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Effect of Smaller Left Ventricular Capture Threshold Safety Margins to Improve Device Longevity in Recipients of Cardiac Resynchronization-Defibrillation Therapy

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Abstract

Device longevity in cardiac resynchronization therapy (CRT) is affected by the pacing capture threshold (PCT) and programmed pacing amplitude of the left ventricular (LV) pacing lead. The aims of this study were to evaluate the stability of LV pacing thresholds in a nationwide sample of CRT defibrillator recipients and to determine potential longevity improvements associated with a decrease in the LV safety margin while maintaining effective delivery of CRT. CRT defibrillator patients in the Medtronic CareLink database were eligible for inclusion. LV PCT stability was evaluated using 2 measurements over a 14-day period. Separately, a random sample of 7,250 patients with programmed right atrial and right ventricular amplitudes 2.5 V, LV thresholds 2.5 V, and LV pacing 90% were evaluated to estimate theoretical battery longevity improvement using LV safety margins of 0.5 and 1.5 V. Threshold stability analysis in 43,256 patients demonstrated LV PCT stability of <0.5 V in 77% of patients and <1 V in 95%. Device longevity analysis showed that the use of a 0.5-V safety margin increased average battery longevity by 0.62 years (95% confidence interval 0.61 to 0.63) compared with a safety margin of 1.5 V. Patients with LV PCTs >1 V had the greatest increases in battery life (mean increase 0.86 years, 95% confidence interval 0.85 to 0.87). In conclusion, nearly all CRT defibrillator patients had LV PCT stability <1.0 V. Decreasing the LV safety margin from 1.5 to 0.5 V provided consistent delivery of CRT for most patients and significantly improved battery longevity.

Cardiac resynchronization therapy (CRT) generator replacement is a costly, invasive procedure with risks including infection, bleeding, and damage to previously implanted leads. Thus, strategies are needed to safely prolong battery life without sacrificing CRT effectiveness.^{1–3} In particular, selecting a pacing output safety margin that optimizes reliable left ventricular (LV) capture and maximizes battery longevity remains an unexplored opportunity for improving patient care. The goals of this study were (1) to define the

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stability of LV pacing thresholds in a representative, nationwide sample of CRT defibrillator (CRT-D) recipients and (2) to determine the potential improvement in battery longevity associated with a decrease in the LV safety margin while maintaining effective delivery of CRT.

Methods

The Medtronic CareLink database (Medtronic, Inc., Minneapolis, Minnesota) collects device-based information as part of the routine clinical care of patients with Medtronic pacemakers, implantable cardioverter defibrillators, and CRT-D systems. Patients with these devices can be followed through a remote monitoring system involving a home base station that collects device programming data and diagnostic information either by wireless telemetry or with a telemetry wand. Collected data are relayed to clinicians for use in routine clinical care and are also stored in the Medtronic CareLink database for research and quality control purposes. The Medtronic CareLink database contains devices implanted mainly in the United States. Enrollment in Medtronic CareLink is at the discretion of the treating physician.

Medtronic provides access to deidentified CareLink data as part of an investigator-initiated extramural research program for projects with sufficient scientific merit. The proposal for this study was approved by an internal review board at Medtronic and was reviewed by the Institutional Review Board at the Beth Israel Deaconess Medical Center.

All patients implanted with compatible Medtronic CRT-D models (Consulta) from March 2008 to December 2013 with data stored in the Medtronic CareLink database as of December 2013 were eligible for inclusion in this analysis. We extracted the most recent 14 days of LV thresholds, as measured by the LV Capture Management (LVCM) feature, for each patient. LVCM is a daily measure of threshold that uses LV-to-right ventricular (RV) conduction time to determine LV capture irrespective of lead position, type, or chronicity. Patients were excluded if they had <2 LVCM measurements in the previous 14 days or LV thresholds > 2.5 V. The minimum LV threshold was subtracted from the maximum LV threshold to derive LV threshold stability. We assessed stability in all patients and identified those with stability <0.5 V and <1 V during the 14-day period. A 2-week time period was selected on the basis of previous studies demonstrating that this time period is highly correlated with long-term stability.^{4,5}

Patients implanted with compatible Medtronic CRT-D models (Consulta and Protecta) from March 2008 to June 2013 with data stored in the Medtronic CareLink database as of June 2013 were eligible for inclusion in this analysis. From this group of patients, we selected a group of 7,250 patients using simple random sampling based on device number. We excluded any patients with programmed right atrial and RV amplitudes >2.5 V at the time of the most recent transmission, patients with LV thresholds >2.5 V, patients not programmed to CRT pacing, and patients with LV pacing <90% over their follow-up period. We also excluded patients with LV thresholds >2.5 V to focus on the group of patients most likely to benefit from a reduced LV threshold safety margin.

Theoretical 0.5- and 1.5-V safety margins were applied to each patient's most recent LV threshold from CareLink to generate 2 LV amplitude candidates (LVA and LVB) for each patient. Programmed lower rate, pacing mode, right atrial amplitude and pulse width, RV amplitude and pulse width, and LV pulse width, as well as percent atrial pacing, percent ventricular pacing, and right atrial, RV, and LV pacing impedance were also extracted from the Medtronic CareLink database for each patient. These parameter and measured values retrieved from CareLink, in combination with LVA and LVB, were then applied to the current drain and battery models for the current generation Medtronic Viva CRT-D devices to calculate device longevity for safety margins of 0.5 and 1.5 V. Calculations of device longevity assumed a sensing rate of the greater of 70 beats/min or 10 beats/min above the programmed lower rate and semiannual full-energy charges. Confidence intervals for longevity increases were calculated using the *t* distribution.

Results

There were 43,256 CRT-D patients with 2 LVCM measurements in the previous 14 days. We excluded 4,990 patients (12%) because of high LV thresholds (>2.5 V). Among the 38,266 remaining patients available for the LV threshold stability analysis, the mean LV threshold was 1.12 ± 0.52 V. LV pacing capture thresholds (PCTs) demonstrated stability of <0.5 V in 77% of patients and <1 V in 95% of patients (Figure 1).

We randomly selected 7,250 CRT-D patients from the total Medtronic CareLink database. We excluded 844 patients (12%) with LV thresholds >2.5 V, which yielded 6,406 eligible patients for inclusion in this analysis. Using a proprietary algorithm integrating model-specific data and current device settings, we calculated that the use of a 0.5-V LV safety margin increased device longevity by an average of 0.62 years (95% confidence interval 0.61 to 0.63) compared with an LV safety margin of 1.5 V. Patients with LV PCTs >1 V were calculated to have the greatest benefit, with an average longevity increase of 0.86 years (95% confidence interval 0.85 to 0.87 years) compared with an LV safety margin of 1.5 V (Figure 2).

Discussion

In this nationwide sample of CRT-D patients, overall LV PCTs were remarkably stable, and simulations of narrowing the programmed safety margin from 1.5 to 0.5 V demonstrated a significant increase in battery longevity with consistent delivery of CRT.

Previous investigations have demonstrated that for patients with LV thresholds ≥ 2.0 V, a safety margin of 1.0 V is sufficient to ensure LV capture,⁶ because LV threshold variability is modest, and automatic verification of LV capture can ensure 100% LV stimulation with a threshold safety margin of 0.5 V. This reduced safety margin can increase device lifetime by 25% as battery longevity is maximized when LV stimulation occurs below battery voltage.⁴

Our study extends these results by evaluating the prevalence of LV threshold stability <1.0 V and by demonstrating a more specific battery longevity benefit in a large, "real-world" patient cohort. On the basis of our findings, decreasing the LV PCT is safe for most patients without compromising consistent LV pacing for CRT.

Improving device longevity is associated with significant cost savings to the health care system.⁷ Other analyses have demonstrated that the cost-effectiveness of CRT devices and implantable cardioverter-defibrillators is tied directly to battery longevity.^{8,9} In patients with impaired LV function, increasing CRT-D device longevity from 4 to 7 years resulted in a total savings of nearly €1,000 per patient, with avoidance of a generator replacement accounting for 46.6% of these savings.

A significant number of patients receiving CRT-D generator changes die <1 year after the procedure. On the basis of previous analysis of the National Cardiovascular Data Registry, 15.7% of patients died <1 year after CRT-D generator replacement.¹⁰ Thus, our results suggest that increasing device longevity by even as little as 1 year could result in a reduction in the number of CRT-D generator replacements and their associated health care costs.

Device battery longevity also has a direct relation with patient outcomes, as generator replacement has a small but significant rate of complications. In the REPLACE registry, there was a 7% rate of major complications <6 months after CRT-D generator replacement without lead revision,² and device infection occurred in 1.3% of device replacements.³ Reducing the frequency of generator change would also reduce the frequency of these complications and their associated costs.

Our study did have several limitations. In our LV threshold stability analysis, we presumed the accuracy of the LVC algorithm, but this assumption is reasonable given that previous work has demonstrated LVC to be a highly reliable means of automatic evaluation of LV lead stimulation threshold irrespective of lead type, position (epicardial vs endocardial), or chronicity.⁵ We evaluated LV thresholds only over a 2-week period rather than over the entire duration of follow-up available in the CareLink database, but prior analysis has shown that LV threshold variability is minimal even over longer follow-up of up to 21 months.⁴ In our longevity increase analysis, we based our reference on current-generation battery and device parameters. Extension to different models or brands of generators may not be appropriate, and we did not have access to information regarding the specific lead models, which may have also contributed to variations in battery performance. Our model also assumed no battery drain from therapies for ventricular arrhythmias, and we did not evaluate the impact of implantable cardioverter-defibrillator shocks on battery longevity. Finally, we only examined CRT-D patients, not patients with CRT pacing devices. We also were unable to assess patient outcomes, and this study should be viewed as a hypothesis-generating simulation exercise, which requires prospective confirmation.

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Figure 1.
LV threshold stability.

Figure 2.
Additional years with 0.5-V versus 1.5-V safety margin.