Left bundle branch pacing in patients with right bundle branch block

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Abstract

Abstract Background The paced morphology of right bundle branch block (RBBB) pattern is one of the parameters which can be used to confirm the left bundle branch capture during left bundle branch pacing (LBBP) implantation. However, changes of paced morphology after LBBP performed in patients with RBBB have not been well discussed. Objective To compare the paced morphology in patients with RBBB before and after LBBP and to discuss the possible mechanisms behind such changes. Methods Patients with RBBB who underwent LBBP implantation were selected. The QRS duration was measured before and after the implantation of LBBP for each patient and compared Student t test. Results We included 34 consecutive patients (median age 72.76 years, 73.53% male), of whom 3 had sick sinus syndrome (SSS) and 31 had high-grade atrioventricular conduction block (AVB). The average QRS duration was 144.87±5.22ms before LBBP implantation and 116.18±6.15ms after LBBP implantation, with a mean decrease in QRS duration of 28.70±3.30ms (95% CI: 27.55-29.85 ms, $P < 0.01$). Conclusion In patients with RBBB, the QRS duration after LBBP is narrower than that before LBBP. The specific mechanism is still unclear.

Introduction

The adverse effects of His bundle pacing (HBP) have been realized, including the higher capture thresholds, risks of acute loss of capture, early battery depletion, and lower R-wave amplitudes[1]. Some studies have reported that the left bundle branch pacing (LBBP) has lower capture thresholds, higher success rate and stability, and larger R-wave amplitudes [2,3]. Therefore, LBBP has emerged as a novel technique that can directly capture the left bundle branch (LBB) or LBB area by a transventricular septal approach [4]. Different from HBP, LBBP induced a right bundle branch block (RBBB) morphology while shortening the stimulus-peak left ventricular activation time (stim-LVAT), which represents the negative effect of LBBP on right ventricular activation[5]. However, there is only limited information about LBBP performed on patients with RBBB. In practice, we observe that the QRS complex is narrower than the intrinsic one in almost all patients with RBBB after implantation of LBBP (Figure 1). In this article, we describe the changes in the QRS complex in patients with RBBB after LBBP and discuss the possible mechanisms for this situation.

2 Methods

2.1 Study design

We performed a single-center, observational, prospective cohort study with patients in Xiamen Cardiovascular Hospital.

2.2 Participants recruitment

Consecutive patients who met the inclusion criteria were enrolled between February 9, 2018 and October 16, 2020. The inclusion criteria should meet the following: (1) an ECG showed a morphology of typical complete RBBB (cRBBB). The diagnostic criteria of cRBBB is as following : the QRS duration ¿0.12 sec, rSR' or RR' pattern in leads V1 and/or V2, wide and slurred S wave in leads V6 and I (S¿R duration or S wave duration [?] 0.06 sec) [6]. (2) patients were indicated for pacing therapy, (3) the LBB or LBB area was captured. Patients with any one of the following conditions were excluded: (1) incomplete RBBB (iRBBB), defined as the QRS duration in 0.10-0.12 sec and rsr' pattern in leads V1 and/or V2 [6]. (2) right ventricular septal pacing (RVSP), (3) left bundle branch block (LBBB), including complete LBBB, incomplete LBBB, left anterior fascicular block (LAFB), and left posterior fascicular block (LPFB), (4) patients declining guideline-indicated pacing therapy. The study was approved by the Ethics Committee of Xiamen Cardiovascular Hospital, Xiamen University, and the informed consent of each patient was obtained. The study was conducted in accordance with the principles of the Declaration of Helsinki.

2.3 Implantation of the lead

Huang et al. have described in detail the process of left bundle branch pacing [4]. In summary, this process consists of the following three steps. Firstly, the thickness and scar of interventricular septum were evaluated by Echo to improve the success rate of lead fixation. Secondly, the HBP location was determined and then identified as an anatomic marker for LBBP lead implantation, which is located on the line connecting the HBP lead position to the right ventricular (RV) apex, about 1–1.5 cm below the former[3,4,7]. Once the paced QRS morphology showed a "w" notch in V1, the lead was screwed in perpendicular to the RV septum surface. Thirdly, during screwing, as soon as the pacing pattern converted from LBBB to RBBB, and the stim-LVAT remained shortest and consistent so regardless of the output, indicating that the LBB was finally captured, the lead was fixed.

2.4 Electrocardiographic measurements

Baseline patient characteristics were collected retrospectively. The surface electrogram was recorded by the GE CardioLab Electrophysiology recording system (GEHealthcare Inc, Marlborough, MA) at 100 mm/s. We measured two parameters, which are the intrinsic QRS duration (iQRSd) and the paced QRS duration (pQRSd). The iQRSd was defined from the first deviation from isoelectric line to the last deviation of the QRS complex in the 12 leads. The pQRSd was measured - for SLBBP - from the onset of the first sharp vector of the QRS complexes crossing the baseline and - for NSLBBP - from the onset of the sharpest deflection to the end of the last deflection of the complex in the 12 leads, respectively. All two of these parameters were measured by Cardio Calipers 3.3 (Inconico, Inc, New York, NY). Three continuous QRS complexes on the lead V1 were measured and the averaged values were reported. The electrocardiographic recording and measurements were performed and analyzed by two independent and experienced ECG specialists.

2.5 Statistical analyses

Continuous variables were expressed as mean ± standard deviation and categorical variables were expressed as percentages. QRS duration before and after LBBP in the same group of samples was compared Student t test. Statistical analysis was performed with the SPSS 22.0 (SPSS Inc, Armonk, NY). The P value of less than .05 was considered statistically significant.

3 Result

In applying these selection criteria, there was a total of 34 patients with cRBBB recruited in the present study. The basic clinical details are shown in Table 1. The age was 72.76 ± 8.71 years (range 58-89 years) with 25 males in total (73.53%). 3 patients had sick sinus syndrome (SSS) while the rest had high-grade atrioventricular conduction block (AVB). Atrial fibrillation (AF) was recorded in 4 patients, and premature

ventricular contraction (PVC) was recorded in 2 patients. There was a significant decrease compared to the iQRSd with the pQRSd (144.87±5.22ms vs. 116.18±6.15ms, $P < 0.01$), see Table 2. The pQRSd was 28.70±3.30ms (95% CI:27.55-29.85ms, $P< 0.01$) shorter than the iQRSd (Figure2). There were 12 patients with a greater than 30ms shortening in QRS duration after LBBP.

4. Discussion

The paced morphology of the typical RBBB is considered as one of the necessary parameters during the LBBP implantation[8-10]. It is important to determine the LBBP lead depth into ventricular septum. As the advancement of the tip of the lead in the interventricular septum, the notch on the paced QRS in lead V1 will change from the LBBB morphology to the RBBB morphology[4]. We previously thought the pQRSd should not be shorter than the iQRSd in the patient with RBBB, as excitation is conducted forward through the LBB and Purkinje fibers to activate the LV first, and then to activate the RV through the intercalated discs of myocardium. In other words, paced morphology of the typical RBBB is formed because the LV is activated earlier than the RV (Figure 3 A). To our surprise, both selective and non-selective LBBP performed on patients with the RBBB caused a narrower QRS complex. The mechanisms by which this occurs have never been reported. In the following paragraphs, we discuss several possible mechanisms.

An excited fusion of the LV and local RV septum

SLBBP and NSLBBP are two subgroups of LBBP, the fundamental difference between them is the region captured. During low output pacing at near-threshold, SLBBP capturing only the LBB is characterized by an isoelectric interval between the pacing stimulus and the onset of surface QRS complex. With increasing pacing output, SLBBP is converted to NSLBBP with a narrower QRS complex and no isoelectric interval, which means both LBB and local adjacent septal myocardium are captured[4,11]. Chen et al. described the changes of paced morphology of QRS obtained by NSLBBP under different pacing outputs, showing a narrow paced QRS complex (QR with narrow R wave in lead V1, and narrow S wave in lead I, V5 and V6) [12]. We hypothesize that under NSLBBP, myocardial excitation no longer follows the sequence of excitation of the LV first and then the RV, but follows the excitation of the LV along with the local RV septum. In this condition, excitation would be transmitted from the LBB area to the local RV septum through the intercalated discs of septal myocardium, leading to a fusion of the excitation of the LV, LBB area and local RV septum, which eventually forms a narrow paced QRS complex (Figure 3 B).

Virtual electrode polarization

Virtual electrode polarization (VEP) effect refers to the fact that when a depolarized and hyperpolarized region is created surrounding the tip of the electrode, increased output would create a larger virtual electrode surrounding the tip, which results in larger volume of myocardium being depolarized [13-15]. In bipolar pacing, the anodal right ventricular ring might pre-excite a portion of the right septum. When right ventricular anodal capture occurs, QRS duration is minimized, presumably because in this situation there are at least 2 depolarization waves fronts activating the ventricles, shortening conduction time from the left ventricle to the right ventricle.[16] High output bipolar pacing would produce a narrower QRS duration as the right ventricular delay during LBBP is compensated by pre-exciton of a portion of the right septum[12]. To sum up, a fusion of right ventricular septal excitation along with ventricular excitation will be caused by the VEP. That is why the paced morphology of the typical RBBB changes, including the isoelectric interval fainted, the R wave disappeared in V1 and the QRS complex duration minimized.

Transverse interconnection

Song-Yun Chu et al. describing the LBBP as a choice to correct the RBBB in a case report putting forward an intriguing theory that unipolar pacing captured the intra-Hisian LBB then recruited the distal RBB through transverse interconnection fibers (TF). TF, connecting the left and right bundle branches, can transmit the electrical signals from LBB to RBB, thus correcting the distal RBBB and causing a narrower QRS complex [17]. (Figure 3 C) Back in the 1970s, Lazzara et al. stimulated the incised His bundle intracellularly and found that the native conduction restored, which suggested that functional transverse interconnection (FTI) exists

in the His bundle and the bundle branches and can transmit an electrical signal across fibers[18]. Transverse interconnection challenges the traditional theory of longitudinal dissociation that the LBB and RBB are longitudinally separated by collagen sheaths within the His bundle, making conduction better "end to end" than "side to side" within the His bundle. [19]. The limitation of transverse interconnection has been noticed before, if transverse connections coexist with longitudinal dissociation, then the native conduction would circumnavigate the structure block [20]. We suspected that if there is indeed a transverse connection between bundle branches, the excitation generated by LBBP would bypass the block to RBB and then conduct forward through RBB and Purkinje fibers to excite the RV with no paced morphology of RBBB pattern. Besides that, the anatomical structure of these fibers has not been clearly reported before, which requires further studies, especially in the human body [21].

Retrograde conduction of LBB activation

Previous studies have shown that there was the retrograde activation of the His bundle in the human heart [22-24], which was also confirmed by the retrograde His potential recorded in the process of determination of SLBBP [4]. Zhang et al. had suggested that without RBBB or proximal LBBB, besides the stimulus conducts rapidly through the LBB and Purkinje fibers to activates LV, it reversely conducts to His bundle and then conducts forward through the RBB and Purkinje fibers to activates the RV [25]. However, the process by which retrograde conduction of LBB activation overcomes structural barriers of longitudinal dissociation within His bundle to activate RBB is obscure and may be successful through AVN or TF/FTI. (Figure3 D&E) Even if it can, it is unknown whether it can recruit the distal RBBB or not.

Conclusions

In patients with RBBB, the duration of QRS complex after LBBP is narrower than that before LBBP. We propose several possible mechanisms, including excited fusion, virtual electrode polarization, transverse interconnection, and retrograde conduction of LBB activation. However, the specific mechanism is not yet clear, and the further electrophysiological mapping of the propagation is needed to confirm it.

Study Limitations

There are some limitations in this study. Firstly, our study was an observational study with a small sample size. Secondly, we only compared the changes of QRS duration on the twelve-lead surface EGM, which should be further studied by using the mapping electrode catheter. Thirdly, we did not explore the effect of output voltage of LBBP on the paced QRSd in detail. However, the pQRSd narrowing caused by LBBP is evident in patients with RBBB, and the specific mechanisms behind this may be multifactorial, which requires more precise mapping of the propagation and further anatomical study of the conduction system of the heart.

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FIGURE LEGENDS

Figure1

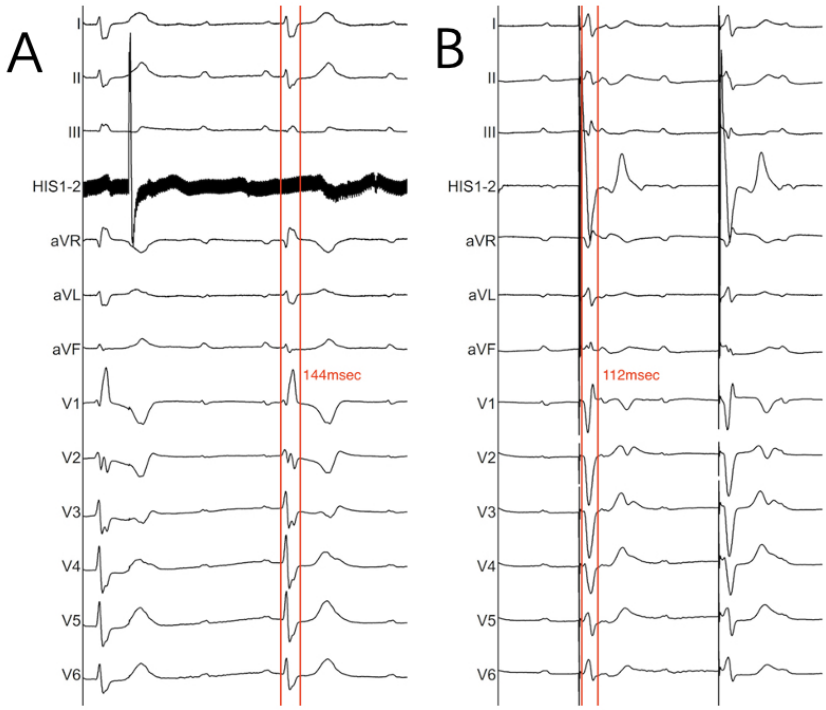

Figure 1 IGEM of a patient with RBBB after LBBP at 25 mm/s. **A:**Intrinsic RBBB pattern, a morphology of typical cRBBB, with the QRS duration of 144msec, rSR' pattern in leads V1 wide and slurred S wave in leads V6 and I. **B:** LBBP with the qR pattern in V1 but significantly narrower QRS duration of 112ms. IGEM = intracardiac electrocardiogram, RBBB = right bundle branch block, LBBP = left bundle branch pacing, cRBBB = complete right bundle branch block.

Figure2

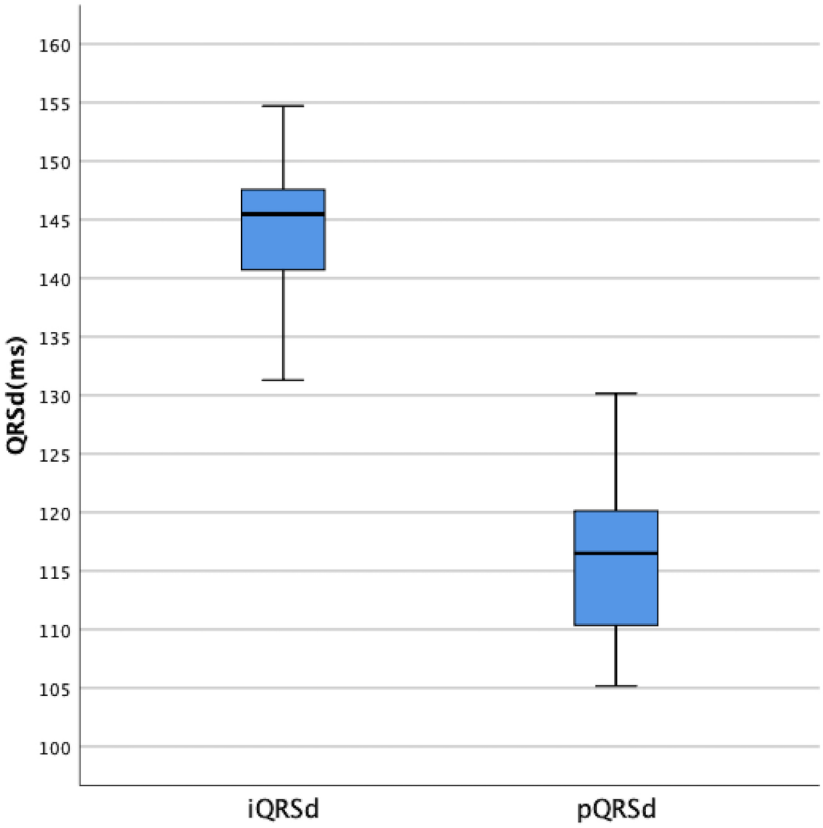

Figure2 Comparison of QRS duration before and after LBBP implantation in patients with RBBB. It is obvious that QRS duration is significantly shortened after LBBP implantation. iQRSd = intrinsic QRS duration, pQRSd = paced QRS duration.

Figure3

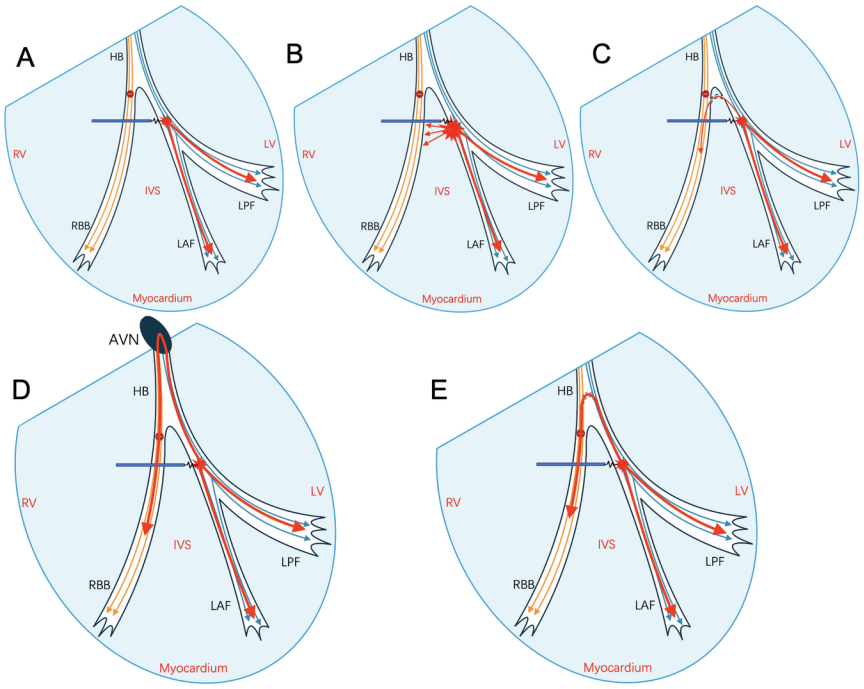

Figure3

A: During low output pacing at near-field, SLBBP capturing only the LBB and the excitation is conducted forward through the LBB.**B:** As output increasing, the SLBBP is converted to NSLBBP which causing a fusion of excitation of the LV and the adjacent local septal myocardium around the LBB by capturing the LBB area. **C:** LBBP might bypass the block of RBB through TF/FTI (dashed line) and eventually activate RBB with no paced morphology of RBBB. **D:**Excitation is conducted forward through the LBB and Purkinje fibers to activate the LV, meanwhile it reversely conducts to AVN and then recruit the RBB. **E:** TF/FTI (dashed line) may also exist within HB, connecting LBB and RBB transversely, which can transmit the retrograde excitation of LBB to RBB and then capture RBB. AVN = atrioventricular node; HB = His bundle; RBB = right bundle branch; LPF = left posterior fascicular; LAF = left anterior fascicular; TF = transverse interconnection fibers; FTI = functional transverse interconnection; RV = right ventricle; LV = left ventricle; IVS = interventricular septum

TABLE

Table 1 Baseline characteristics (N=34)

Patient parameters	Value
Age, years	72.76 ± 8.71
Male sex, n (%)	73.53
Indication of pacing, n SSS High-grade AVB	3 31

Data are shown as mean ± SD.

SSS = sick sinus syndrome; AVB = atrioventricular conduction block.

Table 2 Intrinsic QRS duration and paced QRS duration (N=34)

Variable	Value
Intrinsic QRS duration (ms)	144.87±5.22
Paced QRS duration (ms)	116.18±6.15

Data are shown as mean ± SD.

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`TABLES.pdf` available at https://authorea.com/users/390888/articles/505103-left-bundle-branch-pacing-in-patients-with-right-bundle-branch-block