Changes in Ventricular Repolarization After Right Ventricular and Left Bundle Branch Pacing

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***Abstract*—Left bundle branch pacing (LBBP) has recently emerged as an alternative to the widely used right ventricular pacing (RVP), which presents limitations related to the induced ventricular activation dyssynchrony. Here, we measured the QRS complex duration (QRSd) and an index of sympathetic modulation of ventricular repolarization, called Periodic Repolarization Dynamics (PRD), one day and one year after pacemaker implantation. In our cohort of patients with right and left bundle branch block, LBBP induced a decrease in QRSd (median [IQR] at baseline: 160.5 [20.5] ms, after one day: 133.5 [25.0], after one year: 133 [23.8] ms), thus indicating higher activation synchronization. On the other hand, RVP showed no significant changes (155.0 [15.5], 156.5 [30.5] and 150.5 [34.5] ms). PRD was reduced after one-day pacing for both LBBP and RVP, but returned to baseline values after one year. In conclusion, LBBP shows improved activation synchronization as compared to RVP, with no significant differences in sympathetically-mediated repolarization oscillations between the two pacing techniques.**

***Index Terms*—left bundle branch pacing, right ventricular pacing, QRS duration, periodic repolarization dynamics**

I. Introduction

In recent years, there has been a shift in cardiac pacing techniques from right ventricular pacing (RVP) towards pacing of the cardiac conduction system, including His bundle pacing (HBP), right bundle branch pacing and left bundle branch pacing (LBBP) [1]. HBP presents some limitations, such as high capture threshold, low R-wave amplitudes or restrictions for a wider adoption in patients with left bundle branch block (LBBB). LBBP has emerged as an alternative to HBP, as it requires lower capture thresholds and may overcome the HBP-related ventricular undersensing and atrial oversensing. Nevertheless, further studies are needed to assess the long-term safety and the efficacy of LBBP [2].

To assess the synchronization of ventricular activation following pacing, most studies investigate the duration of the QRS complex (QRSd) measured from the electrocardiogram (ECG) [3]. The effects of pacing on ventricular repolarization and its modulation by the autonomic nervous system have been, however, scarcely investigated. Periodic Repolarization Dynamics (PRD) has been proposed in the literature to characterize sympathetically-mediated low-frequency oscillations in the T-wave vector and it has been shown to predict cardiac mortality and arrhythmic risk in several populations [4], [5]. This study aims to compare QRSd and PRD following RVP and LBBP in patients with LBBB and right bundle branch block (RBBB).

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II. Materials and methods

A. Study population

The study population consisted of 56 patients with wide baseline QRS (QRSd>120ms), mean age 77±8 years, who underwent permanent pacemaker implantation at Hospital Clínico Lozano Blesa, Zaragoza, Spain, from March 2020 to March 2023. High-resolution (1,000 Hz) 12-lead ECG signals were recorded before the intervention and one day and one year after the pacemaker implantation. The study population was randomly assigned LBBP or RVP. LBBP was performed in 36 patients (11 LBBB, 23 RBBB, 2 isolated hemiblocks) and RVP in 20 patients (6 LBBB, 14 RBBB).

B. Signal processing

Preprocessing of the raw ECG signals included: i) baseline wander removal using a high-pass filter; ii) semiautomatic detection and removal of pacing spikes [6]; iii) application of a 50-Hz notch filter to remove powerline interference; iv) low-pass filtering to attenuate electric and muscle noise. The preprocessed ECG signals were delineated using a multi-lead wavelet-based automatic system [7]. The RR interval was calculated from consecutive QRS fiducial marks.

C. ECG markers

From the processed ECG signals, the method described in [8] was applied to compute PRD. This method uses the Phase-Rectified Signal Averaging (PRSA) technique [9] on the series of consecutive T-wave angles. Anchor points were defined as points meeting the following condition:

$$\frac{1}{M}\sum_{j=0}^{M-1} x_{i+j} > \frac{1}{M}\sum_{j=1}^{M} x_{i-j}$$

with M = 9 and x being the T-wave angle series. Subsequently, 40-point windows centered around each anchor point were selected. The PRSA series was obtained by computing the average of the T-wave angle series over all selected windows. Finally, the PRD index was defined as the difference between the maximum and minimum values of the PRSA series.

For QRSd measurement, a representative beat for each ECG recording was defined from the median of all the beats corresponding to the bin of the RR histogram associated with the statistical RR mode [6]. A post-processing selection rule was applied over all single-lead onset and end locations of the QRS complex in the median beat [7]. QRSd was computed from the multilead onset to end marks.

D. Statistical analysis

PRD and QRSd measurements were compared at the three stages: baseline, one day (day 1) and one year (year 1) after the pacemaker implantation. Values are presented as median [IQR] over recordings. The Mann-Whitney U test (or Wilcoxon rank-sum test) was used to compare the values of the two pacing techniques. The Wilcoxon signed-rank test was used for comparison of different time points in each pacing group. Statistical differences were considered significant if the associated p-value$<$0.05. MATLAB R2017a (9.2) was used for the analysis.

III. Results

Table I presents the QRSd and PRD values for each pacing technique, LBBP and RVP, at each temporal point (baseline, day 1, year 1). At baseline, there were no significant QRSd differences between pacing groups. LBBP led to a reduction in QRSd both at day 1 and year 1. RVP, however, did not change QRSd at any time point. QRSd was significantly shorter for LBBP than RVP at both day 1 and year 1.

TABLE I
QRS DURATION AND PRD VALUES FOR LBBP AND RVP PATIENTS

		LBBP	RVP	p-value
QRSd (ms)	baseline	160.5 [20.5]	155.0 [15.5]	0.13
	day 1	133.5 [25.0]	156.5 [30.5]	**(6.2)** $\mathbf{10^{-7}}$
	year 1	133.0 [23.8]	150.5 [34.5]	**0.03**
p-value: day 1 vs base		**(4.6)** $\mathbf{10^{-7}}$	0.90	
p-value: year 1 vs base		**(6.1)** $\mathbf{10^{-6}}$	0.37	
PRD (degrees)	baseline	3.98 [4.00]	4.57 [4.10]	0.64
	day1	2.60 [2.70]	1.92 [1.78]	0.05
	year 1	4.53 [4.53]	2.23 [2.35]	**(5.2)** $\mathbf{10^{-3}}$
p-value: day 1 vs base		0.12	**(2.0)** $\mathbf{10^{-3}}$	
p-value: year 1 vs base		0.05	0.25	

PRD did not differ between the two pacing groups at baseline. Both LBBP and RVP reduced PRD at day 1, even if the difference was only significant for RVP. At year 1, PRD returned to baseline values, holding this true for both LBBP and RVP. The PRD value at year 1 was significantly lower for RVP than for LBBP.

IV. Discussion and conclusions

This study assessed QRSd and PRD following cardiac pacing in patients with LBBB or RBBB undergoing permanent pacemaker implantation. Patients were divided into two groups, RVP and LBBP, according to the pacing technique.

The evaluation of QRSd allowed to conclude that ventricular synchronization, despite being similar between pacing groups at baseline, was significantly higher for LBBP than for RVP both one day and one year after the pacemaker implantation. This difference between RVP and LBBP in the effects of pacing on ventricular depolarization is in line with previous studies [10], [11] and highlights the benefits of LBBP over RVP.

Our results from the evaluation of PRD showed a decrease after one day pacing with respect to baseline, for both LBBP and RVP. Such a decrease was, however, not maintained after one year of pacing, with a return of PRD values to those found at baseline. These results suggest that, despite the significant differences between LBBP and RVP on the depolarization characteristics after long-term pacing, the effects of repolarization seem to be transient for the two pacing techniques.

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