Characterization of ventricular activation pattern and acute hemodynamics during multipoint left ventricular pacing

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BACKGROUND Multipoint left ventricular (LV) pacing (MultiPoint Pacing [MPP], St Jude Medical, Sylmar, CA) in a single coronary sinus branch has been introduced as a novel means of cardiac resynchronization therapy (CRT). It is speculated that MPP improves LV function by capturing a larger LV tissue area, resulting in uniform wavefront propagation throughout the ventricles, in comparison to conventional biventricular pacing (BIV).

OBJECTIVE The purpose of this study was to evaluate MPP by means of contact mapping and hemodynamic measures to understand the underlying mechanisms and effects.

METHODS Ten patients with non–ischemic cardiomyopathy (mean age 69 ± 9 years; 6 men (60%); New York Heart Association heart failure class II or III; QRS duration 173 ± 20 ms; LV ejection fraction 27% ± 5%) received a CRT-defibrillator capable of MPP. After the implantation procedure, an acute pacing protocol was implemented, including 2 BIV and up to 9 MPP interventions. In all pacing interventions, LV electrical activation patterns and hemodynamics (dP/dtmax) were evaluated, and for each patient, both the resulting measures were compared between MPP and BIV interventions.

RESULTS Compared with BIV, MPP resulted in an increase in LV dP/dtmax (30% ± 13% vs 25% ± 11%; $P = .041$), a reduction in QRS duration (22% ± 11% vs 11% ± 11%; $P = .01$), and a decrease in total endocardial activation time (25% ± 15% vs 10% ± 20%; $P = .01$). MPP resulted in a larger capture of LV mass during the first 25 ms (35% ± 22% vs 16% ± 8%; $P = .005$) and during the first 50 ms (78% ± 27% vs 60% ± 23%; $P = .03$) of pacing, suggesting a quicker wavefront propagation throughout the left ventricle.

CONCLUSION In this acute study, MPP in CRT improved both endocardial and surface electrical parameters and hemodynamics in comparison with BIV.

KEYWORDS Heart failure; Cardiac resynchronization therapy; MultiPoint Pacing; Hemodynamics; Activation time; Surface ECG

ABBREVIATIONS **BIV** = biventricular pacing; **CRT** = cardiac resynchronization therapy; **CS** = coronary sinus; **Dvect** = distal left ventricular pacing vector; **ECG** = electrocardiogram; **IVCD** = intraventricular cardiac delay; **LBBB** = left bundle branch block; **LV** = left ventricular; **MPP** = MultiPoint Pacing; **Pvect** = proximal left ventricular pacing vector; **QRSd** = QRS duration; **RV** = right ventricular; **TAT** = total activation time

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Introduction

In patients suffering from heart failure with electrical dyssynchrony, as detected by surface electrocardiogram (ECG), cardiac resynchronization therapy (CRT) has proved to exert positive effects. CRT restores the contractile function and improves exercise tolerance and quality of life[1–3] in addition to promoting reverse remodeling and reducing mortality.[4,5] However, about a third of patients receiving CRT do not obtain any clinical improvement. A few recent studies have suggested that simultaneous multisite pacing delivered by 2 left ventricular (LV) leads placed in 2 coronary sinus (CS) branches may improve response to CRT.[6–8] More recent studies using MultiPoint Pacing (MPP) from a single CS branch with a quadripolar LV lead (Quartet, St Jude Medical, Sylmar, CA) have demonstrated that MPP exerts favorable acute hemodynamic effects,[9,10] reduces echocardiographic dyssynchrony,[11] and improves mid-term and long-term outcomes.[12] However, little is known about the effects of MPP on the activation sequence of the left ventricle and its relationship to acute hemodynamics. We set out to examine the underlying mechanisms of MPP in improving the electrical activation pattern and acute hemodynamics.

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Methods

Study population

This study enrolled consecutive patients meeting the inclusion and exclusion criteria at a single investigational center. The study population consisted of patients with the following characteristics: ≥18 years old indicated for a CRT implant

approved by European Society of Cardiology/European Heart Rhythm Association (ESC/EHRA) guidelines, non–ischemic etiology, New York Heart Association heart failure class II or III, LV ejection fraction (EF) $\leq$35%, typical left bundle branch block (LBBB) or intraventricular cardiac delay (IVCD), sinus rhythm, and no or nonsignificant coronary lesions. Patients who had recently undergone heart surgery or who had been on intravenous inotropic therapy in the previous month were excluded. All patients provided written informed consent. The study was approved by the local ethics committee.

Device implantation

Patients received a CRT device with MPP (Quadra Assura MP, St Jude Medical, Sylmar, CA) in accordance with the standard implantation technique. A quadripolar LV lead (Quartet) was positioned at a CS branch having at least 2 available pacing vectors from different cathodes with consistent capture at 5 V@0.5 ms pulse width without phrenic nerve stimulation.

Pacing protocol

After completing LV lead implantation per standard practice, a number of pacing configurations were tested. Two LV pacing vectors—proximal (Pvect) and distal (Dvect)—were identified based on the following: relative anatomical electrodes position (Pvect, the one involving the proximal LV electrode as a cathode, and Dvect, the one involving the most distal electrode as a cathode) together with capture threshold values and the absence of phrenic nerve stimulation. In addition, RV-LV Conduction Time Measurement (St Jude Medical; automatic programmer-based method) was performed during intrinsic rhythm (recent studies[13] suggest that RV-LV guidance in selecting an LV location/electrode could provide better CRT response rate and patients outcome) to obtain earliest and latest activated electrode vectors (see Online Supplemental Table A1).

Up to 15 pacing interventions were tested by pacing at a rate of 10 beats/min above patient's spontaneous rhythm (AV delay was set to 130 ms in order to ensure ventricular capture)—AAI mode (baseline), right ventricular (RV) only, LV only (each with Dvect and Pvect), traditional biventricular pacing (BIV; each with Dvect and Pvect with the V-V interval optimized by means of a commercially available device algorithm, QuickOpt [St Jude Medical, Sylmar, CA])—and up to 9 MPP configurations with various delays. In particular, the simultaneous pacing (LV1-LV2 = Δ1 = 5 ms; LV2-RV = Δ2 = 5 ms) and the partially simultaneous pacing (Δ1 = 20 ms; Δ2 = 5 ms) were tested first after the Dvect-Pvect sequence and then after the Pvect-Dvect sequence. The choice of the other MPP interventions' delays was derived from the QuickOpt algorithm results in order to understand whether this feature could give an indication on the total interventricular delay (Δ1 + Δ2) (Table 1; also see Online Supplemental Appendix B).

LV electroanatomic mapping

At each pacing intervention, electroanatomic mapping of the left ventricle was performed using the EnSite Velocity system (St Jude Medical, St Paul, MN). A steerable decapolar catheter (Biosense Webster Inc, Diamond Bar, CA) was inserted into the left ventricle through a right femoral arterial access and used as a roving catheter for electroanatomic mapping of the LV endocardium. At each stable catheter position on the LV endocardial surface, the bipolar electrograms were recorded for approximately 15 consecutive beats sequentially for each pacing intervention. The activation time was then annotated at the maximum negative slope of each bipolar electrogram. The total activation time (TAT) of the left ventricle and the percentage of ventricular endocardial surface that is activated in various time phases (0: 25 ms; 25: 50 ms; 50: 75 ms; 75: 100 ms; 100: 125 ms; 125: 150 ms; 150: 175 ms) were analyzed. The difference in TAT % between each test configuration and baseline (delta TAT %) was also computed.

Table 1 Pacing protocol

Protocol	Pacing delays*				
SR (AAI)	NA				
DDD RV only	NA				
DDD LV only with Dvect	NA				
DDD LV only with Pvect	NA				
BIV with Dvect, V-V interval	QOd				
BIV with Pvect, V-V interval	QOp				
MPP protocol	Test 1	Test 2	Test 3	Test 4	Test 5
MPP Dvect-Pvect, Δ1†; Δ2‡	5 ms; QOd-5 ms	20 ms; QOd-20 ms	5 ms; 5 ms	20 ms; 5 ms	QOd-QOp; QOp§
MPP Pvect-Dvect, Δ1; Δ2	5 ms; QOp-5 ms	20 ms; QOp-20 ms	5 ms; 5 ms	20 ms; 5 ms	QOp-QOd; QOd‖

BIV = biventricular pacing; Dvect = distal left ventricular pacing vector; LV = left ventricular; MPP = MultiPoint Pacing; NA = not applicable; Pvect = proximal left ventricular pacing vector; QOd = VV delay indicated by the QuickOpt algorithm with distal left pacing vector; QOp = VV delay indicated by the QuickOpt algorithm with proximal left pacing vector; RV = right ventricular; SR = sinus rhythm.

*AV delay = 130 ms.

†Δ1 = delay between LV1 and LV2.

‡Δ2 = delay between LV2 and RV.

§Only if QOd > QOp.

‖Only if QOp > QOd.