Conduction System Pacing Versus Biventricular Pacing For Cardiac Resynchronization – Preliminary Electrocardiographic Results

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Abstract

Cardiac resynchronization therapy with biventricular pacing (BiV) is the cornerstone treatment for heart failure patients with ventricular dyssynchrony. Recently, the conduction system pacing (CSP) has being introduced as a possible alternative. We hypothesized that CSP could produce a more complete electrical resynchronization compared to conventional BIV pacing.

To trace the spreading of myocardial depolarization, we assessed equivalent dipole (ED) trajectories utilizing the BEM method with a tailored human torso from the high resolution 12-lead ECG before and after device implantation in 17 patients included in our ongoing randomized CSP-SYNC study.

We observed a similar relative shortening of the QRS duration (0,23 in CSP and 0,25 in BiV) and relative ED trajectory length (0,16 in CSP and 0,20 in BiV). However, a significant change of ED trajectory direction occurred after the therapy. In BiV pacing, the trajectory direction shifted more towards the base of the heart, but more apically in CSP, mimicking normal heart depolarization

Resynchronization with CSP seems to restore more physiological depolarization compared to BiV pacing. The assessment of the ED trajectories provides additional insight into the electrical heart remodelling after the therapy.

1. Introduction

Cardiac resynchronization therapy (CRT) with biventricular pacing (BiV) is an integral part of heart failure therapy in patients with reduced ejection fraction and left bundle branch block (LBBB). Previous studies have demonstrated improved quality of life, reduced heart failure hospitalization and decreased all-cause mortality. [1] However, around 30% of patients still do not benefit from this therapy. [2, 3] Variable venous anatomy, phrenic nerve stimulation, and higher epicardial lead thresholds are common problems with BiV stimulation. [1, 4] Newer CRT systems with improved programmability and algorithms in conjunction with quadripolar left ventricular (LV) leads have mitigated same of the challenges of BiV pacing, yet there is still quite a substantial number of patients that do not benefit from BiV. [2, 3] Fundamentally, BiV stimulation with epicardial activation, does improve mechanical dyssynchrony, but does not produce physiological resolution of LBBB. [5] On the other hand, CSP could provide synchronous physiological ventricular activation with possible superior electrical and mechanical resynchronization compared to BiV pacing. [2, 4] Electrical activetion maps obtained during CSP showed normalization of left bundle branch block with more homogeneous electrical resynchronization than in BiV. [6] However, studies evaluating the value of CSP as an alternative approach to CRT in heart failure patients are limited.

In the present study, we present some preliminary electrocardiographic analysis comparing BiV and CSP with utilizing the application for assessing the equivalent dipoles (ED) trajectories from the standard 12-lead ECG, which incorporates the boundary element method (BEM) to calculate potentials on the surface of a tailored human torso model. (the inverse model). [7]

2. Methods

2.1. Study design

This is a sub-study of the ongoing single center randomized study (CSP-Sync, *NCT05155865*) which will include 60 heart failure patients with LBBB that have a Class I indication for CRT [8]. Patients received BiV or CSP device. In this study we have included 17 patients that had at least on follow-up after device implantation.

Inclusion criteria: 1. Optimal medical heart failure therapy for at least 3 months before enrollment; 2. patients are older than 18 years of age 3. sinus rhythm with LBBB according to Strauss criteria. [9] Exclusion criteria: 1. Patients with diagnosed unstable angina, acute myocardial infarction, with coronary arterial bypass-grafts or percutaneous coronary intervention done within the past 6 months were excluded from the trial. 2. mechanical tricuspid valve replacement, more than moderate valvular disease; 3. persistent or permanent atrial fibrillation, higher degree atrioventricular block; 4. life expectancy of less than 12 months; 5. pregnancy and breastfeeding.

2.2. Determination of the ED trajectory dynamics

All recordings were five-minute (or more) supine resting 12-lead ECGs (sampling rate of 1 kHz, 300 Hz low pass filter) from which we extracted nine signals (VR, VL, VF, V1 to V6) corrected for the Wilson's central terminal. After recognizing separate heart beats we constructed the signal templates served for identification of a beat, the most similar to the template, which was used for the assessment of ED trajectories.

The QRS duration was measured manually using Cardiax ECG software v.4.44.4 (IMED KFT., Budapest, Hungary) on 100 mm/s and 20 mm/mV recordings in the precordial leads. The relative QRS shortening was defined as difference between baseline QRS duration and post-implant QRS duration divided by baseline QRS duration. Similarly, relative ED length shortening was calculated.

A patient-specific torso was introduced by tailoring a torso framework by considering individual anthropometric measures, such as the torso height, width, and depth at the shoulders, waist, and hip level [Fig 1]. The framework consists of 24 vertically aligned rounded isosceles trapezoids, each with 48 nodes at the border to provide N=1152 discretized quadrangular surfaces for determination of surface potentials on the torso surface.

To find a set of moving EDs that make the ED trajectory best describing the measured signals of 12-lead ECG, we applied an inverse algorithm that included the regularization terms to overcome the problem's ill-posedness. As the forward model, we utilized our application which incorporates the BEM method to calculate potentials on the surface of a tailored human torso model. [7] The error of determination was calculated as the mean difference between measured and calculated potentials.

2.2. Heart model for evaluation of ED trajectory dynamics

To study the position of ED trajectories concerning the ventricular walls, a heart model with its 3-D orientation was necessary to build. The left ventricle (LV) was represented as a rotational ellipsoid with the short axis (b=3.5cm) rotated around its long axis (a=5cm) and truncated at the atrioventricular (AV) plane 1.5 cm above the ellipsoid origin. The right ventricle was represented similarly, using only one half of the longitudinally cut ellipsoid attached to the LV. We assumed that the long axis is oriented similarly to that one based on data from Odille F et al. [10].

In the short-axis view we determined azimuth $\varphi=0$ in the mid-septum direction and $-180º \leq \varphi \leq 180º$, φ increasing during clockwise rotation. In the long-axis view we determined elevation $\vartheta=0$ in the equatorial plane and $-90º \leq \vartheta \leq 90º$, ϑ increasing from the basal to the apical orientation [Figure 2].

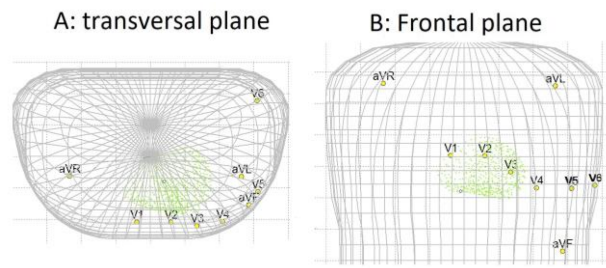

Figure 1. Human torso model with the standard 12-lead electrode positions and discretized quadrangular surfaces.

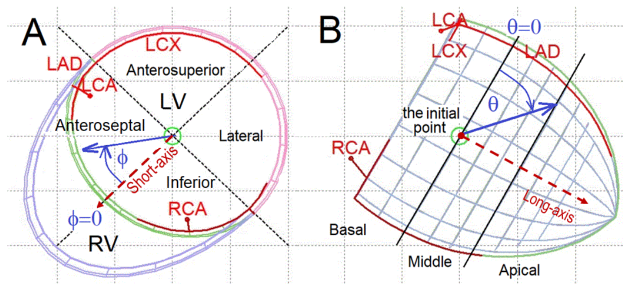

Figure 2. A: The short-axis view the wall segments. B: The long-axis view the regions. RCA, LCA, LAD, and LCX are the coronary arteries

3. Results

The study included 17 patients (11 male, non-ischaemic 14, 8 in CSP arm, NYHA II, of the average age of 66 years). All the patients in CSP and BiV arm had optimal medical treatment. The average QRS duration (Table I) before implantation was 180 ms in the BiV arm and 164 ms in the CSP arm (p=0,09). After implantation, paced QRS measurement decreased to an average of 133 ms in the BiV arm and 125 ms in the CSP arm (p=0,32). The relative QRS shortening was 0,23 for the CSP group and 0,25 for BiV (p=0,61). The average relative ED trajectory shortening was in CSP group 0,16 and BiV 0,20 (p=0,72).

Table I. QRS duration and ED trajectory length

Arm	N	Age	QRS_{ini}	QRS_{end}	ΔQRS	ΔED
CSP	8	68	164	125	-0.23	-0.16
BiV	9	65	180	133	-0.25	-0.20

TableII. Changes in the ED trajectory orientation

Arm	N	Angle θ	p value	Angle φ	p value
CSP	8	6	0.03	222	0.02
BiV	9	-33		109	

The percentage of ventricular pacing was similar in both groups. Before the pacing, the baseline LBBB ED trajectories were in both groups of similar length and orientations toward LV's lateral and inferolateral walls (Figure 3). One month after pacing, there was a significant difference in the ED trajectory orientation between both pacing modalities after therapy: the angle θ (elevation) rotated more toward the apex after CSP and more toward the base after BiV pacing (Table II). In BiV patients, the orientation of the ED trajectories was shifted anterosuperior toward the base (Figure 4). In the CSP group, the trajectories were shifted more apically and laterall (Figure 4), mimicking normal heart depolarization (Figure 3).

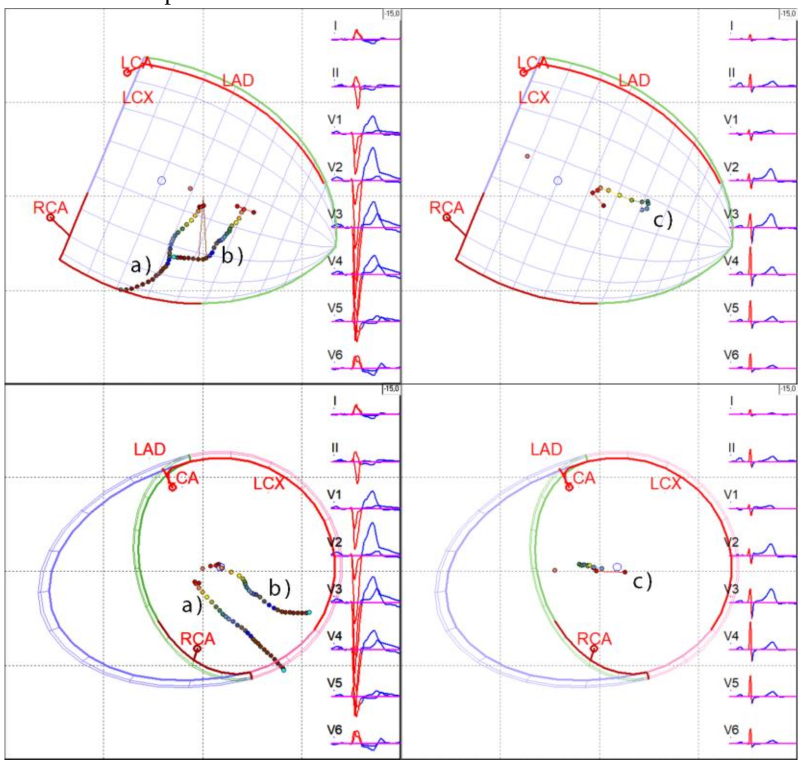

Figure 3.: ED trajectories samples in: a) and b) subjects with LBBB, c) healthy subject

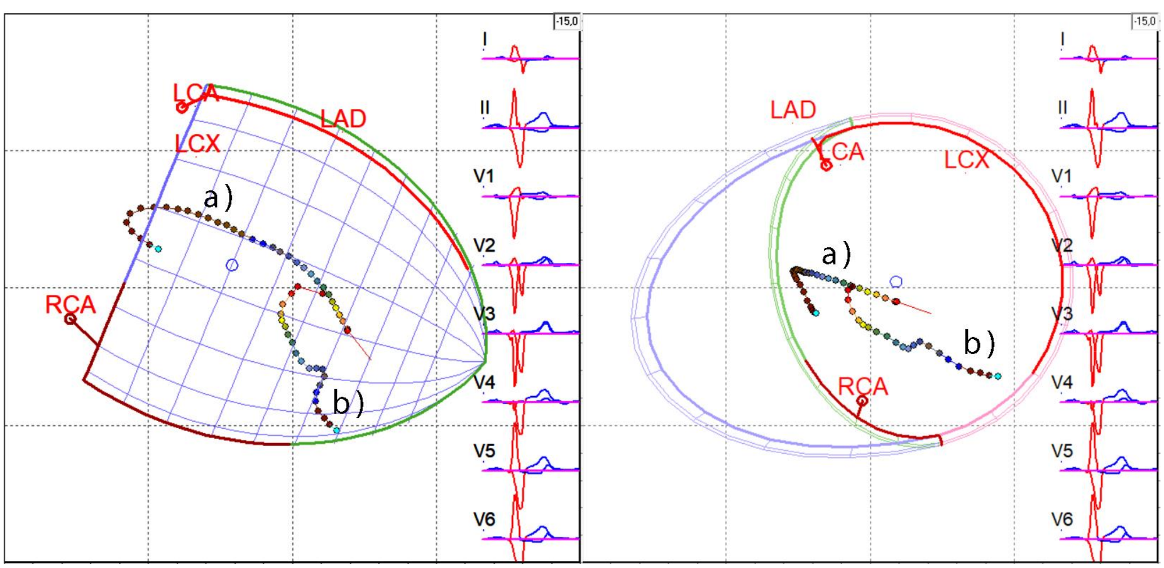

Figure 4.: Representative ED trajectories in two subject from the analysed group; a) BiV pacing, b) CSP pacing

4. Discussion

Biventricular pacing achieves cardiac resynchronization with the fusion of paced wave fronts with the help of epicardial left ventricular stimulation. The wavefronts travel via slow cell-to-cell conduction from the left ventricular epicardium and right ventricular endocardium.[3] Therefore, while it provides some electrical and mechanical resynchronization, it cannot entirely eliminate electrical dyssynchrony. [3] On the contrary, CSP uses native conduction system for the activation of the ventricles and has the potential of even greater cardiac resynchronization. Some nonrandomized studies have already shown the potential benefit of CSP pacing over BiV in heart failure patients with wide QRS. [3]

The simple QRS width measurement is probably the most common used tool in everyday clinical practice for assessing the acute success of cardiac resynchronization. It has been shown that QRS width reduction after BiV implantation is associated with favourable long-term outcomes. [11] Average shortening of QRS and shortening of equivalent dipole lengths were similar in both groups. However, there was a significant difference in the shift of trajectory orientations. The trajectory of the CSP arm was more in line with the trajectory of the healthy subject, with a shift towards the lateral wall. The reason for this finding could be the utilization of the residual intrinsic conduction system, which is the main advantage of CSP resynchronization compared to BiV. In BiV pacing, the trajectory orientation points opposite to that in CSP, which is probably the result of left ventricular depolarization slightly preceding the right ventricle due to earlier left ventricle electrode activation.

Although different ED trajectory orientation between both pacing modalities is already noticeable, this observation has to be confirmed on larger sample size. In addition, the dipole orientation will have to be associated with clinical response parameters.

In conclusion, CSP resynchronization seems to restore more physiological depolarization than that with BiV pacing. However, these findings will have to be confirmed on a larger sample size with the assessment of the impact on clinical outcomes.

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