as RR. We addressed this limitation using sensitivity analysis (where we excluded REVERSE), which revealed very similar results. It is noteworthy that the REVERSE trial also had a broad clinical end point, not only including mortality and heart failure hospitalization but also worsened heart failure symptoms or NYHA functional class.

CONCLUSIONS

While CRT was very effective in reducing clinical events in patients with systolic heart failure and a baseline QRS duration of 150 milliseconds or greater, it did not reduce such events in patients with QRS intervals less than 150 milliseconds. This finding was observed not only in trials that enrolled patients with NYHA 1 and 2 disease but also in those that enrolled patients with NYHA 3 and 4 disease. These results have implications regarding patient selection for this important treatment technique.

Accepted for Publication: April 4, 2011.
Correspondence: Ilke Sipahi, MD, Harrington-McLaughlin Heart & Vascular Institute, University Hospitals Case Medical Center, Case Western Reserve University School of Medicine, 11100 Euclid Ave, LKS 5038, Cleveland, OH 44106 (ilkesipahi@gmail.com).
Authors Contributions: Dr Sipahi had full access to all the data used in the study and takes responsibility for the integrity of the data and accuracy of the analysis. Study concept and design: Sipahi and Carrigan. Acquisition of data: Sipahi and Carrigan. Analysis and interpretation of data: Sipahi, Carrigan, Rowland, Stambler, and Fang. Drafting of the manuscript: Sipahi, Carrigan, and Rowland. Critical revision of the manuscript for important intellectual content: Sipahi, Carrigan, Rowland, Stambler, and Fang.
Statistical analysis: Sipahi and Rowland. Administrative, technical, and material support: Sipahi and Fang. Study supervision: Sipahi and Fang.
Financial Disclosure: Dr Stambler is a consultant and speaker for Boston Scientific, Biotronik, Medtronic, and St Jude Medical and serves on the advisory board and/or receives research grant support from these institutions.
Funding/Support: Medtronic supports the heart failure and transplantation fellowship program at University Hospitals Case Medical Center.
Online-Only Material: The eTable, eAppendix, and eFigure are available at http://www.archinternmed.com.

REFERENCES

10. Dickstein K, Cohen-Solal A, Filippatos G, et al; Task Force for Diagnosis and Treatment of Acute and Chronic Heart Failure 2008 of European Society of Cardiology; ESC Committee for Practice Guidelines. ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure 2008: the Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure 2008 of the European Society of Cardiology: developed in collaboration with the Heart Failure Association of the ESC (HFA) and endorsed by the European Society of Intensive Care Medicine (ESICM). Eur Heart J. 2008;29(19):2388-2442.


23. Linde C, Abraham WT, Gold MR, St John Sutton M, Ghio S, Daubert C; REVERSE (Resynchronization reVERses Remodeling in Systolic left vEntricular dys-
Correspondence: Dr O’Malley, Department of Medicine, Division of General Internal Medicine, Walter Reed Army Medical Center, 6900 Georgia Ave, Washington, DC 20307 (pomalley@usuhs.mil).

Financial Disclosure: None reported.

Disclaimer: The views expressed herein are those of the author only and are not to be construed as those of the Department of the Army or Department of Defense.

Additional Contributions: Mitchell Katz, MD, provided helpful edits and comments.

REFERENCES


Correction

Typographical Error in Abstract. In the “Background” section of the abstract of the Original Investigation “Impact of QRS Duration on Clinical Event Reduction With Cardiac Resynchronization Therapy: Meta-analysis of Randomized Controlled Trials” by Sipahi et al, published in the September 12, 2011, issue of the Archives (2011;171[16]:1454-1462) and published online June 13, 2011, the reported range for moderately prolonged QRS duration was incorrect. The correct range is 120 to 149 milliseconds.