Review

Detection of atrial tachyarrhythmias in an implantable monitoring device

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ABSTRACT

State-of-the-art, implantable, dual-chamber cardiac devices provide useful diagnostic information, including the number and duration of automatic-mode switch episodes in cases of atrial tachycardia and atrial fibrillation encountered in clinical practice. However, to acquire accurate diagnostic information, special attention must be paid to the device settings; to the presence or absence of ventriculoatrial conduction, which, when present, often represents repetitive non-reentrant synchrony (RNRVAS) or pacemaker-mediated tachycardia; to the post-ventricular atrial-blanking period and atrial sensitivity; and to the sensing of far-field R waves (FFRW) in the atrial channel. Physicians should be careful about the information gathered during the monitoring of patients with implantable devices.

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1. Introduction

Implantable cardiac monitoring devices are a useful and reliable means of diagnosing atrial tachycardia and atrial fibrillation (AT/AF) in clinical practice. The yearly incidence of symptomatic or asymptomatic paroxysmal AT/AF diagnosed by pacemakers may exceed 50% [1–6]. Current guidelines recommend long-term anticoagulation therapy in patients with non-rheumatic, paroxysmal, or permanent AF and risk factors. The lowest atrial rate and duration of AT/AF (as detected by implantable monitoring devices) associated with an increased risk of thromboembolisms have not yet been defined. In one study, brief episodes of paroxysmal AF (often <30 s in duration) recorded during a mean of 22.6 h of ambulatory electrocardiographic monitoring were found to be associated
with acute and chronic brain infarcts on brain imaging; the lesions were cortical, in particular, and the findings were consistent with embolisms [7]. The importance of very brief episodes of AT/AF was confirmed by the asymptomatic atrial fibrillation and Stroke Evaluation in pacemaker patients and the atrial fibrillation Reduction atrial pacing Trial (ASSERT) [8]. In that trial, over a mean follow-up period of 2.8 years (1) episodes of AT/AF lasting > 6 min at a rate > 190 bpm were detected by the atrial high-rate episode (AHRE) function in 36% of 2580 pacemaker or implantable defibrillator recipients who had no history of AT/AF before device implantation, and (2) patients with AT/AF detected by the AHRE function were found to have a 2.5-fold higher incidence of ischemic strokes or systemic embolisms than those without [8,9]. Notably, among pacemaker recipients without a history of AT/AF, 35% of all strokes or systemic embolisms were preceded by AT/AF detected by the pacemaker [9]. Therefore, an accurate identification of AT/AF allows the planning of optimal antiarrhythmic and antithrombotic therapy [3].

2. Detection methods in implantable monitoring devices

State-of-the-art, implantable, dual-chamber cardiac devices provide useful diagnostic information, including the numbers and duration of automatic mode switch (AMS) episodes upon detection of AT/AF. However, to collect accurate diagnostic information, special attention must be paid to the following factors: the device settings; the presence versus absence of ventriculoatrial (VA) conduction, which, when present, often represents repetitive non-reentrant synchrony (RNRVAS) or pacemaker-mediated tachycardia (PMT); the post-ventricular atrial-blanking period (PVAB) and atrial sensitivity; and the sensing of far-field R waves (FFRW) in the atrial channel. Preventing FFRW sensing by the atrial channel is challenging since it is inversely correlated with the duration of the PVAB and with the atrial sensitivity. Furthermore, the presence of VA conduction may cause RNRVAS or PMT. Although FFRW sensing, RNRVAS, and PMT are not atrial tachyarrhythmias, they (a) are considered AT/AF episodes by implantable monitoring devices, (b) may be the source of inaccurate diagnostic information and inappropriate AMS from DDD to DDI or VVI mode, and (c) may trigger AT/AF or cause pacemaker syndrome [10–20].

This review focuses on the incidence and characteristics of non-AT/AF events, such as RNRVAS and FFRW oversensing, which can be detected by implantable monitoring devices.

3. Prevalence of AT/AF in recipients of implantable cardiac devices

The reported incidence of symptomatic or asymptomatic AT/AF, detected by AHRE in recipients of implantable monitoring devices, is variable and as high as 51% per year among populations that included patients with or without previously documented AT/AF, and with or without organic heart disease [1–6]. One explanation for the variable incidence among studies is the criterion of AT/AF duration, which ranged between ≥ 30 s and ≥ 1 h, depending on the study protocol [1–5]. In the ASSERT trial, AT/AF was arbitrarily defined as lasting for > 6 min [8,9]. The duration of follow-ups also varied widely between 29 days and 27 months among studies [1–5]. Finally, in most previous studies, the AT/AF was defined on the basis of the numbers of AHRE or of AMS, with or without the application of the atrial overdrive pacing algorithm. Thus, the incidence of AT/AF detected by implantable devices depends on the following factors: (a) the definition of AT/AF, (b) the presence or absence of a history of AT/AF before pacemaker implantation, (c) the cumulative percentage of atrial (Cum% Ap) or ventricular (Cum% Vp) pacing, (d) the ventricular pacing site, (e) the presence or absence of sinus node disease or atrioventricular (AV) block as a pacing indication, and (f) the AHRE settings, which include the atrial sensitivity and detection rate.

4. Variables influencing the detection of AT/AF by implantable devices

4.1. Far-field R-wave sensing

FFRW sensing is defined as the sensing of ventricular potentials in the absence of atrial contraction in the atrial channel (Fig. 1). The intracardiac electrogram (iEGM) channel in the figure shows a sensed atrial event after ventricular pacing, which may represent retrograde atrial activation of a paced ventricular event or FFRW sensing without atrial depolarization, with the latter being confirmed in this case. The implantable device counted 1 sensed FFRW event in the atrial channel, which exceeded the programmed atrial rate of AHRE, and 1 normal atrial paced or sensed event, resulting in double counts of atrial activation for a single paced ventricular event. If the rate of paced atrial events and sensed FFRW exceeds the AMS detection rate, the latter is activated, and the device erroneously diagnoses AT/AF. Fig. 2 shows the disadvantages of FFRW sensing by a dual-chamber implantable device. The erroneous detection of AT/AF causes inappropriate AMS, resulting in incorrect conclusions, such as AHRE and AF burden, as well the automatic conversion of the pacing mode to DDI or VVI, which may cause pacemaker syndrome due to AV dyssynchrony, or induce new episodes of AF. Furthermore, in recipients of implantable cardioverter defibrillators, the delivery of antitachycardia pacing or shocks may be delayed, and in patients undergoing cardiac resynchronization, the treatment effects may be decreased by an insufficient percentage of ventricular pacing.

The atrial pacing site influences the detection of AT/AF by the atrial channel of dual-chamber devices. The right atrial appendage (RAA) is unsuitable for the prevention of AT/AF, because it lengthens the inter- or intra-atrial conduction times and increases the dispersion of atrial refractoriness [21]. Instead, low right atrial septal (LRAS) pacing has been recommended [22] although it has not been tested in a randomized clinical trial [23]. Figs. 3 and 4 show a chest roentgenogram and electrocardiogram, respectively, of a dual-chamber pacemaker recipient, in
whom the atrial lead was implanted in a LRAS site and the right ventricular lead was implanted in the septum. The tip of the LRAS pacing lead was located inferiorly and posteriorly (Fig. 3), and the P wave was negative in the inferior leads and in leads I, V5, and V6 (Fig. 4). However, because the LRAS region is closer to the ventricle than the RAA, it is associated with a higher likelihood of FFRW sensing [22–24], although the prevalence and characteristics of FFRW sensing associated with LRAS pacing have not been formally studied. Preventing sensing of FFRW in the atrium is a major challenge since it is inversely correlated with the duration of the PVAB and with the atrial sensitivity setting.

The atrial sensing function is influenced by the use of various atrial pacing/sensing leads. For example, the interelectrode spacing of bipolar atrial leads determines, in part, the likelihood of FFRW oversensing [14,25–27], which tends to decrease with the reduction in the spacing [25–27]. In the RAA, at a sensitivity of 0.3 mV, FFRW was sensed in 30% of recipients of leads with 10-mm inter-electrode spacing, and in none of the patients receiving leads with tip-ring electrodes separated by 1.1 mm [25,26]. The capture and sensing characteristics of these new leads were similar and remained stable over a long period of time [25–27]. Thus, a closer interelectrode spacing of the atrial lead lowered the likelihood of sensed FFRW, without interfering with pacing.

4.2. Repetitive non-reentrant VA synchrony

Repetitive non-reentrant VA synchrony (RNRVAS) is not a rare occurrence with dual-chamber implantable devices [20,28–31]. Most previously described cases of RNRVAS, which accelerate the pacing rate, have been associated with sensor-driven DDDR pacing [28,29]. This form of VA synchrony is usually associated with the programming of long AV intervals and relatively high atrial rates during DDD or DDDR pacing, and it is found to be greatly facilitated by atrial overdrive pacing, which is achieved by algorithms such as AF suppression and atrial referential pacing (APP). An example of RNRVAS is shown in Fig. 5. The disadvantages of RNRVAS include (1) loss of optimal AV delay, (2) inappropriate increase in ventricular pacing rate, (3) triggering of atrial arrhythmias, and (4) inaccurate AHRE. Because of its adverse effects on ventricular function, unnecessary RV pacing must be minimized; in dual-chamber implantable devices, this can be achieved by programming a long AV delay, particularly, in the presence of sinus node disease and preserved AV conduction. Since the AHRE function offered by implantable monitoring devices provides useful diagnostic information, which facilitates therapeutic decisions, including whether or not to administer anticoagulation therapy for

Adverse effects of far-field R wave sensing

Fig. 1. Adverse effects of far-field R-wave sensing in dual-chamber implantable devices. Far-field R-wave sensing may cause the erroneous detection of AT/AF and inappropriate AMS, yielding inaccurate diagnostic information, such as AHRE, AF burden and numbers of AMS; it may also cause pacemaker syndrome due to AV dyssynchrony or development of new AF. In addition, antitachycardia pacing or ICD shock therapy may be delayed, and the cumulative percent ventricular pacing in recipients of cardiac resynchronization therapy devices may be decreased, lowering their therapeutic effects.

Fig. 2. Representative case of far-field R-wave sensing. Arrows shows far-field R wave oversensing in atrial channel. With permission of Ref. [33].
atrial tachyarrhythmias, inaccurate information may lead to erroneous diagnosis and inappropriate treatment.

The induction of RNRVAS by atrial overdrive pacing is explained as follows: (1) the retrograde P wave after ventricular pacing falls within the post-ventricular atrial refractory period (PVARP); (2) the atrial overdrive pacing algorithm is activated immediately after the sensed retrograde P wave; (3) since the interval between the sensed retrograde P wave and the next atrial event initiated by the atrial overdrive pacing algorithm is very short, the atrial pacing stimulus falls inside the atrial refractory period and fails to capture the atrium; (4) ventricular pacing after an AV interval long enough for the recovery of the atrial myocardium allows repetitive VA conduction and perpetuation of RNRVAS. Therefore, RNRVAS is generally observed when (1) VA conduction and retrograde P waves sensed within the PVARP after ventricular pacing are present, thereby triggering atrial overdrive pacing, and (2) a relatively long AV interval has been programmed, to limit the cumulative percentage of ventricular pacing, particularly in sick sinus syndrome [20,30,31]. RNRVAS could theoretically be prevented by inhibiting VA conduction, or ineffective atrial pacing by a high atrial pacing rate, or both. Antiarrhythmic drugs administered to suppress paroxysmal AF may prolong the atrial refractory period and increase the likelihood of RNRVAS by increasing the percentage of ineffective atrial pacing events.

Furthermore, high atrial pacing rates, induced by the use of the atrial rate responsive function or the atrial
overdrive pacing algorithm for the prevention of AF, increase the likelihood of ineffective atrial pacing events; these events, in turn, induce ventricular pacing in the absence of intrinsic AV conduction, including after a retrograde P wave sensed inside the PVARP.

We have recently observed that RNRVAS, which is stored as AHRE in the pacemaker memory, is induced by the atrial overdrive pacing algorithm for the prevention of AT/AF [20,30] and by rate-adaptive DDIR pacing in patients permanently paced for sinus node dysfunction [31]. The initiation of RNRVAS is usually due to (1) VA conduction and retrograde P waves sensed within the PVARP, (2) additional programming of rate-responsive or atrial overdrive pacing for the prevention of AF, and (3) programming of a long AV interval.

We studied the incidence and characteristics of RNRVAS in 39 recipients of dual-chamber pacemakers (mean age = 79.7 ± 6.6 years); these patients had no history of AT/AF, and their pacemakers were set to AHRE at 190 bpm, in the DDD mode [20]. The atrial overdrive pacing algorithm was randomly set at “ON” in 19 and “OFF” in 20 patients. AHRE was detected in 20 patients (51%), with 15 of them having AT/AF and 8 having RNRVAS; all these patients belonged to the group with the atrial overdrive pacing set at “ON.” A total of 257 of 1528 episodes of AHRE were analyzed, including 181 and 76 episodes in the groups with the atrial overdrive pacing settings of “ON” and “OFF,” respectively. Among the 181 episodes detected in the group with the “ON” setting of atrial overdrive pacing, 72 (40%) were RNRVAS, whereas 100% of the episodes in the groups with the “OFF” setting of the atrial overdrive pacing were AT/AF (Fig. 6). The detection of RNRVAS was closely associated with a high Cum% Ap. With the atrial overdrive pacing algorithm activated, the specificity of AT/AF detection by AHRE was 40%, as against 100% in its absence. In addition, most episodes of RNRVAS lasted ≤ 10 min (Fig. 7) [20]. Thus, AT/AF was common in pacemaker recipients without a history of AT/AF. The increase in Cum% Ap associated with the use of the AF suppression algorithm appears to be closely associated with the incidence of RNRVAS, i.e., non-AF, as detected by AHRE. These observations suggest that close attention should be paid to the detection of AT/AF by AHRE and the use of iEGM in particular [20,30,31].

5. Optimal setting of atrial sensitivity and post ventricular atrial blanking

An optimal setting of the atrial sensitivity is crucial to an accurate detection of AT/AF by implantable dual-chamber monitoring devices. The setting of a low atrial sensitivity decreases the likelihood of FFRW oversensing as well as the chances of detecting AT/AF; this is because undersensing of the atrial electrogram during ongoing tachyarrhythmia may lead to the underestimation of the incidence of clinical AT/AF. Conversely, the setting of a high atrial sensitivity increases the chances of detecting AT/AF and the likelihood of FFRW oversensing, which can lead to the overestimation of the incidence of clinical AT/AF. While an optimal setting of atrial sensitivity remains
unclear, a < 0.5 mV setting is generally recommended for recipients of implantable devices who have a history of AF.

Increasing the duration of PVAB might be an effective means of preventing FFRW oversensing in the atrial channel. However, this narrows the search window of atrial sensing and shortens the window of AT/AF detection, which might decrease the likelihood of detecting AT/AF. Conversely, a short PVAB widens the search window of atrial sensing and of AT/AF detection, thereby decreasing the specificity of AT/AF detection. In clinical practice, a setting of +25 ms between the ventricular pacing spike and FFRW sensing is generally recommended for the PVAB [23].

6. Conclusions

Implantable monitoring devices have become highly useful diagnostic tools for AT/AF [32]. However, the accuracy of the obtained diagnostic information is influenced by several factors, including the presence of non-AT/AF events, such as RNRVAS or PMT, caused by VA conduction or by suboptimal settings of the atrial sensitivity and PVAB duration.

7. Conflict of interest

The author has no conflicts of interest to declare.

References


