INFLUENCE OF PACEMAKER TIMING ON DETECTION OF ATRIAL TACHYCARDIAS AND SIGNALS OF DIFFERENT FREQUENCIES

Jan Morava[1,2,3], Aneta Lhotová[2], Aleš Richter[2,3]

[1]Department of Cardiology, Regional Hospital Liberec, Liberec, Czech Republic

[2]Faculty of Health Studies, Technical University of Liberec, Liberec, Czech Republic

[3]Faculty of Mechatronics, Informatics and Interdisciplinary Studies, Technical University of Liberec, Liberec, Czech Republic

Abstract

The pacemaker (PCM) timing is a basic feature of the stimulation system. The device tries to bring the function of the heart with the conduction system disorder as close as possible to its original physiologically correct state. The main function of the PCM is a bradyarrhythmia therapy. Current devices are programmable and can adequately respond to any fluctuations in a heart rate from required values. Common parts of these devices are algorithms for the atrial tachycardias detection such as atrial fibrillation. The interpretation of a fast heart rate is affected by the pacemaker timing and different refractory intervals, especially in the case of tachycardias of lower frequencies. In this paper we discuss the effect of different atrial event frequencies to the adequate PCM response according to the timing behavior of the device. We prove our hypotheses by an experimental verification on the phantom of the pacemaker system by the in vitro method. The obtained results are compared with the case report from clinical practice. We set limit intervals for the detection of atrial tachycardias and verify the rate of the activation of the PCM program response for different frequencies. Finally, we discuss the behavior of cardiac implantable electronic devices (CIEDs) during the detection of signals of higher frequencies.

Keywords

pacemaker, cardiostimulation, timing, electrophysiology, biosignals, tachycardia

Introduction

The time continuity of all electrical processes is necessary for the correct heart activation. By the complex timing of individual parameters of the pacemaker (PCM) we try to bring the physiological electrical cardiac activation as close as possible. Each type of cardiac implantable electronic devices (CIEDs) uses timing cycles depending on the pacing mode, pacing limits and other stimulation parameters. These parameters or intervals are described in frequency or time range. Each timing cycle operates in one of two states, where the timer continues until it completes its cycle (its completion leads to the application of a pacing pulse or it starts another timing cycle), or it can be reset (in this case the timing cycle starts from the beginning) [1, 2].

The CIED timing is based on the lower pacing limit interval, which is the minimum stimulation rate for a given heart chamber. It is based on the detection of sensed or paced atrial or ventricular events. In asynchronous modes (usually temporary states) the device paces continuously at a given frequency. In inhibited modes the device paces only in the case of the absence of its own electrical activity. The adequate signal detection is based on the timing of refractory intervals, resp. intervals of relative and absolute (also blanking interval) refractory. Absolute refractory intervals are the first phase of refractory intervals and always follow sensed or paced events. At these intervals, which prevent cross talks of other events or double counting of one event, no sensing occurs. During relative refractory intervals (following blanking periods) the input amplifiers are active, and all sensed events are classified and marked as refractory. This means that they do not affect the pacing function of the stimulator, but they are included into the diagnostics of arrhythmias and counters that affect other algorithms. The refractory event does not directly affect timing cycles and cannot reset or start a given interval. The aim is to prevent improper detection of inappropriate

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signals outside the window of interest—the alert window [3, 4].

The aim of our research was to demonstrate the AMS function, to find out the limit intervals and the activation time for different frequencies and to find out an imaginary limit when increasing frequency level have no longer an effect on the acceleration of AT detection time.

Methods

Detection of atrial tachycardia

Current CIEDs are equipped with a function that prevents fast ventricular triggered pacing during atrial tachycardias. The algorithm is called automatic mode switching (AMS) or mode switch (MS) at various manufacturers. It is available to all CIEDs with the atrial and the ventricular channel. After the AMS is activated, the PCM temporarily switches to inhibited pacing mode, which prevents fast triggered ventricular pacing. The sensing of an atrial channel is still active, and the temporary pacemaker reprogramming lasts for the duration of an atrial tachycardia, such as an atrial fibrillation. The AMS does not use the current atrial rate, because of discrimination of single fast beats (events) and a prolonged tachycardia. It uses filtered atrial rate (FARI). The FARI interval is compared to the atrial event interval (P-P) and if the P-P interval is shorter than the FARI, the FARI is shortened by 38 ms. Otherwise, if the P-P is longer, then the FARI will increase by 25 ms. When the filtered atrial rate interval reaches the value of the AMS activation interval (nominally 333 ms), the AMS is activated. When the FARI interval falls below this value, the CIED returns to its original pacing mode. Consequently, the CIED response to atrial tachycardia (AT) detection or termination is not immediate [5].

In vitro experiment

The evaluation of the AMS response took place in laboratory conditions on a model of a stimulation system placed in a container with saline. The atrial and the ventricular lead were electrically insulated from each other as needed. An external electrophysiological stimulator with a stimulation frequency of 180–1000 min^{-1} was used as a source of signals of various frequencies. The parameters of external pacing pulses were adequate for stable PCM detection. The CIED behavior analysis and interpretation of sensed events was realized real-time on the programmer's screen.

The AMS function was left in its nominal setting in the system model. Activation occurs at a rate on the atrial channel >180 min^{-1} and the PCM then switches to inhibited DDIR (inhibited dual-chamber) mode with a pacing rate 80 min^{-1}. All other parameters affecting timing were left at a default setting (paced atrial refractory period 190 ms, sensed 93 ms). The interval from the beginning of an external stimulation to the AMS activation was measured on the programmer's screen.

Case report

The case report below (Fig. 1) shows the intracardiac record of the fast ventricular pacing during the AT obtained from the clinical practice.

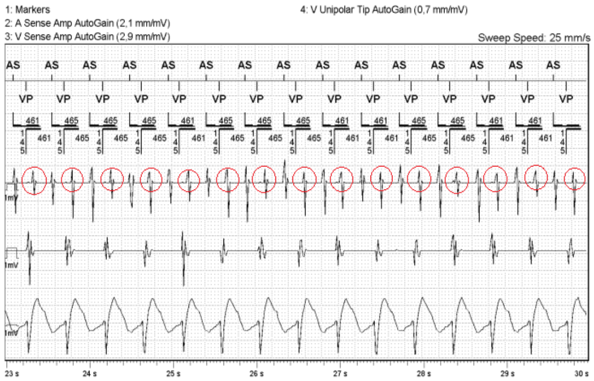

Fig. 1: The fast ventricular pacing due to the improper atrial channel detection. The atrial events in the blanking period are highlighted.

The cycle length of the atrial arrhythmia was approximately 231 ms, which corresponds to a frequency about 260 min^{-1}. The AT detection and the AMS activation did not occur because every second sensed atrial action falls within the blanking interval and it does not affect the counters. Because of this each event marked as atrial sense (As) triggered rapid right ventricular pacing 465 ms (129 min^{-1}), which can be perceived negatively by the patient at rest. In this case it was necessary to adjust the CIED programming.

Variability of signal interpretation of different frequencies

The CIED behavior described in the following section (and in conclusions) is again related to a conventional dual chamber pacemaker with an atrial and ventricular channel. The response of cardioverter-defibrillators is significantly different due to the antitachyarrhythmic function and other additional discriminant algorithms. In the PCM it is crucial whether the fast action is sensed on just one of the sensing channels or on both of them at the same time.

On the atrial channel, the sensed event triggers 1:1 ventricular response timer to a max track rate (MTR) depending on the programming and the device type. Between the MTR and the AMS rate the atrial action triggers a ventricular response according to the limit rate of MTR. At higher frequencies the NRM described on the previous page becomes activated.

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High ventricular rate (HVR) is detected above the MTR and just on the ventricular channel. When HVR is detected, the intracardiac recording is stored in the device's memory and it is also reflected in arrhythmia counters. This is a programmable CIED feature that varies across manufacturers.

When there are signals present on both sensing channels, the response of the PCM in controlled by the ventricular channel. This is clinically more important for the patient condition. Thus, AMS does not apply here, but the fast sensed action is classified as HVR up to a given frequency or subsequently as an external interference, which activates NRM. According to the programming, the NRM can temporarily change the pacing mode to asynchronous pacing at a higher rate as a prevention of a pacing inhibition.

Results

It can be seen from the measured results in Tab. 1 that the time of the program response to AT differs significantly for the selected frequencies. The shortest values were measured at higher frequencies. The detection at lower frequencies is affected by absolute refractory intervals, which include useful signals that the CIED does not classify. E.g., at a frequency of 190 min^{-1} all signals were detected by the device (in the alert window or in a relative refractory period) and the AMS was activated approximately after 6.5 s. This case is shown in Fig. 2. The detection of individual frequencies during in vitro experiment by external pacemaker was analyzed. The selected frequencies with recorded program response time are shown in the table below.

Tab. 1: Time to activation of AMS mode from the start of external pacing.

Pacing freq. (min^{-1})	Pacing freq. (ms)	AMS activation time (ms)
190	316	6 543
210	286	5 278
220	273	5 606
230	261	6 403
250	240	7 141
260	231	14 466
280	214	8 090
300	200	5 360
500	120	3 016
700	86	3 027

The AMS activation time was slightly shortened for frequency 210 min^{-1} (and also 200 min^{-1} that is not pointed in the table with results). There was a trend of extending the limit interval for AT detection from a frequency 230 min^{-1} to 260 min^{-1} where the detection time exceeded 10 s. Then, the AT detection time was shortened with increasing frequency up to 500 min^{-1}. In this range the interval fluctuated around 3 s. The frequency 500 min^{-1} was determined as the cut-off. From this rate the increasing frequency no longer influences the CIED's response time. From rate 860 min^{-1}, the AMS was not applied, but noise reversion mode (NRM) was activated. This algorithm is used to detect non-physiological high frequency signals and, during activation, inhibits pacing or temporarily reprograms the CIED into asynchronous mode. It is usually a programmable response. At some frequencies, such as 290 min^{-1}, the AMS was not detected and activated at all. That happened due to the timing of the atrial channel, where a part of these signals fell alternately to the refractory period (influences AMS counter), to the blanking period and to the alert window. It alternated regularly. Such a rate will cause fast triggered ventricular pacing or irregular ventricular pacing.

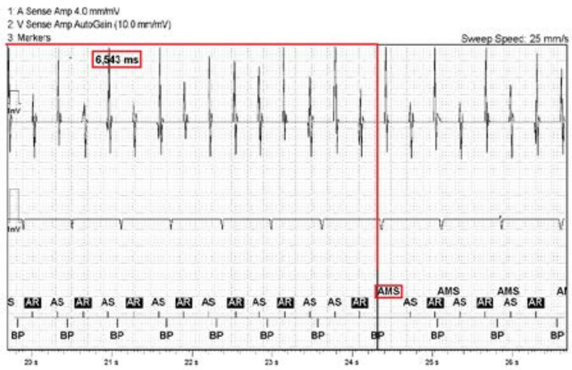

Fig. 2: The AMS activation during an external stimulation at a rate of 190 min^{-1}.

Signal interpretation differs by sensed frequencies. On the atrial channel, the sensed event triggers 1:1 ventricular response timer to MTR of 110–130 min^{-1}, depending on the programming and the type of the CIED. Between the MTR and the AMS detection rate (180 min^{-1}) the atrial action triggers a ventricular response according to the limit rate of MTR rate. The AMS is applied and the PCM is temporarily reprogrammed between the frequencies 180–860 min^{-1}, as we found out during our research. At a signal frequency higher than 860 min^{-1}, the NRM described on the previous page become activated. High ventricular rate (HVR) is detected above the MTR up to 620 min^{-1} (97 ms) on the ventricular channel. NRM was activated above the frequency 620 min^{-1}.

Discussion

In this paper we try to point out the fact how the timing of CIEDs influences the detection of lower

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frequency signals. Information may be lost due to blanking of useful signals as a result of the application of various refractory periods. Such a phenomenon occurs in the case of slower atrial tachyarrhythmias, on which we demonstrate our hypotheses. In general, it is easier for the device to discriminate higher frequency signals to interpret the intracardiac action correctly. The special stimulator software function is activated for such purposes. It can temporarily change PCMs pacing mode for the duration of the tachycardia. In the case of irregular detection of slow atrial tachycardia, the sensing of individual signals on the atrial channel is lost and this can lead to the irregular triggered ventricular pacing in the case of dual chamber devices. This is not a clinically serious problem for the patient who can perceive this condition as an irregular heartbeat. Other algorithms may also be used for the group of cardioverter-defibrillator devices or for the sensing of non-physiological interference signals such as an internal lead failure or an external electro-magnetic interference. Our measured values do not take into account the possible sensor (rate adaptive) frequency of the PCM, which affects (shortens) the timing cycles proportionally.

Current cardiostimulation devices are at such a level that they allow individual adjustment of the detection settings to adapt to specific events and needs of the patient. The consequences for the patient can be more or less severe. The benefits and possible side effects should always be considered very carefully. We can significantly affect several related parameters by minimal changing one of them, which will lead to the change of the behavior of the CIED. It is important to note that CIEDs may reach their limits when sensing physiological or non-physiological signals at selected lower frequencies. However, it happens in specific cases.

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Conflict of interest

Authors declare no conflict of interest.

Ethical statement

Authors state that the research was conducted according to ethical standards.

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Ing. Jan Morava
Faculty of Mechatronics
Technical University of Liberec
Studentská 1402/2461 17 Liberec 1

E-mail: jan.morava@tul.cz
Phone: +420 736 410 545

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