Physiological versus non-physiological cardiac pacing as assessed by Ultra-high-frequency electrocardiography

Karol Curila[1], Pavel Jurak[2], Pavel Leinveber[3], Radovan Smisek[2,4], Petr Stros [1], Filip Plesinger[2], Ivo Viscor[2], Vlastimil Vondra[2], Jan Mizner[1], Ondrej Sussenbek[1], Lucie Znojilova[1], Jakub Karch [1], Marketa Susankova[1], Josef Halamek[2], Frits W. Prinzen[5]

[1] Cardiocenter of University Hospital Kralovske Vinohrady, Prague, Czechia
[2] Institute of Scientific Instruments, the Czech Academy of Sciences, Brno, Czechia
[3] ICRC at St. Anne´s University Hospital, Brno, Czechia
[4] Department of Biomedical Engineering, Brno University of Technology, Brno, Czechia
[5] Department of Physiology, Maastricht University Medical Center, Maastricht, the Netherlands

Abstract

Background: *Permanent cardiac pacing can cause heart failure, with the ventricular dyssynchrony being identified as the main cause for its development.*

Method: *His bundle pacing (HBp), left bundle branch pacing (LBBp), and left ventricular myocardial septal pacing (LVSP) were introduced recently. Their impact on ventricular dyssynchrony was not known. We used ultra-high-frequency ECG (UHF-ECG) to compare ventricular depolarization in these pacing techniques.*

Results: *We showed the nonselective HB pacing produces the same pattern of UHF-ECG ventricular depolarization as selective HB pacing. Next, we showed the nonselective His bundle pacing in the area below the tricuspid valve has the best interventricular synchrony from all other RV pacing locations with myocardial capture. We also compared UHF-ECG-derived parameters of ventricular depolarization during HBp, LBBp, and LVSP and we showed that both pacing types from the left septal area are less physiological than nsHBp.*

Conclusion: *UHF-ECG is an effective tool that can be used in clinical practice to assess the electrical dyssynchrony caused by cardiac pacing. Furthermore, its real-time implementation allows recognizing between physiological vs. non-physiological pacing during an implant procedure.*

1. Introduction

Permanent cardiac pacing is an established method of treatment of patients with bradycardia. However, in a substantial part of them, it leads to the decline of the heart function with the possibility of developing heart failure [1]. The dyssynchrony of the heart ventricles caused by the right ventricular (RV) myocardial pacing was identified as the leading cause of adverse effect of RV pacing [2].

Several ECG-based methods of dyssynchrony measurement have been applied in the past. They are QRS duration and QRS area measurement, body surface mapping, ECGi, or electroanatomical mapping [3]. However, their clinical application is limited due to different reasons. The ultra-high-frequency ECG (UHF-ECG) is a method introduced recently and shown to provide intramural/volumetric information about the activation of particular ventricular segments [4-6]. The concept of the method allows displaying the sequence of ventricular activation based on acquisition and processing of the ultra-high-frequency signals emerging during phase 0 of the myocyte's action potentials.

The new methods of permanent pacing, which should preserve the synchronous ventricular activation, were introduced in the last years into clinical practice. They are His bundle pacing (HBp), left bundle branch pacing (LBBp), and left ventricular septal pacing (LVSP). During these pacing methods, conductive or myocardial tissue capture or simultaneous capture of both occur frequently. The impact of different types of ventricular capture during these pacing techniques on the pattern of ventricular depolarization was unknown and was the topic of our previous research. The results have been published recently [7-9].

2. Methods and Results

During a period of 2019-2021 patients with bradycardia and pacing leads implanted or temporarily placed in the His bundle region, various location in the RV of in the left septal area were included in one of the following projects. Schematic presentation of the locations within the conductive system where pacing leads were placed is

shown in Figure 1.

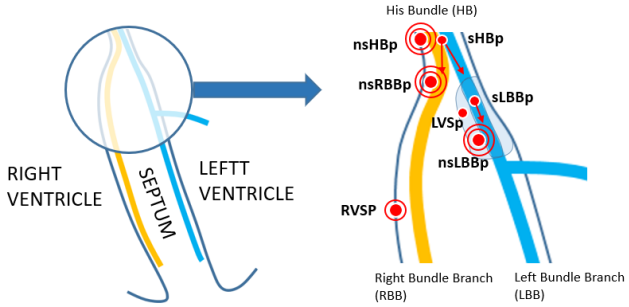


Figure 1: Schematic presentation of paced locations with resultant capture types. sHBp = selective His bundle pacing, nsHBp = nonselective His bundle pacing, nsRBBp = nonselective right bundle branch pacing, RVSP = right ventricular septal pacing (subclassified as RVIT or RVOT), sLBBp = selective left bundle branch pacing, nsLBBp = nonselective left bundle branch pacing, LVSP = lesft ventricular septal pacing

2.1 Ventricular synchrony during selective, nonselective, and myocardial pacing in patients with narrow QRSs

When placing the lead in the area of the His bundle, three different types of ventricular capture could be observed. They are; a/ selective His bundle pacing (sHBp), during which the ventricles are being activated exclusively through the conductive system and resultant QRS complex is the same as the QRS complex during the spontaneous rhythm in patients with narrow QRS; b/ myocardial para-hisian capture with pure myocardial capture of myocytes in the para-hisian area leading to wide paced QRS complex; and c/ nonselective His bundle capture (nsHBp), during which both the His bundle and myocytes in the parahisian area are captured at the same time, which cause QRS duration prolongation due to formation of the pseudo-delta wave.

To study above mentioned ventricular captures, we compared 44 spontaneous rhythms in patients without bundle branch block to 28 sHBp, 43 nsHBp, and 18 myocardial captures. All patients underwent the pacemaker implantation due to bradycardia with His bundle lead placement in the past. UHF-ECG data acquisition was performed during in-office visits. First, a decremental output pacing was performed to identify specific ventricular capture types, and then 5 minutes of data recording was done. These parameters of dyssynchrony were evaluated: 1/ QRSd – as the longest QRS duration in any chest lead, 2/ e-DYS – as the absolute value of the maximal difference between all V1–V8 activation times, 3/ QRS area – computed as QRSarea = √(〖Xarea〗 ^2+ 〖Yarea〗 ^2+ 〖Zarea〗 ^2) and 4/ Vd – average value of the UHFQRS duration at the 50 percent threshold of V1-V8 leads. The linear mixed model effect was used to compare measured values between different ventricular activation types.

We showed that although the nsHBp had longer QRS duration and greater QRSarea than sHBp and spontaneous rhythm, both e-DYS and Vd were statistically the same between nsHBp, sHBp and similar to spontaneous rhythm [9]. However, contrary to it, pure myocardial capture in the para-hisian area led to a significant increase of e-DYS and Vd compared to all other studied captures. Representative UHF-ECG maps showing the differences between studied capture types are shown in Figure 1.

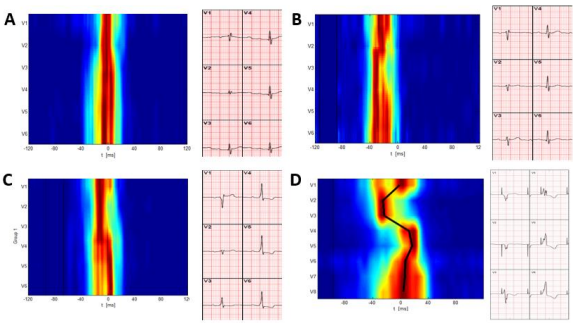


Figure 1: UHF-ECG depolarization maps during spontaneous rhythm (A), sHBp (B), nsHBp (C), and pure myocardial para-hisian capture (D).

2.2 Ventricular synchrony during ´distal´ His bundle pacing and myocardial pacing at various sites in the right ventricle

Although HBp provides the most physiological activation of the ventricles, it has some shortcomings. They are lower sensing values and a higher need for lead reinterventions. A possible solution is to pace the ventricular portion of the His bundle below the level of the septal leaflet of the tricuspid valve, where greater lead stability and higher sensing values are seen[10]. But, in that location, possible greater involvement of myocardial tissue could be expected during nsHBp, and more significant dyssynchrony appeared during nsRBBp.

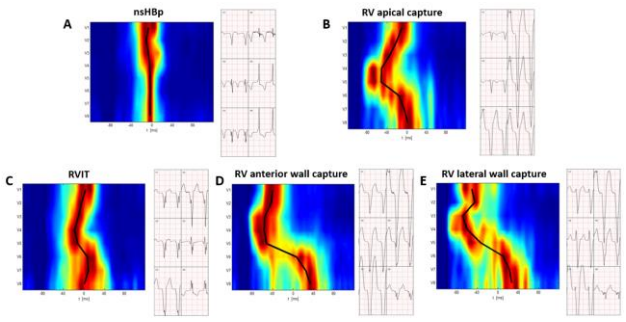
Pacing the conduction tissue (HB or RBB) below the level of the tricuspid valve should be just a variant of the RV septal pacing, with faster ventricular activation thanks to the engagement of the conductive tissue. The difference in ventricular depolarization between HB or RBBp and other types of RV was newer studied.

In our project, using UHF-ECG, we compared 32 narrow QRS spontaneous rhythms, 46 nsHBp or RBBp, 30 RV septal pacing in RV inflow area (RVIT), 39 septal pacings in RV outflow area (RVOT), 46 RV apical pacing, 39 RV anterior wall pacing and 47 RV lateral wall pacing in 51 patients. All UHF-ECG recordings were performed during the implant procedure when the pacing leads were temporarily placed in predefined pacing locations. UHF-ECG data acquisition lasted for 2-3 minutes of pacing at

100-120 bpm in each pacing location. We studied and compared the left ventricular lateral wall delay (LVLWd) and RV lateral wall delay (RVLWd), measured as V8 or V1 delay from the pacing artefact, between all capture types. The linear mixed model effect was used to compare measured values between different ventricular activation types.

We found out that UHF-ECG describes in detail ventricular depolarization during all studied RV capture types[7]. The RVIT was showed to produce better LV synchrony than other RV pacing locations with RV myocardial capture, although the QRS duration during the RVIT was the same as during the RVOT. However, LV dyssynchrony seen during the RVIT was still worse than the nsHBorRBB, which produced similar levels of right and left ventricular dyssynchrony as seen during spontaneous rhythm with narrow QRSs. Moreover, RV apical pacing compared to other pacing locations also created significant RV dyssynchrony – Figure 2.

Figure 2: UHF-ECG depolarization maps during nsHBp (A), RV apical (B), RVIT (C), RV anterior wall (D), and RV lateral wall pacing (E) in one patient.

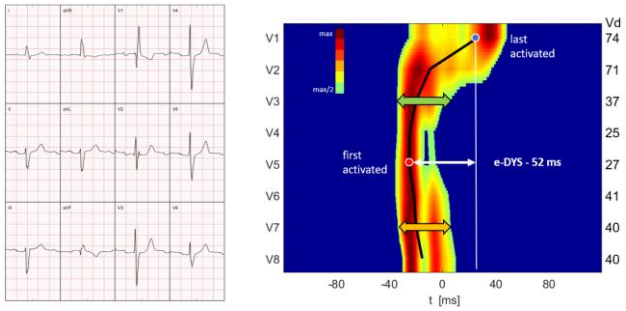


2.3 Comparing ventricular synchrony during nonselective His bundle, nonselective left bundle branch, and left septal myocardial pacing

Following after HBp, two new physiological pacing techniques were introduced. They are: left bundle branch pacing (LBBp) and left ventricular septal pacing (LVSp). Both share similar characteristics with respect to the lead placement in the left septal area and pace QRS complex with pseudo-right bundle branch morphology (RBBB) in lead V1[11, 12]. Their impact on ventricular depolarization and the difference between them was not known.

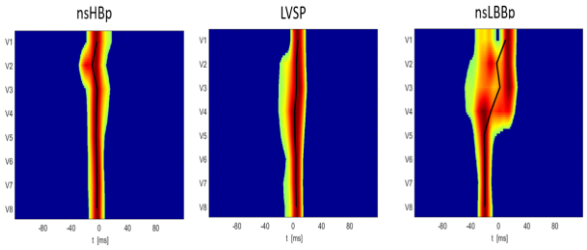
To study them, we compared 35 nonselective LBBP (nsLBBp) vs. 96 LVSP with 55 nonselective His bundle captures (nsHBp), which represented the physiological pattern of ventricular depolarization, in 68 patients with bradycardia and an indication for pacemaker implantation. All UHF-ECG recordings were performed during the implant procedure when pacing with specified capture types was performed at 110 bpm. The parameter of electrical dyssynchrony e-DYS (defined as the difference between the first and last activation under V1-V8) and Vxd (defined as UHFQRS duration at the 50% level of its amplitude) were measured as shown in figure 3. The linear mixed model effect was used to compare measured values between different ventricular activation types.

Figure 3: Presentation of the UHF-ECG depolarization map in a patient with spontaneous left anterior hemiblock and RBBB with measured parameters of dyssynchrony. The first activation occurred in V5 and last in V1, so the e-DYS = 52 ms. Local depolarization durations (Vxd) at 50% of UHFQRS amplitude under V3 (green arrow) and V7 (yellow arrow) were 37 ms and 40 ms, respectively. Vxd for other leads are displayed in ms on the right side of the map.



We have found that both nsLBBp and LVSp are less physiological than nsHBp and significant differences are present between them[8]. The LV lateral wall activation pattern during the nsLBBp was practically the same as seen during the nsHBp. However, more delayed activation of ventricular segments under the lead placed above the septum and RV (V1-V3) resulted in more significant interventricular dyssynchrony in nsLBBp than LVSP. LVSP preserved the interventricular dyssynchrony on the same level as nsHBp, but local depolarization durations under all chest leads were compared to nsHBp longer – Figure 4. This finding was valid for all included patients irespective of QRS morphologies during the spontaneous rhythm and also for patients with narrow QRSs or patients with nonLBBB morphologies.

Figure 4: UHF-ECG depolarization maps in one patient with nsHBp, LVSP, and nsLBBp.



3 Discussion

Unphysiological RV myocardial pacing can lead to significant ventricular dyssynchrony with a detrimental effect on cardiac function in some patients[2]. Most of the patients tolerate it for many years, but in some, heart failure develops shortly after the institution of pacing[13]. The experimental methods that can measure ventricular dyssynchrony, such as body surface mapping or ECGi, are expensive and time-consuming, so their widespread use in clinical practice cannot be expected.

UHF-ECG uses standard chest lead configuration to display the time course of ventricular depolarization in spontaneous and paced rhythms. Real-time data collection and processing allow displaying the resultant ventricular dyssynchrony immediately after acquiring a sufficient number of QRS complexes – usually 1-2 minutes. This allows the operator to quickly assess the effect of cardiac pacing on the resultant ventricular depolarization pattern. This could lead to the consideration of changing the pacing location to minimize the resultant dyssynchrony. A clinical trial that aims to validate the UHF-ECG parameters of ventricular dyssynchrony in the prediction of adverse LV remodeling in pacemaker recipients is currently ongoing - ClinicalTrials.gov Identifier: NCT04908033

4 Conclusion

UHF-ECG is an imaging method that allows displaying the time course of ventricular depolarization during spontaneous and paced rhythms. It could be used in outpatient conditions or during the operation procedure. Contrary to other methods of electrical dyssynchrony assessment, it is practical, cost-effective, and easy to operate. If it proves to be able to predict adverse LV remodeling and/or the clinical outcome of patients with pacemakers, then its use could have a significant role in improving the morbidity and mortality of pacemaker recipients and possibly also of heart failure patients.

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Address for correspondence:

Karol Curila, MD, PhD, MSc
Cardiocenter of 3rd Faculty of Charles University and University Hospital Kralovske Vinohrady in Prague, Srobarova 50, 100 34, Prague, Czech Republic, curilakarol@seznam.cz