T-wave inversions during conduction system pacing: A marker of more physiological ventricular activation

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Permanent myocardial pacing can preserve adequate heart rates and improve symptoms and mortality in patients with bradycardia [1]. Conventional right ventricular (RV) pacing is far from the optimal treatment since up to 20% of patients experience a reduction in the left ventricular (LV) ejection fraction, which can lead to heart failure (HF) [2]. This was the main incentive for developing 'conduction system pacing (CSP)' techniques that target (directly or indirectly) the capture of conduction tissue, initiating more physiological ventricular activation. Although His bundle pacing (HBP) leads to the best ventricular synchrony [3], proper positioning is complicated, requires high pacing thresholds, and is associated with lower sensing values. For these reasons, left bundle branch area pacing (LBBAP), where the lead tip is deployed in the left subendocardial septal area, is currently preferred over HBP.

While ventricular activation is reasonably well understood [4, 5], little is known about the repolarization sequence during LBBAP. In a sizeable group of patients, Geng et al. [6] investigated the effect of LBBAP on occurrence and characteristics of T-wave inversions (TWIs). They showed that TWIs frequently (in 66% of cases) occurred one day after initiating LBBAP. TWIs appeared more frequently in patients with bundle branch blocks, and the main TWI predictor was QRS duration ≥120 ms. TWIs were unrelated to myocardial ischemia and, in most patients (88%), partially or entirely disappeared during a median follow-up of 10 days.

It is 40 years since Rosenbaum described the occurrence of transient TWIs in animal experiments [7]. He showed that temporary ventricular pacing could lead to changes in T-wave vectors and polarities that persisted after cessation of pacing and restoration of physiological ventricular activation. Interestingly, T-wave inversions were observed in the same leads in which the polarities of QRS complexes had been changed during pacing. Rosenbaum coined the term "cardiac memory" to note this phenomenon. This phenomenon has been observed in patients after cessation of RV pacing, successful ablation of accessory pathways associated with intermittent LBBB and ventricular tachyarrhythmias [8].

In a normal heart, the last activated regions of the ventricular wall generally have shorter action potential durations (APD) compared to the ones activated earlier. Myocytes that depolarize last will therefore repolarize first [9]. However, when the ventricular activation sequence suddenly changes, the distribution of APD does not immediately adapt to this change. Consequently, ventricular wall regions that were previously activated late (with shorter APD) may become activated sooner, creating a situation where myocytes that depolarize first also repolarize first. A similar situation was reported in patients with HF and wide QRS complexes [9].

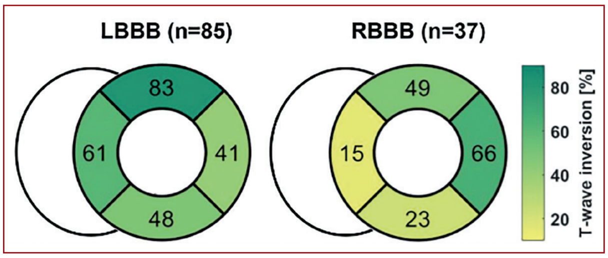

Figure 1. Visual representation of regional T-wave inversion distribution in LBBB (left) and RBBB (right) patients. data presented in Table 3 in the study by Geng et al. [6] was used as input. The regional TWI percentages were computed by averaging the percentages belonging to leads V1 and V2 (septum), V2 and V3 (anterior), V5, V6, I, and aVL (lateral), II, III, and aVF (inferior)

Abbreviations: LBBB, left bundle branch block; RBBB, right bundle branch block; TWI, T-wave inversion

This property appears to explain the observation by Geng et al. that TWI locations depend on the type of the bundle branch block; i.e., in LBBB patients, they occurred more frequently in leads V1–V4, II, III, and aVF, but in RBBB patients, leads I and aVL were affected more often. Figure 1 visualizes the incidence of TWIs per ECG-lead using data from Geng et al. (Table 3) [6] and assumes the following lead associations: leads V1 and 2 with the septum, V2 and V3 the anterior, V5, V6, I, and aV — the lateral wall, and II, III, and aVF — the inferior wall. In this representation (Figure 1), it becomes clear that TWIs in LBBB patients occurred most often in regions in which the sequence of ventricular activation and polarities of QRS complexes changed significantly during LBBAP. It would be interesting to determine if TWIs distribution in RBBB patients was associated with fascicular hemiblocks, which lead to less physiological LV activation. That was, however, not analyzed by the authors. Another reason may be including the patients with heart failure, which may lead to the inclusion of altered activation-repolarization relationships even in the absence of conduction disturbances [9]. Few studies have investigated repolarization changes following biventricular pacing in HF patients. Dispersion of repolarization appears to have a time-dependent character, with a high amount of dispersion observed within one month after implantation and decreasing over time [10].

Interestingly, computer simulations have demonstrated that acute biventricular pacing reduces LV repolarization dispersion on a regional level while increasing RV repolarization dispersion, leading to a higher degree of interventricular repolarization dispersion. During chronic biventricular pacing, however, an adaptation of APDs occurs, leading to a reduction in repolarization dispersion [10]. These processes are compatible with physiological adaptations to minimize dispersion of repolarization, so the disappearance of TWIs appears to be a physiological process.

Although inverted T-waves concern cardiologists, it is unclear to what extent TWIs related to cardiac memory are associated with an elevated risk for arrhythmias. Most clinical studies investigating the efficacy of conventional biventricular pacing did not find an association with ventricular tachyarrhythmias [11–13]. However, multiple individual cases describing the occurrence of electrical storm shortly after CRT implantation raised concerns about the pro-arrhythmic effect of LV epicardial pacing [14]. While Geng et al. [6] did not investigate T-wave changes during conventional biventricular pacing, Gupta et al. [15] recently demonstrated that CSP (both HBP and LBBAP) was associated with reduced repolarization heterogeneity (defined as Tpeak-Tend on a surface ECG) and greater cardiac memory resolution compared to conventional biventricular pacing. Additional studies comparing the temporal evolution of repolarization changes during biventricular vs. conduction system pacing are certainly warranted. More mechanistic insights can be obtained using invasive or non-invasive electro-anatomic mapping techniques.

Article information

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