Factors involved in correct analysis of intracardiac electrograms captured by Medtronic Inc. pacemakers during tachycardias

Masaru Takagaki, MEa,*, Shigeru Ikeguchi, MDb, Tomoyuki Yamada, MDC, Kazuhiko Katsuyama, MDE, Yuzo Takeuchi, MDb, Shinsaku Takeda, MDb, Yoshitaka Kawata, MDb, Takeshi Harita, MDb, Akiu Morii, MDe, Hiroaki Nanba, MDb, Shinsaku Takeda, MDb, Yuzo Takeuchi, MDb, Shinsaku Takeda, MDb, Kazuhiko Katsuyama, MDc, Tomoyuki Yamada, MDc, Hiroaki Nanba, MDb, Akio Morii, MDe, Hiroshi Terada, MEa, Shinichi Hasegawa, MEa, Shinichiro Sukenari, MEa, Hiroshi Terada, MEa

a Shiga Medical Center for Adults, Division of Clinical Engineering, 5-4-30 Moriyama, Moriyama City, Shiga Prefecture, Japan
b Division of Arrhythmia Service, Shiga Medical Center for Adults, 5-4-30 Moriyama, Moriyama City, Shiga Prefecture, Japan
c Division of Cardiovascular Surgery, Shiga Medical Center for Adults, 5-4-30 Moriyama, Moriyama City, Shiga Prefecture, Japan

Article history:
Received 20 August 2011
Received in revised form 26 December 2011
Accepted 14 August 2012
Available online 20 November 2012

Keywords:
Single recording channel
Summed EGM
Atrial EGM
Post ventricular atrial blanking
Incorrect diagnosis

ABSTRACT

Background: To thoroughly investigate the diagnostic information obtained by pacemakers, it is important that the stored intracardiac electrograms (EGMs) are analyzed. However, in Medtronic pacemakers, only a single intracardiac recording channel is available and thus EGM channel selection is critical.

Methods: The study population comprised 150 patients who underwent implantation of Medtronic’s dual chamber pacemakers with a single intracardiac EGM memory channel. We first set the electrogram channel to “summed,” and the automatic EGM diagnosis during the tachycardia was compared with the manual analysis findings. When the results were not identical for the 2 methods, the atrial EGM (AEGM) and ventricular EGM channels were sequentially selected and the results of each EGM selection were compared to conclude which channel was more valuable for diagnosis of high-rate episodes. The post-ventricular atrial blanking (PVAB) period was adjusted to the shortest interval with a relevant margin to avoid any far-field R wave over-sensing.

Results: A total of 130 patients were eventually enrolled. High-rate episodes were observed in 115/130 patients (88%). The results of the automated tachycardia diagnosis obtained using the “summed” EGM differed from those obtained manually in 43/115 patients (37%). Changing the intracardiac EGM channel from “summed” to “AEGM” enabled a much better manual diagnosis with intracardiac EGMs because of improved atrial potential sensing, clearer manifestation of atrial electrograms within the PVAB, and more prominent atrial electrograms fused with the ventricular potentials. The ventricular EGM channel was not as useful as the AEGM channel for tachycardia diagnosis.

Conclusions: In Medtronic pacemakers with single intracardiac EGM channel recording capability, AEGM is the most useful of the 3 EGM channel settings; PVAB should also be set to a much shorter value to achieve a more accurate automatic diagnosis.

© 2013 Japanese Heart Rhythm Society. Published by Elsevier B.V. All rights reserved.

1. Introduction

Pacemakers are equipped with a memory function for intracardiac electrograms (EGMs), which facilitates analysis of the pacing and sensing status of the pacemaker while also providing an automated diagnosis function for arrhythmia episodes [1–3].

Dual chamber pacemakers generally have 2 memory channels: atrial EGM (AEGM) and ventricular EGM (VEGM). However, all Medtronic pacemakers except for the “EnRhythm” and “Advisa” models have only 1 memory channel at present. Therefore, the summed EGM (SEGm), which comprises merged AEGM and VEGM, is usually selected. However, when the intracardiac EGM captured during a tachycardia episode is analyzed in the SEGm, the atrial electrogram is occasionally obscure and can be difficult to differentiate from the ventricular potential.

Furthermore, it is important to correctly set the post-ventricular atrial blanking (PVAB) period to avoid far-field R wave (FFRW) over-sensing and to maintain an adequate mode.
switching function. However, too large a PVAB value prevents proper sensing of the atrial wave and leads to an incorrect automated diagnosis of tachyarrhythmia because of under-sensing of the atrial potentials.[4–6].

Thus the purpose of the present study was to investigate which EGM channel was most useful in Medtronic pacemakers when an automated diagnosis of the arrhythmia was evaluated manually using the intracardiac EGM. We also reviewed the present programmability of the PVAB value in these Medtronic devices.

2. Methods

The study population comprised 150 patients who underwent implantations of Medtronic dual chamber pacemakers and who had maintained both atrial and ventricular sensing (either in DDD, DDI, or VDD modes) from March 2008 to October 2010. The implanted pacemaker generators were either Kappa series (n=80), EnPulse series (n=17), or ADAPTA series (n=53).

At the subjects’ first visit to the pacemaker clinic after enrollment in this study, the settings of the parameters for storing intracardiac EGMs were chosen; the detection rates for atrial high-rate (AHR) episodes and ventricular high-rate (VHR) episodes were set at 170 bpm and 180 bpm, respectively. The supraventricular tachycardia filter was set to the “on” position so that fulfillment of both AHR and VHR excluded the diagnosis of a VHR episode. AHR and VHR episodes were selected as the types of high-rate types of episodes to be saved. “Include” was chosen for refractory senses so that atrial sensing was included in tachyarrhythmia diagnosis even if that sensing was within the refractory period. “Summed” was chosen as the EGM type to be saved; this meant that the SEGM, which is the merged AEGM and VEGM, was selected as the intracardiac EGM to be saved. The time out was set at 12 weeks (that is, EGMs were saved for 12 weeks after being recorded, and after that period, the EGMs would be deleted and only the tachycardia log would be preserved). The EGM allocation was set at 4 for 4/4 s; thus EGMs of 4 episodes were saved including 4-s recordings of the EGMs before and after detection of each high-rate episode.

During the follow-up period, the SEGM was analyzed manually for instances in which AHR or VHR episodes were detected in stored EGMs. When the automated diagnosis was different from that obtained by manual analysis, the episodes were categorized into 4 groups.

Type 1: Automated diagnosis was AHR but SEGM was complicated and the atrial potentials were obscure (Fig. 1A).

Type 2: Automated diagnosis was VHR but atrial tachycardia was suspected (Fig. 2A).

Type 3: Ventricular tachycardia was suspected but atrial tachycardia could not be excluded (Fig. 3A).

Type 4: Suspected misdiagnosis of AHR due to FFRW oversensing, noise sensing, or over-sensing of muscular potentials (Fig. 4A).

After EGM detection of AHR or VHR episodes, the EGM type to be saved was changed from SEGM to AEGM. In several cases, after confirming the AEGM during either AHR or VHR episodes, the EGM channel to be saved was changed from AEGM to VEGM.

When the atrial potential was located within the PVAB period during detected tachycardia episodes, the PVAB was set to the minimum value; this prevented FFRW over-sensing while maintaining conditions for maximum atrial sensing and full capture of ventricular pacing.[4].

3. Results

We initially enrolled 150 patients in our study, but there were some cases of inadequate follow-up or a change in pacing mode to VVI. Thus, we finally analyzed data from 130 patients.

During the follow-up period of 20 ± 4 months (range, 9–30 months), AHR or VHR episodes were detected with saved EGMs in 115/130 patients (88%) when the SEGM channel was selected. In 43/115 patients (37%) with tachycardia detections, the automated

![Fig. 1. Stored intracardiac electrograms (EGMs) of type 1 patient with complete atrioventricular block. Pacemaker settings: mode: DDD, rate: 50 bpm, maximum tracking rate: 120 bpm, atrial sensitivity: 0.5 mV, ventricular sensitivity: 2.8 mV, post-ventricular atrial blanking: 130 ms. (A) Stored EGM using the summed atrial potential and ventricular potential electrogram (SEGM) channel setting. Atrial tachycardia is followed by ventricular pacing and onset of monode switch (MS) function is suspected. SEGM is complex and illegible. The presence of atrial potential is suspected during the interval ( ) marked with asterisk (*); however, overlap of QRS and T wave makes diagnosis difficult. (B) Stored EGM using atrial EGM (AEGM) channel setting. Atrial potentials are clearly visible as QRS and T wave amplitudes are small. Atrial potentials not shown with atrial event markers due to the timing of post-ventricular atrial blanking period (‘) can be clearly identified. Paced ventricular potentials appearing as far-field R waves and are shown with (‘) and can be clearly differentiated from the atrial potentials. Abbreviations: SEGM: intracardiac electrocardiogram of summed atrial potential and ventricular potential, MS: mode switching, AS: extra-atrial refractory sensing, AR: intra-atrial refractory sensing, VP: ventricular pacing, AEGM: atrial intracardiac electrocardiogram.](image-url)
diagnosis result (AHR or VHR episode) was doubtful or discordant with the manual analysis of the EGM. Among those 43 patients, there were 12 type 1 cases, 5 type 2 cases, 9 type 3 cases, and 9 type 4 cases.

Subsequently, the EGM channel was changed from SEGM to AEGM and an appropriate adjustment of the PVAB period was performed; the patients were then followed-up.

In type 1 patients, fusing of atrial and ventricular potentials became more prominent after changing to the AEGM. Atrial potentials without markers within the PVAB period also became more prominent (Fig. 1B).

For the type 2 patients, AEGM selection meant that atrial potentials manifested more prominently within the PVAB and the automated tachycardia diagnosis changed from VHR to AHR in Fig. 2.

In type 3 patients, fusing of atrial and ventricular potentials became more prominent after changing to the AEGM. Atrial potentials without markers within the PVAB period also became more prominent (Fig. 1B).
the same patient after PVAB adjustment (Fig. 2B). However, in a case of atrial tachycardia and impaired atrioventricular conduc-
tion properties, adjustment of the PVAB to the minimum possible value (110 or 130 ms) still led to an incorrect automated VHR diagnosis (Fig. 5).

In type 3, the atrial potentials were not discernible or were fused with the ventricular potentials in the SEGM (Fig. 3A). Selection of the AEGM channel made the atrial potentials more prominent, and the ventricular potentials were confirmed as FFRWs with a constant short cycle length resulting in the diagnosis of ventricular tachycardia (Fig. 3B).

In type 4, tiny irregular atrial signals fused with the QRS complex or T wave in the SEGM were suspected; however, the details were unknown (Fig. 4A). With AEGM selection, any over-
sensing of noisy signals could be clearly differentiated from atrial potentials (Fig. 4B).

A follow-up with a change in EGM selection from the AEGM to the VEGM was then performed only in types 1 and 2, because follow-up with VEGM was considered to be of no use for tachycardia discrimination in type 3.

The presence or absence of atrial potentials could not be confirmed by the VEGM. Consequently, atrial potentials with atrial event markers could not be differentiated from FFRW or noise activity in the VEGM (Fig. 6). In addition, tiny suspected atrial potentials without any atrial event markers could not be differentiated from conditions with no atrial potentials or where
masking of the atrial event markers occurred due to the PVAB period in the VEGM (Fig. 7). In this type 2 case, atrial potentials were intermittently overlaid on the PVAB period and even manual analysis could lead to a misdiagnosis of ventricular tachycardia (Fig. 7).

4. Discussion

In dual chamber pacemakers, there are a number of methods to prevent sensing of cross chamber potentials and thus ensure appropriate atrial and ventricular pacing functions. One of these methods is the PVAB period. The atrial sensing blanking period is set for a certain period after ventricular pacing or sensing. Usually, the PVAB can help prevent over-sensing of FFRWs, maintain a proper mode switch function, and detect atrial tachycardia events. However, if atrial potentials are overlaid in the PVAB period, the pacemaker function for diagnosis of arrhythmia might be misleading.

Conversely, although ventricular potentials might be fused with atrial potentials, the amplitude of atrial potentials is much lower than that of ventricular potentials. Thus, the ventricular blanking period after atrial events is infrequently installed except for a period covering several tens of milliseconds after atrial pacing. In other words, during atrial tachyarrhythmia sensing, no blanking period is established in the ventricle. Consequently, no masking of ventricular event markers occurs during atrial tachyarrhythmia if no ventricular sensing problem exists.

It is therefore important to analyze atrial potentials irrespective of the presence or absence of atrial event markers to evaluate a pacemaker’s automated tachyarrhythmia diagnosis. Ventricular potentials can be confirmed by ventricular event markers if the ventricular potential is properly sensed. Therefore, demonstration of atrial potentials is also crucial to evaluate a pacemaker’s automated tachyarrhythmia diagnosis. In addition, if FFRW sensing occurs, the PVAB should be adjusted to the shortest value; this avoids FFRW over-sensing.

Taking all of the above mentioned points into consideration, we here discuss which intracardiac EGM channel should be selected as the default setting in Medtronic pacemakers to evaluate the automated tachyarrhythmia diagnosis.

In type 1, although the atrial electrogram is visible in the SEGM, it can be masked by a large QRS wave or T wave. The atrial potentials in the PVAB period are particularly difficult to differentiate from FFRWs and the absence of electrical markers makes a complete analysis difficult (Fig. 1A). Conversely, the AEGM can clearly indicate the atrial electrogram without the need for atrial event markers because of the small effect of the QRS and T wave on the atrial electrogram. The ventricular potential is generally large and can be confirmed as an FFRW, which can then be clearly differentiated from the atrial potential (Fig. 1B). Since the VEGM is demonstrated with an auto-adjustment of sensitivity with reference to the ventricular potential, tiny atrial potentials are frequently obscured and confirmation of the atrial electrogram is dependent on the presence of atrial event markers. Therefore, possible under-sensing within the PVAB period and over-sensing due to FFRWs or electrical noise cannot be excluded (Fig. 6).

In type 2, when an atrial potential is located just after a ventricular event, the atrial event marker is not reliable because of the PVAB period. Furthermore, in cases where atrioventricular conduction delay is enhanced, the atrial and ventricular potentials can fuse, thus becoming very difficult to differentiate in the SEGM (Figs. 2A and 8A). Conversely, the AEGM can always demonstrate atrial potentials clearly, and the atrial potential can be confirmed without the need for atrial electrical markers, even if the atrial and ventricular potentials are fused. In addition, ventricular potentials can usually be confirmed as FFRWs by a manual evaluation in the AEGM. If ventricular potentials cannot be confirmed manually, the ventricular marker channel will still show the presence of ventricular potentials because the ventricular electrogram is not associated with the ventricular blanking.
period during atrial tachycardia (Figs. 2B and 8B). With VEGM selection, the atrial potential tends to be obscured and a misdiagnosis of VT can occur if atrial tachycardia is associated with a remarkable ativoventricular conduction delay and atrial potentials repeatedly coincide with the PVAB period (Fig 7–1).

In type 3, the auto-gain control for the SEGM adjusts the amplitude of the ventricular potential, with the result that the atrial potentials become too small to be visible. When the atrial potential is located just before the ventricular potential, the 2 potentials fuse and it is difficult to differentiate the atrial potential from FFRWs; this is true even if atrial electrical markers exist (Fig. 3A). If the atrial potential is located just after the ventricular potential, it can be challenging to differentiate between the 2 potentials; in addition, no atrial electrical markers are available due to the PVAB. However, changing the intracardiac EGM from the SEGM to the AEGM highlights the atrial potential, and the ventricular potential can still be confirmed as an FFRW in most cases. More reliable confirmation of the atrial and ventricular potentials leads to the diagnosis of ventricular tachycardia (Fig. 3B).

In type 4, the SEGM exhibits smaller atrial potential amplitude. When the atrial potential overlaps with the ventricular potential, the atrial potential is masked by the larger amplitude of the ventricular potential and differentiating between atrial potentials and artifacts becomes more difficult (Fig. 4A). Changing the EGM to the AEGM attenuates the ventricular potential, magnifying the atrial potentials so that atrial potentials can be differentiated from noise and FFRWs. Finally, a misdiagnosis of AHR due to oversensing of electrical noise will result (Fig. 4B).

In conclusion, the selection of the AEGM channel for storing EGMs is the most appropriate for tachyarrhythmia follow-up with Medtronic Pacemakers.

For the relationship between the PVAB and FFRWs, setting the PVAB period as short as possible is possible, because not all patients necessarily have problems with FFRWs [4,6]. However, the Medtronic pacemakers investigated in this study had minimum PVAB values as short as 110 ms or 130 ms, which are much longer than those of the other manufacturer’s products (60 ms for the St. Jude Medical and 30 ms for the Guidant products). Therefore, too long a PVAB value prevents the determination of a correct automated arrhythmia diagnosis in cases with a relatively early timing for FFRWs or in cases with small FFRW amplitude compared with atrial potentials (Fig. 5). As for programmable PVAB value, the lower limit of the programmability of the PVAB value should be much smaller. Despite all the attempts to adjust the PVAB value, there are still cases of simultaneous atrial and ventricular activations and this limits the effectiveness of a pacemaker’s automated tachyarrhythmia diagnosis (Fig. 8A and B).

Thus, the intracardiac EGM used for follow-up should be the AEGM rather than the SEGM, because the AEGM enables easy confirmation of atrial potentials.

5. Limitations

The following cases may not be suitable for AEGM follow-up (in such instances, EGM selection should be made on a case-by-case basis):

(1) Cases in which atrial potentials are comparatively larger for the VEGM with outflow tract pacing or His-bundle pacing; in such cases, AEGM may not be required.

(2) Cases where a ventricular lead fracture is suspected; in these cases, noise in the ventricular electrogram might not be recorded when the AEGM is selected. Hence, VEGM is recommended here.

6. Conclusion

We recommend that the AEGM channel be selected for follow-up with the Medtronic pacemakers investigated in this study. It is also important to adjust the PVAB value to an appropriate interval, and we consider it desirable that Medtronic pacemakers become more adjustable so that much shorter PVABs can be programmed with these products.
References