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Double QRS Transition During Left Bundle Branch Area Pacing: A Case Report

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Abstract

Anodal capture, characterized by a different QRS morphology compared to cathodal capture, is a well-known issue in cardiac resynchronization therapy (CRT). Left bundle branch area pacing (LBBAP**),** a novel physiological pacing technique, is also used as a bailout strategy following failed conventional CRT implantation. In LBBAP, QRS transition, defined by a change in paced QRS morphology, serves as a key marker of successful lead placement. This clinical case highlights the importance of recognizing both anodal capture and QRS transition in patients receiving LBBAP combined with an implantable cardioverter-defibrillator (ICD) as bailout strategy for failed cardiac resynchronization therapy with defibrillator (CRT-D) implantation, in order to optimize pacing parameters and device programming.

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1. Introduction

Myocardial stimulation occurs due to a sudden voltage change in myocardial tissue. During bipolar pacing, this stimulation arises from the arrival of negatively charged electrons at the cathodal pole of the lead, which then return to the device via the anodal pole. The initiation of this voltage change is termed the "make" phase, and its termination the "break" phase. [1]

In bipolar pacing configurations, the cathodal pole is typically programmed to the lead tip, while the anodal pole may be programmed to the lead ring, defibrillation coil (bipolar pacing), or the generator itself (unipolar pacing). [1]

Functionally, myocardial capture can occur at both poles. However lower energy is usually required at the cathodal pole to capture tissue (except during the relative refractory period), whereas higher energy is needed at the anodal pole, particularly when the anode has a large surface area, resulting in lower charge density. Anodal stimulation often occurs during the "break" phase of the stimulus. [2–4]

Modern devices, especially cardiac resynchronization therapy (CRT) systems, allow for multiple pacing vectors between right ventricular (RV) and left ventricular (LV) leads. For example, the cathode may be programmed to the LV lead tip and the anode to the RV lead ring to optimize thresholds. [1]

When pacing the left ventricle in a bipolar configuration (LV tip [cathode] → RV ring [anode]), high pacing outputs (e.g., for patients with elevated LV thresholds) may inadvertently cause anodal capture at the RV site. This can result in RV-only pacing (due to failed LV capture), leading to loss of CRT benefits and associated clinical risks. [5] To mitigate this, reprogramming the anode to a larger surface area (e.g., defibrillation coil) reduces charge density and suppresses anodal capture. [4] For this reason, anodal capture is rarely observed with RV leads with an integrated bipolar design. [6]

Left bundle branch area pacing (LBBAP) has emerged as a novel technique in conduction system pacing (CSP), addressing limitations of His Bundle Pacing (e.g., unstable electrical parameters and procedural complexity). [7,8] It produces a physiological LV activation pattern comparable to CRT,

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making it a viable option as a bailout strategy during failed CRT implantations or for patients who do not meet CRT criteria but may benefit from physiological pacing. [9]

Several electrocardiographic criteria are used to confirm successful LBBAP:

1. QRS transition:
- During threshold testing: from non-selective left bundle branch pacing (ns-LBBP) to selective left bundle branch pacing (s-LBBP) or to left ventricular septal pacing (LVSP).
- At programmed stimulation: transition to s-LBBP with pacing output adjustments.

2. V6 R-wave peak time (V6RWPT):
- < 75 ms in patients with narrow native QRS or isolated right bundle branch block (RBBB)
- < 80 ms in patients with left bundle branch block (LBBB), interventricular conduction delay (IVCD), RBBB with fascicular block, wide escape rhythm, or asystole.

3. V6-V1 interpeak interval: > 44 ms
4. Stimulus-to-Potential alignment: potential-V6RWPT matches stimulus-V6RWPT (difference about ± 10 ms). [10]

Among these, QRS transition (though rarely observed) has the highest specificity for confirming true left bundle branch (LBB) capture. [10]

Transition from ns-LBBP to s-LBBP is defined by prolongation of the stimulus-to-QRS interval (measured from the pacing artifact). On the ECG, this manifests as:

- A rounded R' wave in lead V1, accompanied by prolongation of the V1 R-wave peak time (V1RWPT) exceeding 10 ms.
- The development of a deeper S wave in leads V6 and I, while the V6RWPT remains unchanged.

Transition to LVSP, instead, reflects loss of LBB capture, resulting in pure LVSP. Key ECG features include:

- Prolongation of the V6RWPT, indicating delayed activation of the left ventricular lateral wall.
- Reduced R' wave amplitude in V1, reflecting diminished direct LBB activation.
- Disappearance of S wave in lead I and V6, consistent with altered ventricular depolarization patterns. [10]

2. Case Presentation

A 75-year-old man with a history of acute myocardial infarction treated with coronary artery bypass grafting (CABG; left internal mammal artery to left anterior descending artery) and concomitant modified endo-ventricular circular plasty (Dor procedure) for apical aneurysm and atrial flutter treated with transcatheter ablation in 2022, targeting a critical isthmus at the cresta terminalis, subsequently developed sinus node dysfunction requiring permanent pacemaker implantation. Optimal medical therapy for heart failure was initiated and titrated over several months.

Transthoracic echocardiography revealed left ventricular hypertrophy, septal dyskinesia, and apical akinesia, resulting in severe left ventricular dysfunction (left ventricular ejection fraction, LVEF 25%). Given persistent LV dysfunction despite optimal medical therapy and the presence of LBBB with a QRS duration of 164 ms, an upgrade to CRT was indicated.

Pre-procedural contrast venography demonstrated occlusion of the left axillary vein; thus, the patent left subclavian vein was selected for venous access. A single-coil defibrillation lead was first positioned at the mid-apical septum of the right ventricle. Subsequent attempts to cannulate the coronary sinus for LV lead placement were unsuccessful, despite venographic guidance. As a bailout strategy, a lumenless lead (SelectSecure MRI SureScan 3830, Medtronic) was implanted via a C315-His delivery sheath (Medtronic) for LBBAP. The implanted device (Amplia MRI CRT-D SureScan, Medtronic) was connected to the defibrillation lead (DF4 port) and to the LBBAP lead and the preexisting atrial lead (IS1 port).

Initial LBBAP threshold was 2.0V@0.4ms, with QRS transition from non-selective to selective LBB capture at 2.2V@0.4ms. After current of injury (COI) reduction, threshold improved to 1.0V@0.4ms, with QRS transition at 1.1@0.4ms.

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The following day, threshold testing was repeated with multiple vectors to optimize pacing parameters.

During bipolar pacing (LBBAP tip → RV defibrillation lead ring) starting from 5V@0.4ms, two distinct QRS morphology changes were observed:

1. At 4.5V@0.4ms: morphology consistent with right ventricular apical pacing, attributed to anodal capture at the RV defibrillation lead ring changes to a ns-LBBAP morphology (Figure 1).

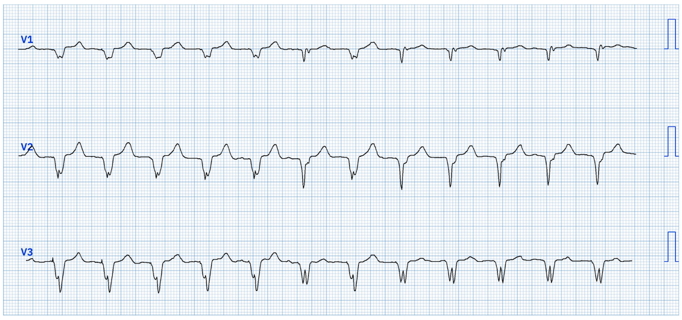

Figure 1. High output decremental pacing at voltage from 5V@0.4ms to 4.25V@0.4ms (auto decrement each three beats) with initial anodal capture resulting in right ventricular apical pacing and then transition of QRS to non-selective Left Bundle Branch Area Pacing (ns-LBBAP).

2. At 1.0V@0.4ms: transition from ns-LBBAP to s-LBBAP, with threshold at 0.75V@0.4ms (Figure 2).

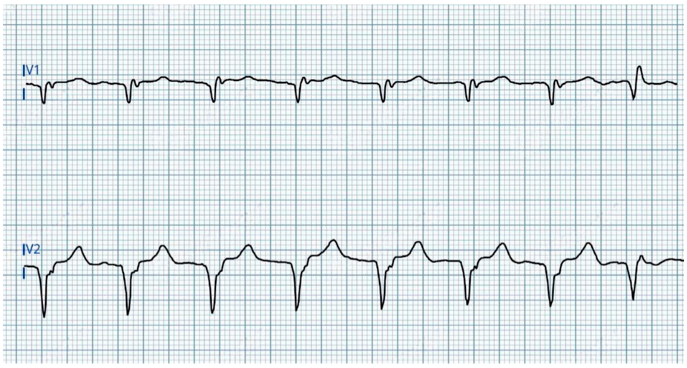

Figure 2. ECG during threshold tests between 1.5V@0.4ms and 1V@0.4ms showing QRS transition (last beat) from ns-LBBP to selective Left Bundle Branch Pacing (s-LBBP).

In summary, three distinct QRS morphologies were observed:

> 4.5V@0.4ms: dominance of anodal capture (RV apical pacing) due to high charge density at the anode.

4.5V-1.25V@0.4ms: ns-LBBAP due to progressive reduction of anodal interference.

≤ 1.0V@0.4ms: s-LBBAP, with singularly capture of the LBB.

Voltage reduction revealed a critical gradient: anodal capture dominates at high outputs, while physiological LBB capture emerges at lower voltages, underscoring the importance of optimizing stimulation parameters to maximize LBBAP benefits.

3. Discussion

Although the use of CRT devices has declined with the spread of LBBAP, certain challenges, well-known in CRT implantation, must also be considered for CSP.

A straightforward scenario of anodal capture at the LBBAP lead ring has recently been described. In such cases, the physiological benefits of LBBAP could be lost due to anodal capture at the lead ring, however the hemodynamic effects remain controversial. [11,12]

In the case presented here, however, the mechanism of anodal capture resembles that observed in CRT implants, where cathodal and anodal sites are located on two separate leads. This scenario must be carefully considered to prevent the loss of the benefits from both CRT and LBBAP.

To avoid anodal capture in this context it is needed to:

- Confirm that anodal capture occurs only at voltages below the programmed pacing output, ensuring an appropriate safety margin.
- Select a different anodal pole for bipolar pacing. In devices with a defibrillation lead, choosing a larger-area anode (e.g., the defibrillation coil) can reduce charge density.

4. Conclusions

Anodal capture, a well-known issue in CRT implants, must also be considered in the context of LBBAP, particularly in complex devices with both an RV defibrillation lead and a LBBAP lead. This is especially critical in multi-vector pacing configurations to optimize the benefits of physiological stimulation and avoid the detrimental effects of unintended RV apical pacing.

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Abbreviations

The following abbreviations are used in this manuscript:

CRT	Cardiac Resynchronization Therapy
LBBAP	Left Bundle Branch Area Pacing
ICD	Implantable Cardioverter Defibrillator
CRT-D	Cardiac Resynchronization Therapy with Defibrillator
RV	Right ventricular
LV	Left ventricular
CSP	Conduction System Pacing
ns-LBBP	non-slective Left Bundle Branch Pacing
s-LBBP	selective Left Bundle Branch Pacing
LVSP	Left ventricular septal pacing
V6RWPT	V6 R-wave peak time
RBBB	Right bundle branch block
LBBB	Left bundle branch block
IVCD	Interventricular conduction delay
LBB	Left bundle branch
V1RWPT	V1 R-wave peak time
CABG	Coronary artery bypass grafting
LVEF	Left ventricular ejection fraction
COI	Current of injury

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