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Rejection of atrial sensing artifacts by a pacing lead with short tip-to-ring spacing

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Abstract **Aim** The ability of a new pacing lead design, with a 10 mm tip-to-ring spacing, to facilitate rejection of sensed far field R-waves and myopotentials was evaluated.
Methods and results Measurements were performed in 66 patients. The occurrence of far field R-wave sensing and myopotential sensing was determined by means of the surface ECG and the ECG markers provided by the pacemaker. At an atrial sensitivity of 0.25 mV and an atrial blanking of 50 ms far field R-wave sensing was observed in 12 patients (18.2%) and at an atrial sensitivity of 1.0 mV no far-field R-wave sensing was observed. Myopotentials were sensed in 3 patients. In all patients the measured P-wave amplitude was at least twice the estimated amplitude of the far field R-wave at an atrial blanking of 50 ms.
Conclusion The results from this study show that a small tip-to-ring spacing allows for programming of a high atrial sensitivity and short atrial blanking with an acceptably low risk for atrial artifact sensing.

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Introduction

Adequate atrial sensing is a prerequisite for reliable device derived diagnostics and the delivery of appropriate and effective pacing therapies. This is especially true for patients with paroxysmal atrial tachyarrhythmias, implanted with a mode switching DDDR pacemaker or a device providing prevention or termination therapies for atrial fibrillation. Increasing the atrial sensitivity and/or reducing the atrial blanking may improve the atrial sensing performance. However, at some point the advantages of this measure will be outweighed by the disadvantages of sensing of atrial artifacts such as far field R-waves and myopotentials. The incidence of atrial sensed artifacts may be reduced by the use of bipolar atrial leads [1—3] but at higher atrial sensitivities sensing of far field R-waves or myopotentials may still occur.

The incidence of far field R-wave sensing has been studied by several investigators. From a report of 30 patients with bipolar atrial leads, Brandt et al. [4] found far field R-wave sensing in all patients at an atrial sensitivity of 0.1 mV and in 6 patients (20%) at a sensitivity of 0.5 mV. Fröhlig et al. [5] observed far field R-wave sensing with bipolar atrial leads in 27 (47%) of 57 patients at the maximum atrial sensitivity and in 10 (18%) of the patients at a sensitivity of 0.5 mV. Sensing of atrial artifacts may result in erroneous device based diagnostics, especially in the monitoring of atrial fibrillation, and in inappropriate device response, such as inhibition or the application of therapies in response to false detection of atrial tachyarrhythmias [6—8].

In this situation further improvement can be achieved by the elimination of atrial sensed artifacts by optimising the bipolar atrial lead design. Flammang et al. [9] found that reducing the tip-to-ring spacing reduces the incidence of far-field R-wave sensing and improves the ratio between the P-wave amplitude and the far field R-wave amplitude. Many bipolar electrodes have a tip-to-ring spacing of the order of 20 mm. Empirically, it was determined that a tip-to-ring spacing of 10mm would be an appropriate compromise between acceptable P-wave amplitudes, reduced far-field R-wave sensitivity and acceptable mechanical properties. This study investigated the rejection of atrial oversensing artifacts by using a new lead design with a 10 mm tip-to-ring spacing.

Materials and methods

Participation of each centre was approved by the appropriate ethics committee and all patients signed an informed consent prior to their enrolment.

All patients included in the study had a conventional indication for implantation with a dual chamber pacing system with passive fixation leads and were implanted with atrial and ventricular leads with a tip-to-ring spacing of 10 mm (Crystalline lead, Vitatron B.V., The Netherlands). This lead has a silicone insulated lead body and a platinised platinum, steroid eluting, low output energy electrode design (surface area 3.2 mm^2). Implanted pacemakers allowed for atrial sensitivity settings of 0.25 mV. During the study pacemakers were used with identical atrial sensing circuits (Vitatron B.V., The Netherlands: Selection 900E, Clarity DDDR, Diamond 3, Ruby 3). Implanting physicians were requested to implant the leads according to their personal routine and no specific pacing site was required by the protocol.

Pacing and sensing performance were assessed during implantation and subsequently at two separate follow-ups, firstly within 24 hours of implantation and secondly within 3 days of implantation, at the time of hospital discharge, and at two subsequent follow-ups at 2 weeks and 3 months after implantation. At the follow-up 3 months after implantation the incidence of far field R-wave sensing and myopotential sensing was assessed. Relevant device programming for these tests is shown in Table 1. During all oversensing tests the AV delay was programmed sufficiently short to cause continuous ventricular pacing. During the far-field R-wave sensing test, the atrial blanking was programmed to its minimum value (50 ms) as far field R-waves can be expected to occur shortly after the ventricular event. Myopotentials, however, can be expected to occur throughout the cardiac cycle, therefore during the myopotential test the atrial blanking was programmed sufficiently long (200 ms) in order that possible confounding far field R-waves would not be sensed.

Table 1 Device settings during atrial oversensing tests

Test	Atrial sensing polarity	Atrial sensitivity (mV)	Atrial blanking (ms)
Far field R-wave sensing test	Bipolar	0.25 0.50 1.00	50
Myopotential sensing test	Bipolar	0.25	200

Note: Implanted devices had identical atrial blanking after a ventricular pace and a ventriclar sense. The oversensing tests were performed with continuous ventricular pacing.

During the far field R-wave test patients were sitting at rest in an upright position. The myopotential tests were performed in the same position with patients at rest, breathing deeply and isometrically stressing the pectoral muscles by pushing their hands together (''pushing hands''). During the oversensing tests the surface ECG and a marker ECG provided by the pacemaker were simultaneously monitored and recorded. The marker ECG shows the occurrence and classification of any atrial or ventricular sensed or stimulated event. Classification of observed atrial oversensing was based on the following considerations:

- Far field R-wave sensing appears as a single atrial tachyarrythmia marker in the marker ECG without corresponding electrical activity on the surface ECG. Far field R-wave senses usually occur within 150 ms of the ventricular event, although longer V-A intervals are possible. Multiple far field R-wave senses in various ventricular cycles are characterised by a constant V-A interval.
- Myopotential sensing usually appears as multiple atrial tachyarrhythmia markers on the marker ECG without corresponding events on the surface ECG. Additionally, isolated atrial sensed events within different ventricular cycles with a varying V-A interval are also most likely to be due to myopotential sensing.
- Atrial oversensing should be distinguished from retrograde conduction, which usually results in a number of consecutive isolated atrial tachyarrhythmia markers with a constant V-A interval. Retrograde conduction can be differentiated from atrial oversensing by a V-A interval that is usually longer than that associated with far field R-wave sensing and by the appearance of a retrograde P-wave on the surface ECG.

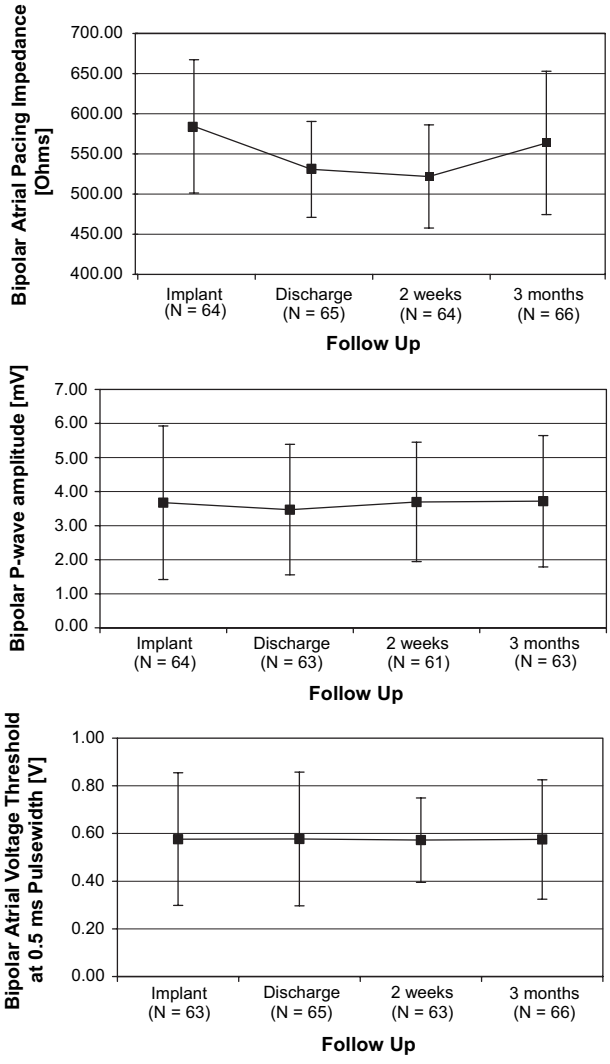

Figure 1 Electrical characteristics measured during follow up. Upper panel: atrial bipolar pacing impedance. Middle panel: bipolar P-wave amplitude. Lower panel: atrial bipolar voltage threshold at 0.5 ms pulsewidth. It should be noted that the implanted pacemakers allowed measurement of P-wave amplitudes up to 7 mV.

Results

General

A total of 66 patients was included in this study (37 females (43.5%) and 48 males (56.5%), mean age: 73 years). One patient received a straight bipolar atrial lead, in the remaining 65 patients J-shaped bipolar atrial leads were implanted.

Electrical performance

The electrical performance observed in the atrium from implantation to the follow up 3 months post implantation is presented in Fig. 1. The mean P-wave amplitude, measured at 3 months after implantation was 3.72 mV (standard deviation: 1.93 mV). Electrode data obtained at implantation was compared with electrode characteristics measured at subsequent follow-ups by means of two-sided, paired statistical testing. The electrode impedance measured at hospital discharge and at two weeks after implantation significantly differed from the impedance at implantation ($P<0.01$). No significant difference from implant data was found for the electrode impedance measured at three months after implantation and the P-wave amplitudes and atrial voltage thresholds measured during all remaining follow ups ($P>0.11$).

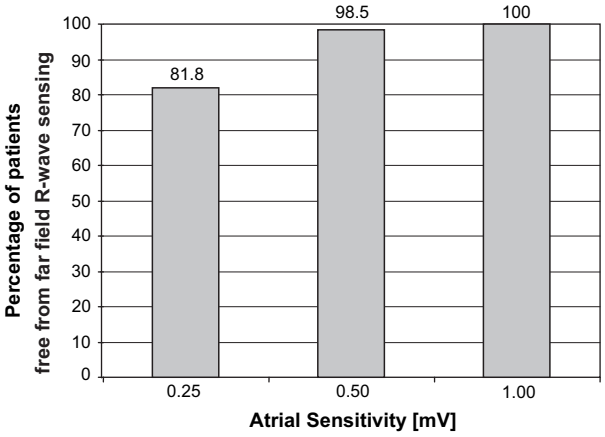

Figure 2 Percentage of patients free from far field R-wave sensing at various settings for the atrial sensitivity (bipolar atrial sensing, atrial blanking programmed to 50 ms).

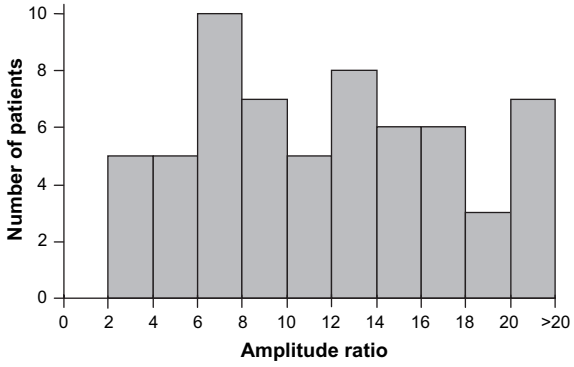

Figure 3 Distribution of the ratio between the P-wave amplitude and the estimated far field R-wave (FFRW) amplitude (P-wave amplitude divided by far field R-wave amplitude). Note that the highest category in the histogram represents all patients with a ratio larger than 20.

Atrial oversensing

A total of 66 patients was included in the far field R-wave sensing test. The percentage of patients who were free from far field R-wave sensing at various atrial sensitivity settings is displayed in Fig. 2.

As indicated in Fig. 2 all patients were free from atrial oversensing at an atrial sensitivity of 1.00 mV. At the most sensitive setting of the atrial sensitivity (0.25 mV), 12 of 66 patients (18.2%) showed atrial oversensing. In 6 of these patients continuous atrial oversensing was observed in all ventricular cycles, in three patients atrial oversensing occurred in almost all ventricular cycles and in the three remaining patients atrial oversensing was only occasionally observed. Based on the timing of the atrial oversenses, the stable V-A interval of the senses and the absence of a corresponding atrial event on the surface ECG, every occasion of atrial oversensing was considered to be far field R-wave sensing.

For an estimation of the far field R-wave amplitude this amplitude was considered to be equal to the most sensitive setting of the atrial sensitivity at which no far field R-wave sensing occurred. For instance, if no far field R-waves were measured at the most sensitive setting of 0.25 mV the amplitude was assumed to be equal to 0.25 mV. The mean estimated far field R-wave amplitude was 0.31 mV (standard deviation: 0.13 mV). Using the estimated far field R-wave amplitude the ratio between the P-wave amplitude and the far field R-wave amplitude was determined for each patient. The distribution of this ratio is shown in Fig. 3. The mean amplitude ratio as determined in 62 patients was 13.2 (standard deviation: 7.3); this ratio ranged from 2.8 to 38, and in 90% of the patients the amplitude ratio was higher than 5.

Results of the myopotential sensing tests are summarized in Table 2. A total of 59 patients was included in these tests.

It should be noted that atrial oversensing while at rest and breathing deeply was observed in the same patient. In contrast, this patient did not show oversensing while pushing hands or during the far field R-wave sensing test. The ECG-marker recordings from this patient showed incidental, isolated atrial tachyarrhythmia senses. These rather unexpected and atypical observations do not allow a definite conclusion as to the origin of the observed atrial tachyarrhythmia senses. These may either be attributed to premature atrial complexes that cannot be excluded on the basis of the surface ECG recording or may be explained by borderline myopotential sensing. In view of the atrial blanking period of 200 ms, programmed during the myopotential sensing tests, occasional far field R-wave sensing is less likely, but cannot be completely excluded.

Three other patients showed myopotential sensing only while pushing hands. The ECG recordings of these patients showed runs of atrial tachyarrhythmia markers, characteristic of myopotential sensing.

Table 2 Results of myopotential tests ($N=59$)

Situation	Number of patients with oversensing	Percentage (%)
At rest	1	1.7
Deep breathing	1	1.7
Pushing hands	3	5.1

Discussion

In all patients in this study the measured P-wave amplitude was more than twice the estimated far field R-wave amplitude. As a result, in all patients included in the study an atrial sensitivity could be programmed at which regular P-waves were sensed without sensing far field R-waves, independent from the programmed atrial blanking period. However, it should be noted that the measurements in this study were performed only during pacemaker follow-up. Although Cools et al. [1] reported that far field R-wave characteristics did not significantly differ between supine and upright positions and during peak exercise, further evaluation of this performance should be done by means of ambulatory data collected during daily life situations.

The P-wave amplitudes and the ratio between P-wave amplitude and estimated far field R-wave amplitude determined during this study compare well with the results reported by Cools et al. [1], although in our study far field R-wave sensing was observed in fewer patients. Besides differences in tip-to-ring distances of the atrial leads used, several other factors could have contributed to these differences, such as the electrical characteristics of the P-wave input circuits of the implanted devices and the atrial pacing site.

Atrial sensing is especially important in patients with atrial tachyarrhythmias, since both the application of therapies and AF related device diagnostics depend heavily on reliable atrial sensing performance [10]. Bipolar atrial electrogram amplitudes have been reported to be lower in atrial fibrillation and flutter [11] requiring higher atrial sensitivities and thereby increasing the risk of atrial oversensing and an over-estimation of the burden of atrial tachyarrhythmia. The atrial blanking period may be extended in order to eliminate far field R-wave sensing. Although Nowak et al. [12] did not observe effects of relatively long blanking periods on the detection of atrial fibrillation at low heart rates (<100 min^{-1}) the reliable detection of atrial fibrillation at higher rates and the detection of atrial flutter may require shorter atrial blanking periods. The results from our study indicate that with a short atrial blanking period (50 ms) and high atrial sensitivities a low incidence of atrial oversensing can be achieved.

Study limitations

During this study the atrial lead implantation site was not documented and as a consequence, the data do not allow for a comparison of various implantation sites with respect to the incidence of atrial oversensing. This study reflects atrial lead placement in a typical patient population, therefore the majority of atrial leads were implanted in the right atrial appendage. Alternative atrial lead implantation sites have been evaluated with respect to pacing therapies for the treatment of atrial fibrillation or prevention of the development of permanent AF [13–16]. Additionally, several investigators have studied the effect of the atrial lead location on rejection of far field R-wave sensing [2,17]. Since the amplitudes of far field R-waves and P-waves may vary as a function of the lead implantation site the results from this study may not necessarily be valid for other atrial lead locations.

Pacemakers used during this study had identical atrial sensing characteristics. The sensing performance of pacing devices depends on the electrical characteristics of the sense amplifiers and the input filters. As a consequence, the results of this study can only be applied to devices with atrial sensing characteristics identical to those used in the study. Other devices may yield different results when used in combination with the pacing lead used in this study.

Conclusion

The results of this study indicate that the implantation of an atrial lead with a 10 mm tip-to-ring spacing results in a low incidence of far field R-wave sensing independent of the programmed atrial blanking period, while maintaining appropriate electrical performance.

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References

[1] Cools FJC, Van Twembeke RRC, Backers J, Verpooten GA. Stability of far field R wave signals in different conditions. Europace 2003;5:175—83.

[2] Brouwer J, Nagelkerke D, Den Heijer P, Ruiter JH, Mulder H, Begemann MJS, et al. Analysis of atrial sensed far-field ventricular signals: a reassessment. Pacing Clin Electrophysiol 1997;20:916—22.

[3] Wiegand UKH, Schier H, Bode F, Brandes A, Potratz J. Should unipolar leads be implanted in the atrium? A Holter electrocardiographic comparison of threshold adapted unipolar and high sensitive bipolar sensing. Pacing Clin Electrophysiol 1998;21:1601—8.

[4] Brandt J, Worzewski W. Far-field QRS complex sensing: prevalence and timing with bipolar atrial leads. Pacing Clin Electrophysiol 2000;23:315—20.

[5] Fröhlig G, Helwani Z, Kusch O, Berg M, Schieffer H. Bipolar ventricular far-field signals in the atrium. Pacing Clin Electrophysiol 1999;22:1604—13.

[6] Brandt J, Fåhraeus T, Schüller H. Far-field QRS complex sensing via the atrial pacemaker lead I. Mechanisms, consequences, differential diagnosis and countermeasures in AAI and VDD/DDD pacing. Pacing Clin Electrophysiol 1988; 11:1432—8.

[7] Lau CP, Leung SK, Hung FT, Barold SS. Automatic mode switching of implantable pacemakers: I. Principles of instrumentation, clinical, and hemodynamic considerations. Pacing Clin Electrophysiol 2002;25:967—85.

[8] Maury P, Schlaepfer J, Arbane M, Girod G, Kappenberger L. Incessant atrioventricular dissociation due to far-field QRS oversensing and recurrent mode switch in a dual chamber pacemaker. Europace 2002;4:149—53.

[9] Flammang D, Renirie L, Begemann M, van Krieken F. Amplitude and direction of atrial depolarisation using a multipolar floating catheter: principles for single lead VDD pacing. Pacing Clin Electrophysiol 1991;14:1040—8.

[10] Yang A, Hochhausler M, Schrickel J, Bielik H, Shlevkov N, Schimpf R, et al. Advanced pacemaker diagnostics in the characterization of atrial fibrillation: Impact on preventive pacing algorithms. Pacing Clin Electrophysiol 2003;26: 310—3.

[11] Wood MA, Moskovljevic P, Stambler BS, Ellenbogen KA. Comparison of bipolar atrial electrogram amplitude in sinus rhythm, atrial fibrillation, and atrial flutter. Pacing Clin Electrophysiol 1996;19:150—6.

[12] Nowak B, Kracker S, Rippin G, Horstick G, Vincent A, Geil S, et al. Effect of the atrial blanking time on the detection of atrial fibrillation in dual chamber pacing. Pacing Clin Electrophysiol 2001;24:496—9.

[13] Bailin SJ, Adler S, Giudici M. Prevention of chronic atrial fibrillation by pacing in the region of Bachmann's bundle: results of a multicenter randomized trial. J Cardiovasc Electrophysiol 2001;12:912—7.

[14] Padeletti L, Porciani MC, Michelucci A, Colella A, Ticci P, Vena S, et al. Interatrial septum pacing: a new approach to prevent recurrent atrial fibrillation. J Intervent Cardiac Electrophysiol 1999;3:35—43.

[15] Padeletti L, Porciani MC, Michelucci A, Colella A, Costoli A, Pieragnoli C, et al. Prevention of short term reversible chronic atrial fibrillation by permanent pacing at the triangle of Koch. J Intervent Cardiac Electrophysiol 2000;4: 575—83.

[16] Kale M, Bennett DH. Atrial septal pacing in the prevention of paroxysmal atrial fibrillation refractory to antiarrhythmic drugs. Int J Cardiol 2002;82:167—75.

[17] Kantharia BK, Wilbur SL, Padder FA, Pennington III JC, Samuels FL, Movsowitz CM, et al. Effect of different location of atrial lead position on nearfield and farfield electrograms in dual chamber pacemaker-defibrillators. J Intervent Cardiac Electrophysiol 2001;5:59—66.