Optimized CRT Stimulation Based on Ultra-High-Frequency QRS Analysis

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Abstract

The optimization of cardiac resynchronization therapy (CRT) stimulation by ultra-high-frequency ECG (UHF-ECG) is presented.

34 subjects (24 men, aged 65.0±10.1) undergoing the implantation of a CRT_D with an automatic optimizing algorithm for atrioventricular and intraventricular delay. Interventricular delay (IVD) from echocardiography and electrical dyssynchrony (e-DYS) from UHF-ECG were analysed using three different CRT configurations - OFF (stimulation off), SMART (SMART algorithm) and OPT (optimal assessment subjectively determined by the electrical depolarization map from UHF-ECG).

The mean±STD values over visits for IVD [ms] were 50.32±29.00, 29.09±29.33 and 25.17±24.54 for OFF, SMART and OPT respectively. For e-DYS [ms], it was 69.18±30.85, 31.18±24.42 and 13.42±18.67 for OFF, SMART and OPT respectively. Significant statistical differences (p<0.01) existed between OFF and both SMART and OPT for both IVD and e-DYS parameters. Between SMART and OPT, significant differences (p<0.01) existed only for e-DYS.

UHF-ECG analysis may be used to optimize CRT stimulation and to minimize electrical dyssynchrony.

1. Introduction

Left ventricular contraction is considered to be synchronous when electrical activation of all ventricular myocardial cells takes less than 120 ms. Ventricular dyssynchrony can be determined at different levels [1]: The early activation of definite left ventricular areas occurs in the presence of intraventricular conduction abnormalities (LBBB). That creates areas of both early and late activation [2]. Intraventricular dyssynchrony means the late activation of the lateral areas of the left ventricle as compared to the interventricular septum. Another level of ventricular dyssynchrony is interventricular dyssynchrony, which means the delayed activation of one chamber compared to the other [1].

In this study, we present the use of ultra-high-frequency ECG (UHF-ECG) [3] to possibly optimize biventricular stimulation CRT (cardiac resynchronization therapy).

2. Methods

An ultra-high-frequency high-dynamic-range 14-lead ECG technique (UHF-ECG) and echocardiography were used in the study.

2.1 Data recording, subjects and study protocol

34 subjects (24 men and 10 women, aged 65.0±10.1) undergoing CRT implantation with a device manufactured by Boston Scientific with the possibility to automatically optimize atrioventricular (AVD) and intraventricular (VVD) delay (SMARTdelay algorithm) were included in the study. The patients were evaluated over 48 visits (33 visits were performed the next day after implantation and 15 visits were at the six-month follow up). Each visit consisted of a repeated 3-min recording of a 14-lead ECG (sampling frequency 5kHz with a dynamic range of 26bits, 2kHz pass band, M&I s.r.o., Prague, Czech Republic) for various CRT_D settings while the patient was in a calm supine position with subsequent echocardiography measurements (Vivid E9, GE Healthcare, Wauwatosa, WI) for selected CRT_D settings. The measurements were taken at the International Clinical Research Center at St. Anne's University Hospital, Czech Republic and all subjects signed their informed consent to the investigation.

Interventricular delay (IVD) and electrical dyssynchrony (e-DYS) were used as the numerical parameters. The optimal stimulation was based on electrical depolarization maps that describe the time-spatial distribution of electrical activity [3]. The irregularities in electrical activation are best described by these maps.

2.2 Processing

UHF Solver (software developed by ISI AVCR, Brno, Czech Republic) was used to process the data for each UHF-ECG record [4],[5]. The software created an electrical depolarization map for each record. The e-DYS parameter was defined as the difference in the position of normalized maxima (red colour) in leads V1-V8 on the electrical depolarization map.

We subsequently programmed various VVD (left ventricular lead and right ventricular lead stimulation delay) and AVD (atrial lead and right ventricular lead stimulation delay) values of CRT_D settings with the goal of finding subjective optimal settings OPT evaluated based on the appearance of the electrical depolarization map obtained from the UHF-ECG measurements. A thin and straight appearance was considered to be the best result (Figure 1).

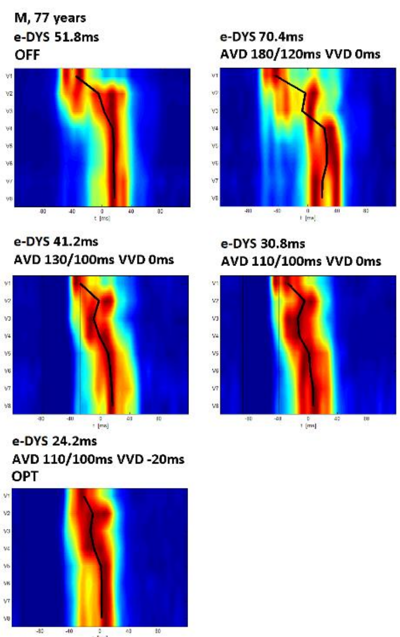

Figure 1. Examples of CRT_D optimization based on the appearance of the electrical depolarization maps.

We tested the settings recommended by the SMART algorithm (SMART) created by the Boston Scientific device. The algorithm was based on measurements taken of the sensing delay between the atrial lead and the right ventricular lead during atrial sensing and pacing and the sensing delay between the right and left ventricular leads. Furthermore, a natural rhythm measurement without stimulation (OFF) was performed (Figure 2).

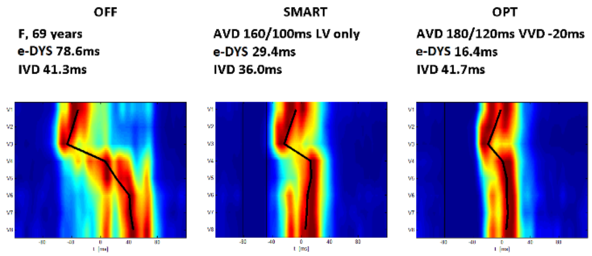

Figure 2. Examples of different CRT_D programming. From the LEFT: OFF (without any stimulation), SMARTdelay settings recommended by device, optimal OPT settings.

Echocardiography was provided for each of these settings (OPT, SMART, OFF). We measured interventricular dyssynchrony (IVD) as the difference between the left and right pre-ejection intervals [2], consisting of the measurement of the aortic pre-ejection time recorded by pulsed-wave (PW) Doppler in an apical 5-chamber view and the pulmonary pre-ejection time recorded in the left parasternal view in the short axis also using PW Doppler [1] (Figure 3).

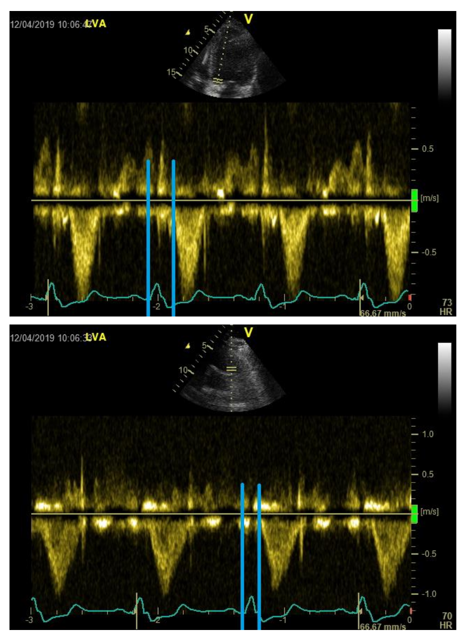

Figure 3. Examples of echocardiography interventricular dyssynchrony measurements. Aortic valve flow at the top, pulmonary valve flow at the bottom (Vivid E9, GE Healthcare).

Each electrical depolarization map was subjectively evaluated using a SUBscore on a scale range of 1 to 5 (1 as maximally synchronous activation and 5 as very asynchronous activation) (Figure 4).

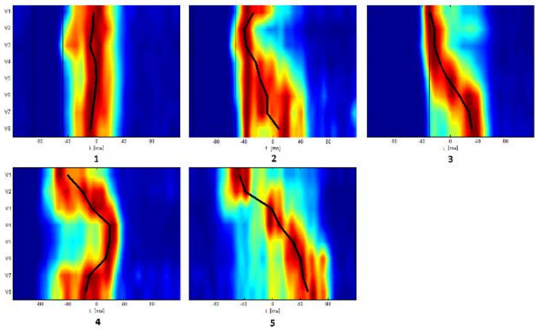

Figure 4. Examples of SUBscores 1 to 5 in different electrical depolarization maps.

3. Results

Figure 1 shows examples of possible electrical depolarization maps during our investigation of CRT_D settings. Measurements taken in CRT-OFF mode show typical dyssynchrony.

Table 1. Values (mean±std) of interventricular delays IVD and electrical delays e-DYS for different CRT_D settings (OFF, SMART, OPT) and the difference between SMART and OPT values.

	IVD	e-DYS
OFF	50.32±29.00	69.18±30.85
SMART	29.09±29.33	31.18±24.42
OPT	25.17±24.54	13.42±18.67
SMART - OPT	4.12±20.61	17.76±24.96

The automatic SMARTdelay algorithm determined left ventricular pacing only (with RV pacing off) in 44% of the cases, biventricular simultaneous pacing (with LV-RV delay 0 ms) in 48% of the cases and biventricular sequential pacing (with nonzero LV-RV delay) in 8%. Atrioventricular delay recommendations were variable.

VVD values of 40/0/-5/-20/-40/-60 ms were used for OPT. Based on the electrical depolarization maps, we set simultaneous biventricular stimulation for 44% of the cases,
VVD -20 ms for 19% of the cases and VVD -40 ms for 21% of the cases. The most common AVD was 180/120 ms (for postpaced/postsensed configuration) for 52% of the cases followed by 130/100 ms for 32% of the cases.

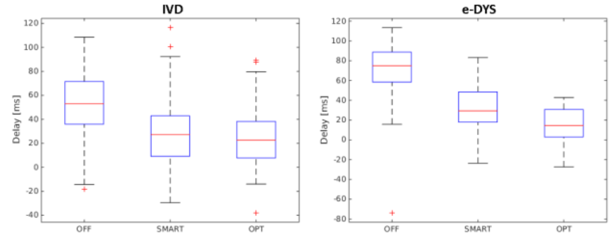

Figure 5. Values of interventricular delays IVD and electrical delays e-DYS for different CRT_D settings (OFF, SMART, OPT)

The IVD parameter decreased by 42% for SMART and by 50% for OPT settings in comparison with OFF. For e-DYS, there was a 55% decrease for SMART and an 81% decrease for OPT (Figure 5).

Significant statistical differences (p<0.01) existed between OFF and both SMART and OPT for both the IVD and e-DYS parameters. Between SMART and OPT, significant differences (p<0.01) existed only for the e-DYS parameter.

The IVD parameter was smaller for OPT (-4.12±20.61), but not statistically significant. The difference between the IVD values in groups subdivided by SUBscore and e-DYS were statistically significant (except for 1 versus 2 and 3 versus 4 for SUBscore and except for 1 versus 2 for e-DYS). Figure 6 shows the delays of the subdivided groups.

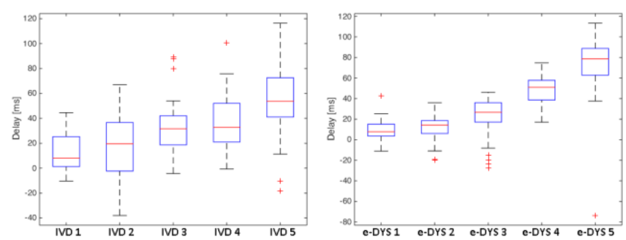

Figure 6. Values of interventricular delays IVD and electrical delays e-DYS subdivided by SUBscore (based on a subjective electrical depolarization map assessment).

4. Discussion

The UHF-ECG technique for assessing dyssynchrony is well described in [3]. In this study, we focused on the effect of different CRT_D settings on interventricular (IVD) and e-DYS. The IVD parameter was chosen because it is easier to measure (even with worse investigability), it is highly reproducible and as is shown in [6], the specificity and positive predictive value of the IVD parameter was higher compared to the parameters based on M-mode and tissue Doppler imaging.

Thereafter, we presented the possibility to find the best CRT_D settings depending on electrical depolarization maps (OPT) and recommended SMARTdelay.

As can be seen in [7], there could be some subjects for whom non-profiting from OPT settings and SMART settings is more beneficial (12%). However, the automatic SMARTdelay algorithm recommended non-biventricular stimulation for 44% of the cases (LV stimulation only), Figure 7.

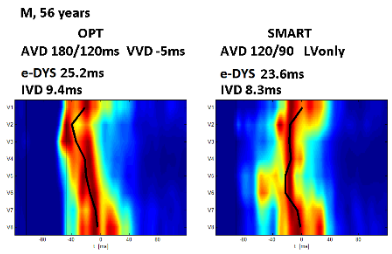

Figure 7. A comparison of numerical parameters and electrical depolarization maps.

We did not set any LV only stimulation (with a straighter appearance of the electrical depolarization map) for optimal settings (OPT) because fusion pacing with spontaneous atrioventricular conduction was not exercise tested [8].

The presence of the stimulation peak directly in the QRS is one limitation of this study. Part of the ultra-high-frequency signal is lost during elimination of the stimulation peak and the results may be distorted.

5. Conclusion

UHF-ECG analysis is a suitable method to optimize CRT stimulation and to minimize electrical dyssynchrony. In addition, there is a growing trend to improve mechanical dyssynchrony in comparison with optimization implemented by a device's own algorithm.

Acknowledgments

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