A New Concept for Right Atrial Sensing Using Permanent Biatrial Pacing

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Summary

Biatrial pacing is an accepted non-pharmacological treatment for re-entrant atrial arrhythmias in patients with atrial conduction disturbances. The problem of assuring the synchrony of atrial excitation not only during pacing but also during sinus rhythm and premature atrial beats has not yet been solved. Standard J-shaped leads with a short distance between the tip and ring located in the right atrial appendage (RAA) provide optimal sensing conditions. Due to anatomical conditions, sinus and ectopic atrial excitation reach the RAA with a minimum 20 - 30 ms delay; they also make early left atrial pacing and proper resynchronization possible. The aim of this study was to investigate a new sensing configuration in the right atrium (RA) that would offer earlier sensing of spontaneous excitation. The study shows that when using a standard J-shaped lead with its tip positioned in the RAA, the beginning of sinus atrial activation is detected with a minimum 30 ms delay after the onset of the P-wave. The potential, which may serve for pacemaker function control, is detected after another 10 ms. Increasing the distance between the tip and ring of the atrial lead by moving the anodal electrode to the opposite site of the arc of a standard J-shaped lead (positioned in the central-superior region of the RA) causes significantly earlier (16 - 20 ms) detection of the RA activation wave; it does not result in significant deterioration of the sensing conditions in the atrial channel. It seems that localizing the tip of a lead and its ring in the horizontal plane towards the main ventricular activation vector will be one of the solutions used to decrease ventricular potential sensing by the atrial channel. Introduction of an additional anodal ring into the central-inferior part of the lead arc provides the opportunity for earlier detection of premature beats originating in the lower RA region without a negative influence on sensing and pacing conditions. The proposed configuration of electrodes does not create the risk of phrenic nerve pacing even after the maximal energy output has been programmed.

Key Words

Biatrial pacing, atrial sensing, atrial pacing lead, electrode spacing, atrial timing

Introduction

In patients with conduction disturbances within the atria, numerous researchers have proposed a variety of resynchronized atrial pacing modes (bifocal right atrial pacing, biatrial pacing) that have become widely accepted. These non-pharmacological methods have prevented the recurrence of atrial arrhythmias [1-8]. Simultaneous pacing of two distant atrial regions aids in rebuilding the synchrony of their activation and diminishes the possibility for completion of re-entry [1-8]. One of the most relevant current problems in bifocal and biatrial pacing is assuring the synchrony of atrial activation not only during pacing but also during sinus rhythm and premature ectopic beats initiated within the right or left atrium [1-8]. In order to achieve resynchronization of atrial beats during spontaneous rhythm acceleration above the programmed pacing rate of the pacemaker, Saksena prefers rate-responsive pacemakers with "hyperchronotropic" rate programming; furthermore, he uses beta-blockers to decrease the spontaneous rhythm rate [2,3,8,9]. Daubert pro-

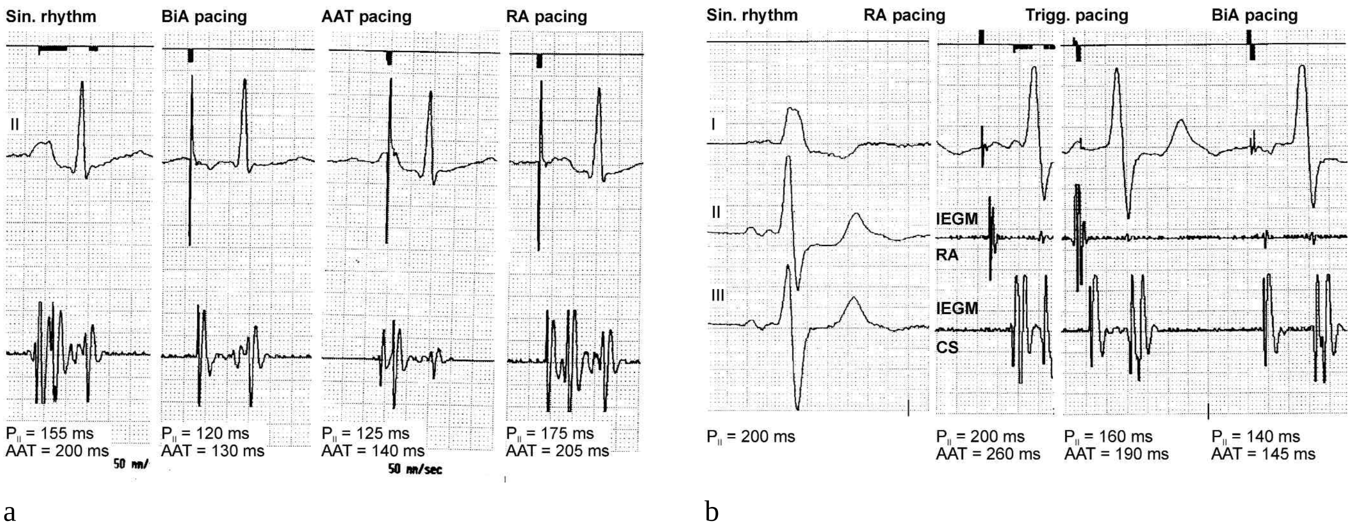

Figure 1. Panel a) Biatrial pacing by a single-chamber pacemaker (split atrial electrode configuration). Both right and left atrial and ventricular potentials are recorded in the IEGMs (bipolar sensing). Figures show the electrophysiological effect of different modes of pacing: P-wave duration time and atrial activation time (AAT). Aggravation of the interatrial conduction disturbances during right atrial pacing, moderate resynchronization effect of atrial-triggered AAT pacing, and the remarkable results of simultaneous pacing of both atria are visible. The incomplete effect of resynchronizing the triggered pacing mode (AAT) is caused by an almost 40 ms delay of the atrial potential detection (result of typical lead localization in the right atrial appendage).

Panel b) Biatrial pacing using the ventricular port of a DDD pacemaker for left atrium pacing. IEGM: the right atrium A-wave is recorded in the atrial channel, and the left atrium A-wave (and V-wave) is recorded in the ventricular channel. Results of the electrophysiological effect of different pacing modes are similar to panel a. Again, there is a > 40 ms delay of the right atrial activation detected in the atrial channel.

posed incorporating an additional, new resynchronizing algorithm into the RAM of the Chorus 7034 pacemaker (Ela Medical, France). The algorithm enables AAT pacing from the atrial channel with standard coordination of the atrial and ventricular channels [1-8]. Each spontaneous atrial beat (both sinus and ectopic ones originating within the right or left atrium) causes immediate triggering for pacing in both atria, and makes activation less asynchronous [1-8]. It is well-known that premature beats are the most frequent factor initiating episodes of arrhythmia. More efficient suppression is achieved by overdrive pacing, and in recent years several new (similar as far as the final result is concerned) algorithms for consistent atrial pacing have been implemented [10-12].

The right atrial appendage (RAA) is a conventional site for atrial pacing because it provides optimal conditions both for lead placement, pacing, and sensing [13-19]. However, due to its anatomical condition, waves of sinus beats as well as ectopic beats (often originating within Koch's triangle and the ostium of the pulmonary veins) reach the RAA after a 20 or even 30 ms delay [20-23] (Figure 1). Therefore, Daubert proposed fixating the tip of the RAA lead as high as possible when implanting biatrial pacing systems [4-7,8,24].

For over 30 years (ever since the time of Smyth, Kastor, Zucker, Porstmann and Schaldach [13-16]) creators of atrial leads have concentrated on improving the sensing conditions, hoping for maximal elimination of the ventricular potential. This effect has been achieved in bipolar leads by decreasing the distance between the tip and the ring of the lead [17-19,25-29]. It resulted in establishing the "local" right atrial potential, which was ideal for operating the pacemaker (and for ventricular routing in standard DDD systems). However, those advantages appear to be shortcomings in biatrial pacing systems [4-7,24]. The possibility of connecting two bipolar, atrial leads (for pacing both atria) with two (DDD) pacemaker ports (e.g., the Biotronik Logos DS as well as other devices) [20] created a challenge. Therefore, a completely new lead for RAA pacing was created to facilitate the sensing of spontaneous atrial activation (sinus or ectopic).

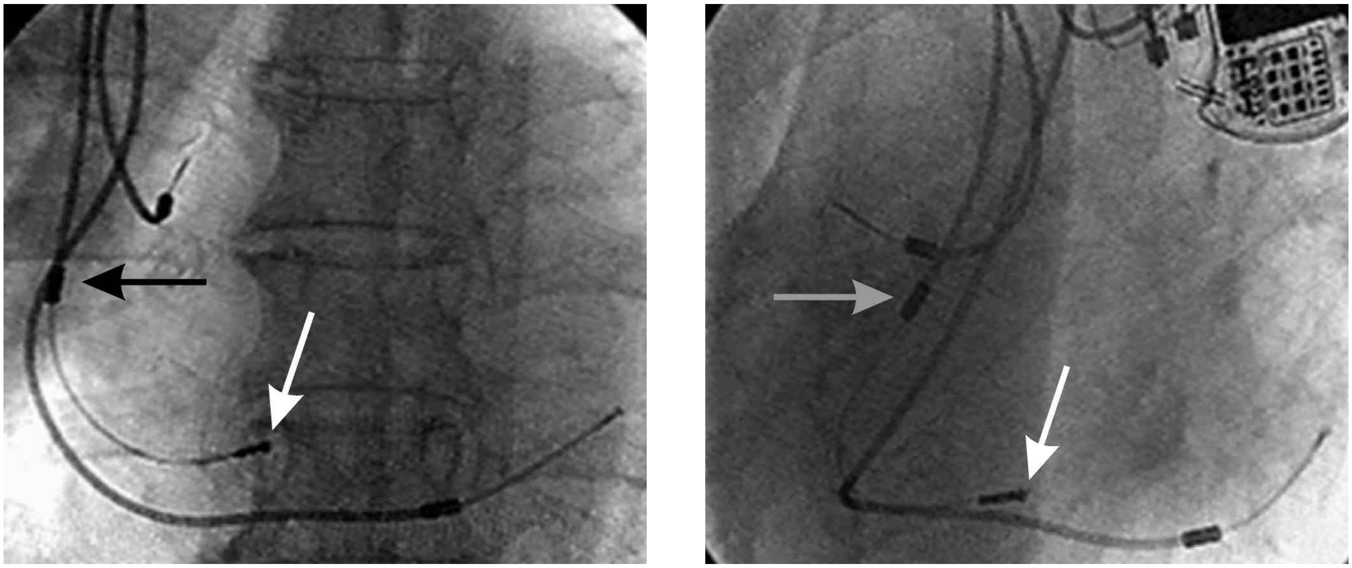

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Figure 2. X-ray of a female patient with trifocal atrial pacing. A previously implanted biatrial pacing system with a screw-in lead (Y 53/S-BP, Biotronik, Germany) was implanted according to Padeletti`s method [30] in the posterior-inferior part of the interatrial septum (white arrow). Please note the position of the lead ring in the high atrium (black and grey arrows). a) postero-anterior plane view; b) lateral plane view.

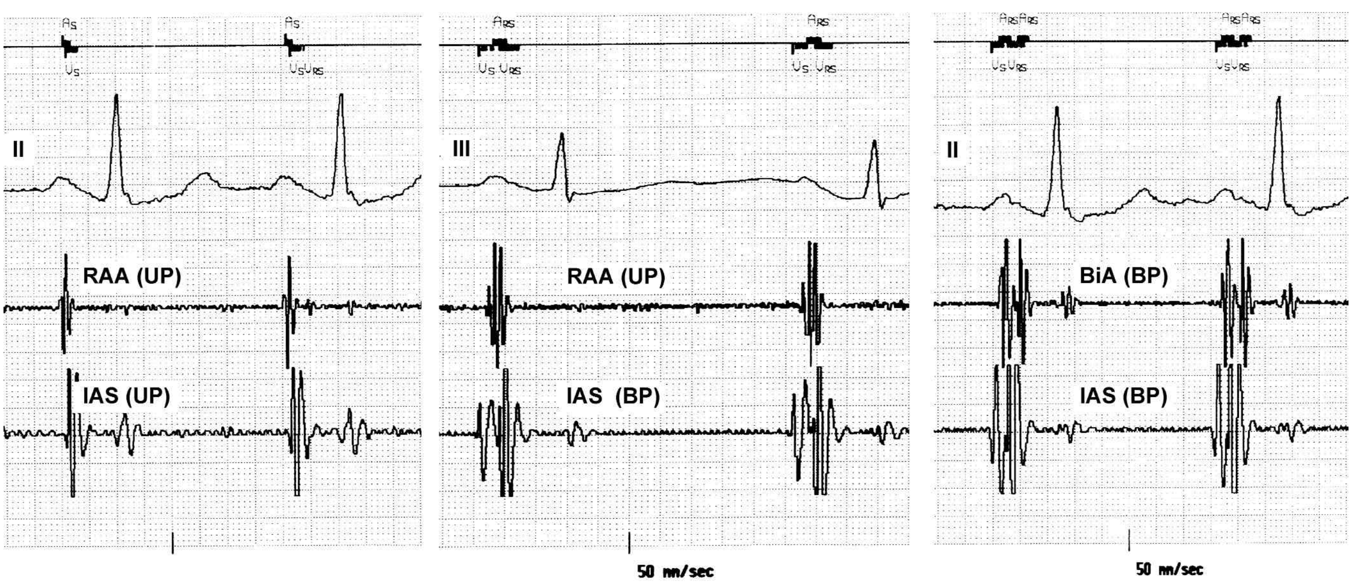

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Figure 3. IEGM recordings performed in the same female patient with the trifocal atrial pacing system.
Panel a) Atrial channel – right atrial appendage (UP sensing), ventricular channel – interatrial septum (UP sensing). The onset of the P-wave is detected with a 75 ms delay by the tip of the septal lead.
Panel b) Atrial channel – right atrial appendage (UP sensing), ventricular channel – interatrial septum (BP sensing). Earlier detection of the A-wave in the ventricular channel (10 ms earlier than P-wave onset).
Panel c) Atrial channel – biatrial recording (BP sensing), ventricular channel – interatrial septum (BP sensing). The remarkable early atrial activation detection results from the localization of the septal lead ring in the high right atrium.UP = unipolar, BP = bipolar.

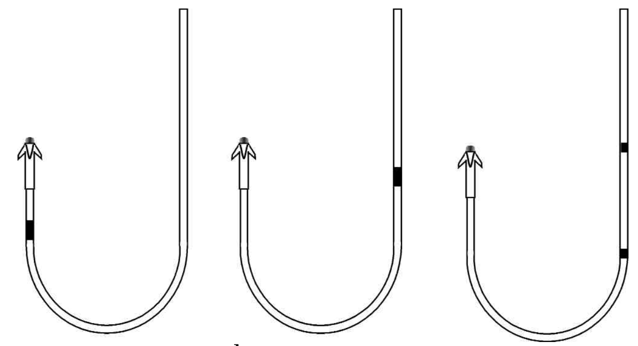


Figure 4. Leads for permanent atrial pacing.
a) standard J-shaped BP lead for right atrial appendage pacing – standard configuration (St);
b) hypothetical right atrial lead for permanent biatrial pacing – non-standard configuration 1 (N_1);
c) an alternative model of a hypothetical right atrial lead for permanent biatrial pacing – non-standard configuration 2 (N_2).

Previously, a conventional system for biatrial pacing had been implanted in a 56-year-old female patient with severe bradytachycardia syndrome. She also experienced recurrent episodes of non-typical atrial flutter several times per day/week. The weak antiarrhythmic effect of biatrial pacing, unfavorable hemodynamic effects of tachyarrhythmia, and predominant conduction disturbances within the right atrium required us to implant an additional lead in the posterior-inferior region of the interatrial septum using the technique proposed by Padeletti [30] and Katsivas [31] (Figure 2). For interatrial septum pacing, we used a screw-in lead (Y 53/s-BP, Biotronik).
Recording of the intracardiac potentials (Figure 3) was conducted during the implantation procedure using the technique described in previous reports [32,33]. The recordings appeared to be extremely interesting and informative. They clearly showed the earlier appearance of an A-wave in the bipolar recordings originating from the bipolar "septal" lead rather than the classical J-shaped RAA lead. We believed that positioning the ring of the lead (which served as an anode during pacing) within the high right atrium would provide earlier detection of the right atrial beat (Figure 4).

The Aim of the Study

The aim of the study was to verify the hypothesis that earlier detection of atrial excitation could be achieved by locating the ring (anode) of the RAA lead in the central-superior lumen of the right atrium, as compared to using a standard J-shaped lead. The additional goal of the study was to evaluate the sensing conditions while using two connected rings (anodal) positioned in the high and low regions of the atrium. The secondary aim was to assess whether and to what extent, the type of lead configuration altered the sensing and pacing conditions, compared to the conventional RAA pacing system with a J-shaped lead.

Material and Methods

Patients

The study was performed in 18 patients (nine male and nine female; average age 64 years) during implantion of biatrial (in 10 cases) and conventional DDD (in eight cases) pacing systems.

Study Protocol

In all patients, the left subclavian vein was punctured and a standard J-shaped lead was inserted through the vein and implanted into the RAA of the heart. A second puncture was made in the same vein and an additional pacing lead was inserted into either the coronary sinus (CS) (Corox V 375, Biotronik) or the right ventricle (RV) (TiR 60 BP or SX 60 BP, Biotronik) through the venous system. After the second lead was introduced into the lumen of the right atrium, we measured the standard sensing and pacing conditions from the tip of the lead (cathode) implanted into the RAA to various anode configurations, i.e.,

- to the ring of the implanted J-shaped lead (standard configuration: St);
- to the (proximal) ring of the second lead temporarily positioned at the level of the right atrium (non-standard configuration1: N_1); and
- to the connected rings of the CS pacing lead or the tip and ring of the RV lead (non-standard configuration N_2).

After performing the measurements, the leads were fixed in the previously planned regions and the implantation procedure proceeded in a typical fashion.

Recordings and Measurements

The main research tool consisted of a sterile cable, an external DDD pacemaker, and the Biotronik PMS 100 pacemaker programmer (Figure 5). The proximal ends

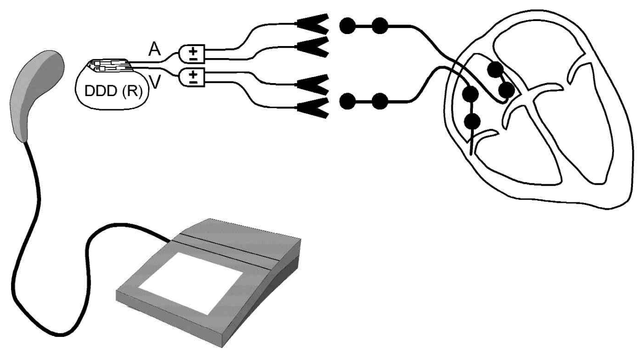
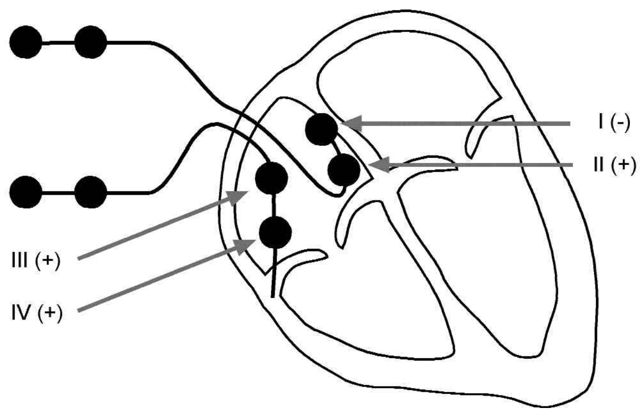


Figure 5. The hardware used for measurements (all from Biotronik). a) sterile, four-wired ECG cable; b) two Y adapters (A1-A-BP); c) external DDD pacemaker (Actros); d) programmer head; e) programmer (PMS 1000).



Configuration	Cathode	Anode
Standard	I	II
Non standard$_1$	I	III
Non standard$_2$	I	III + IV

Figure 6. Right atrial lead connections used during the study (the configurations differ based on the anode localization). A standard J-shaped bipolar lead permanently implanted in the right atrial appendage and a pacing lead for the coronary sinus or right ventricle only temporarily retained in the right atrium for performing recordings. Electrode I: the tip of a standard lead. II: ring of a standard lead; III: (proximal) ring temporarily localized in one atrium; IV: the tip or distal ring of the same lead.

of the leads were successively connected to a pacemaker (cathode and anode configurations are shown in Figure 6). Measurements of the sensing and pacing parameters (A-wave potential, pacing threshold) were performed both in the atrial (standard configuration) and ventricular (non-standard configuration) channels. As the measurements were completed, we recorded simultaneously the intracardiac electrogram (IEGM) and a (standard II lead) surface electrocardiogram at a speed of 50 mm/s. We also measured the temporary parameters by moving the cursors on the frozen screen of the programmer at a speed of 100 mm/s. Pacing threshold measurements were summarized by using the maximal energy output (9.2 V/0.5 ms) to estimate the pacing threshold of the phrenic nerve.

Justification of the Selection Method

To maximally shorten the measurement and recording times, we employed a universal tool that allowed us to reduce the number of connective changes, as well as other procedures. The use of the standard pacemaker enabled us to eliminate the influence of filtering and to amplify the recordings using different hardware from electrophysiologic studies. The documented IEGM recordings facilitated A-wave and V-wave amplitude measurements despite the known inaccuracy of this method; quite often the maximum deflection of the A-wave is cut off. However, it was the only way we could gain at least approximated values of the most important parameter for atrial sensing of the A-wave to V-wave ratio.

Results

Table 1 shows that moving the ring (anode) of the atrial lead from the typical position to the opposite side of the arc of the lead within the atria causes a slight decrease in the amplitude of the atrial potential (from 3.95 mV to 3.55 mV). Doubling the amplitude of the ventricular potential (from approximately 0.25 mV – 0.7 mV) did not influence the value of fluctuations in the recorded atrial potential, but it was highly relevant in increasing of the duration (from 70 ms to 130 ms).

Analysis of the modified connections did not change the pacing threshold; most importantly, the beginning of the atrial activation wave was detected 19 ms (and the potential over 0.5 mV/15 ms) earlier in the non-standard (N_1) configuration rather than in the classical one (St). In the non-standard (N_2) configuration, which consisted of two connected anodal electrodes (rings) positioned in the central-superior and -inferior lumen of the right atrium, the results were similar to those in

Sensing/ pacing configuration		Manual measurement from paper recordings: A-wave amplitude (mV)	V-wave amplitude (mV)	A/V ratio	A-wave duration (ms)	Onset P_{II} – onset A-wave (ms)	Onset A-wave in N_2/N_1 – onset A-wave in St (ms)	P_{II}-onset – first deflection of A-wave	First deflection in N_2/N_1 – first deflection in St (ms)
Standard (St)	Average	2.57	0.248	11.80	71.66	33.61	–	43.06	–
	Range	1.3 – 4.6	0.0 – 0.7	2.3 – 23	55 – 90	25 – 50	–	35 – 60	–
	Median	2.3	0.19	11.5	70.0	35.0	–	40	–
	SD	1.07	0.21	6.82	8.57	6.1	–	5.46	–
Non standard configuration 1 (N_1)	Average	2.29	0.668	5.27	134.16	14.72	18.89	28.06	15.00
	Range	2.2 – 2.3	0.12 – 1.4	1.6 – 19.2	105 – 165	10 – 30	5 – 40	20 – 35	5 – 40
	Median	2.3	0.70	3.29	135	12.5	20	30	15
	SD	0.02	0.37	4.39	16.82	5.81	7.96	5.97	8.22
Non standard configuration 2 (N_2)	Average	2.38	0.639	5.35	128.33	13.88	18.61	25.83	16.94
	Range	2.0 – 4.6	0.20 – 1.4	1.57 – 11.5	100 – 155	10 – 20	10 – 35	15 – 40	5 – 30
	Median	2.3	0.55	4.39	132	10	20	25	15
	SD	0.56	0.37	3.48	17.48	4.71	6.37	6.24	6.44

Sensing/ pacing configuration		Automatic measurement: A-wave amplitude (mV)	A-wave fluctuations (mV)	Pacing threshold at 0.5 ms (V)
Standard (St)	Average	3.95	1.48	0.734
	Range	1.8 – 6.1	0.5 – 2.6	0.2 – 1.7
	Median	4.1	1.6	0.6
	SD	1.52	0.58	0.43
Non standard configuration 1 (N_1)	Average	3.55	1.13	0.71
	Range	0.6 – 6.1	0.6 – 2.1	0.3 – 1.3
	Median	3.2	0.9	0.6
	SD	1.62	0.47	0.33
Non standard configuration 2 (N_2)	Average	3.78	1.58	0.58
	Range	1.7 – 7.0	0.5 – 3.0	0.2 – 1.3
	Median	3.5	1.5	0.5
	SD	1.66	0.95	0.36

Table 1. Sensing/pacing timing parameters and conditions during right atrial pacing/sensing using different configurations (anode location). Onset of A-wave is measured for signals > 0.2 mV; first deflection is measured for signals > 0.5 mV.

N_1, except they had slightly lower values (average 0.15 V) for the pacing threshold. Despite pacing with a maximum energy output, we did not observe phrenic pacing in any patients.

Figures 7 – 11 illustrate our collective findings in the ECG and IEGM recordings. The recordings from the atrial channel showed typical IEGM images detected by a standard J-shaped lead with its tip in the RAA.

Statistical evaluation of mean difference using paired t-test		Manual measurement from paper recordings: A-wave amplitude (mV)	V-wave amplitude (mV)	A/V ratio	A-wave duration (ms)	Onset P_{II} – onset A-wave (ms)	Onset A-wave in N_2/N_1 – onset A-wave in St (ms)	P_{II}-onset – first deflection in St (ms)	First deflection in N_2/N_1 – first deflection in St (ms)
Standard (St) versus Non standard 1 (N_1)	t	1.111	5.544	3.155	15.520	10.064	–	7.737	–
	p	0.282	0.00003	0.007	0.00000	0.00000	–	0.00000	–
Standard versus Non standard 2 (N_2)	t	0.783	4.933	3.852	15.481	12.404	–	11.297	–
	p	0.444	0.00012	0.0017	0.00000	0.00000	–	0.00000	–
N_1 versus N_2	t	0.632	0.736	0.124	1.743	0.511	0.236	1.117	0.941
	p	0.535	0.471	0.903	0.101	0.615	0.816	0.279	0.359

Statistical evaluation of mean difference using paired t-test		Automatic measurement: A-wave amplitude (mV)	A-wave fluctuations (mV)	Pacing threshold at 0.5 ms (V)
Standard versus Non standard 1	t	0.312	1.388	1.443
	p	0.760	1.953	0.174
Standard versus Non standard 2	t	0.018	0.385	2.186
	p	0.985	0.706	0.047
Non standard 1 versus Non standard 2	t	0.473	0.458	1.472
	p	0.646	0.657	0.169

Table 2. Statistical evaluation (paired t-test) of the data of Table 1.

Non-standard configurations (N_1 and N_2) were recorded in the ventricular channel. When the recorded IEGMs in both channels were compared, we observed differences between the non-standard and classical connections, respectively:

- earlier beginning of the A-wave,
- clearly wider A-waves, and
- slightly higher V-waves.

These impressions were confirmed using precise measurements (Tables 1 and 2). Due to incorrect programming of the pacemaker's sensing device, extreme deflection of the A-wave may be automatically cut off. That is why the relationship of the A-wave to V-wave amplitude is fraught with mistakes; (however, in practice the relationship may be much more advantageous).

Discussion

For many years designers of atrial leads have concentrated on achieving the optimal right atrial pacing conditions, i.e., looking for the maximum local atrial potential at the site, while maintaining the furthest distance from the ventricular muscle [13-19,25-29]. In the era of non-programmable and early programmable pacemakers, elimination (or at least maximal limitation) of the ventricular potential detected by the atrial port was an improvement; this assured correct functioning of the pacemaker and prevented endless loop tachycardia [17-19,34]. The existing options for programming most pacemaker parameters and new algorithms [35] significantly increase the safety of pacing therapy and diminish the role of recording the maximal local atrial potential. New methods of pacing and new algorithms for bifocal and biatrial pacing in pacemakers establish new requirements for designers. The "ideal lead" for right atrial pacing should detect the

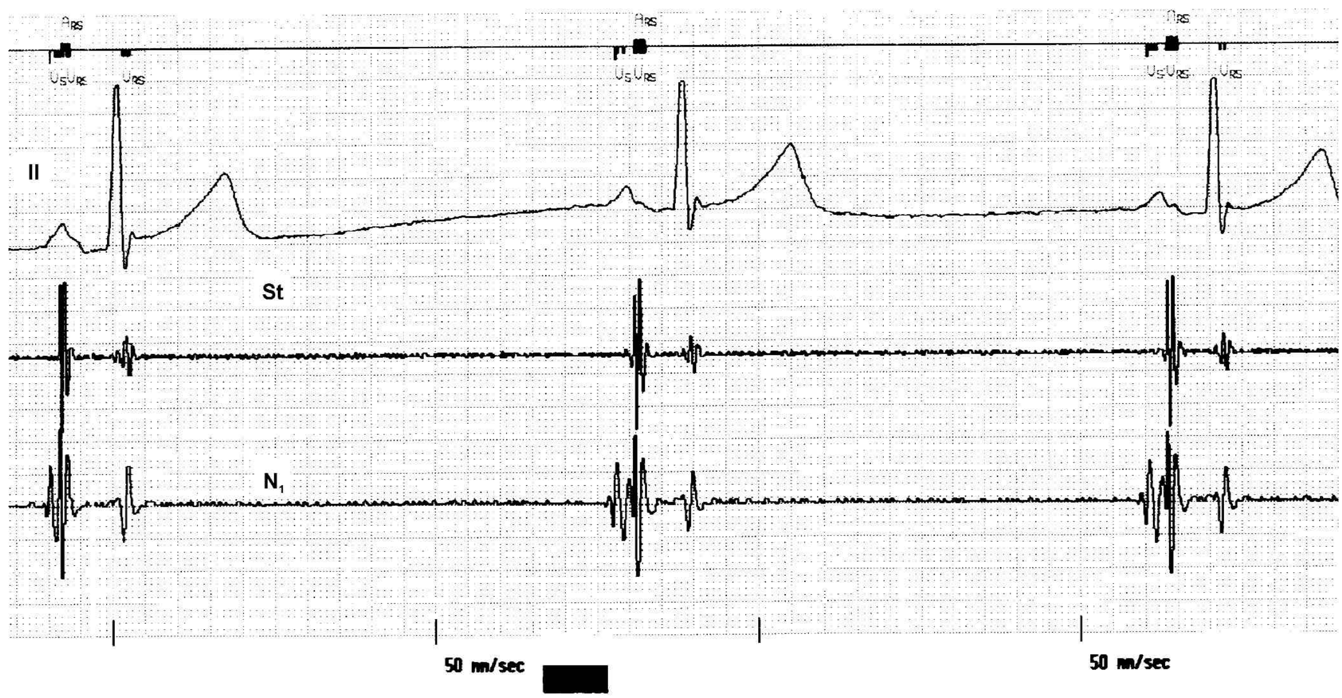


Figure 7. Bradycardia (34 beats/min) with the picture of the wandering pacemaker within the sinus node; the analysis of IEGM from a standard lead St (atrial channel) indicates changeable time of right atrial attainment by an excitation wave. Non-standard configuration N_1 (ventricular channel): extremely early detection of the excitation wave (up to 60 ms).

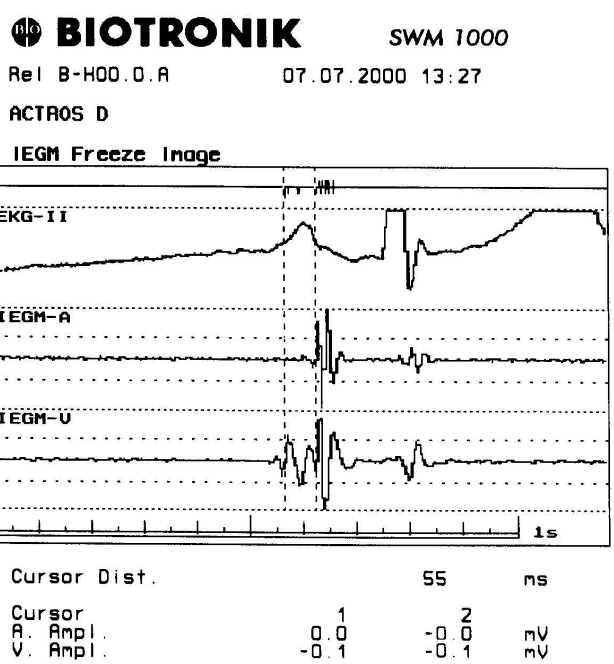


Figure 8. IEGM of the patient in Figure 7; the recording at 100 mm/s is frozen on the programmer screen with cursors marking the beginning of atrial activation detected in both pacemaker channels.

activation of the right atrium as quickly as possible (sinus beats and premature beats originating in the low-posterior region of the right atrium) to permit the earliest pacing of the left atrium. So far, new continuous atrial pacing algorithms do not assure re-synchronized pacing during premature beats of high prematurity [10-12], which determine the most frequent triggers for atrial fibrillation [36-38].

The study shows that moving the anodal electrode to the opposite site of its atrial arc (positioned in the central-superior region of the right atrium) causes detection of a relevant earlier right atrial activation wave without significant deterioration of the sensing functionality in the atrial port of currently available pacemakers. It seems that localizing the tip of a lead and its ring in the horizontal plane towards the main ventricular activation vector will be one of the solutions for decreasing ventricular potential sensing by the atrial channel of a pacemaker [17-19].

Introduction of an additional anodal ring into the central-inferior part of the lead arc provides earlier detection of premature beats originating in the pulmonary vein ostium and the triangle of Koch region without negative-

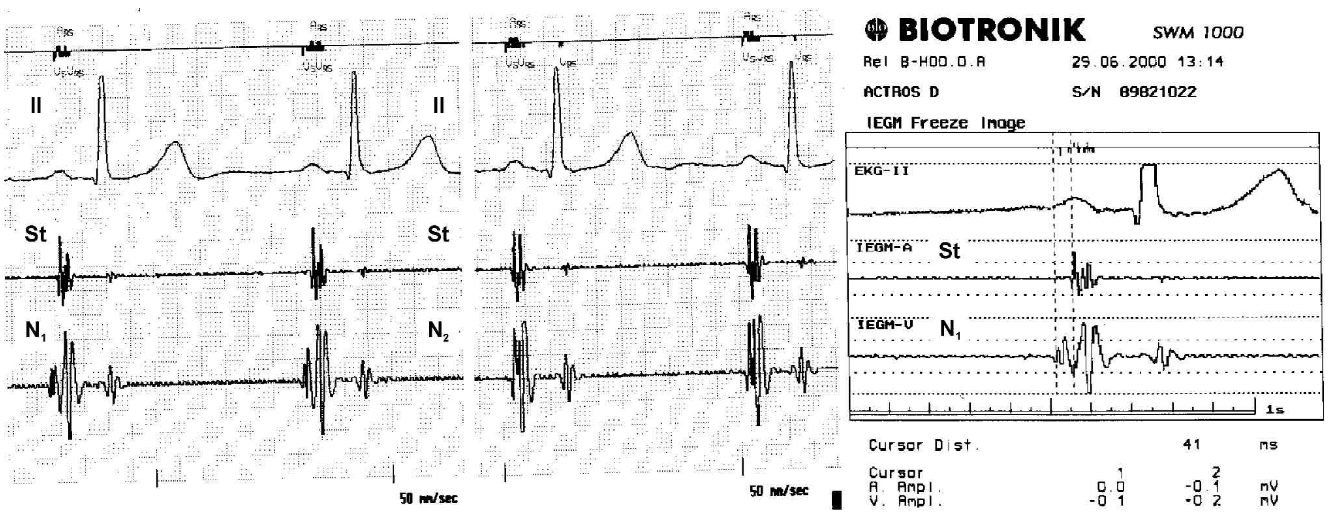


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Figure 9. Another patient's IEGM. Atrial channel: standard lead recording; ventricular channel: recordings in non-standard configurations (N_1 and N_2). Significantly earlier (30 – 40 ms) detection of an excitation wave in the non-standard configuration (N_1 and N_2) of an IEGM.

ly influencing sensing and pacing conditions. The study also showed that this kind of configuration (i.e., ring location) did not increase the risk of phrenic nerve pacing even after programming the maximal energy output.

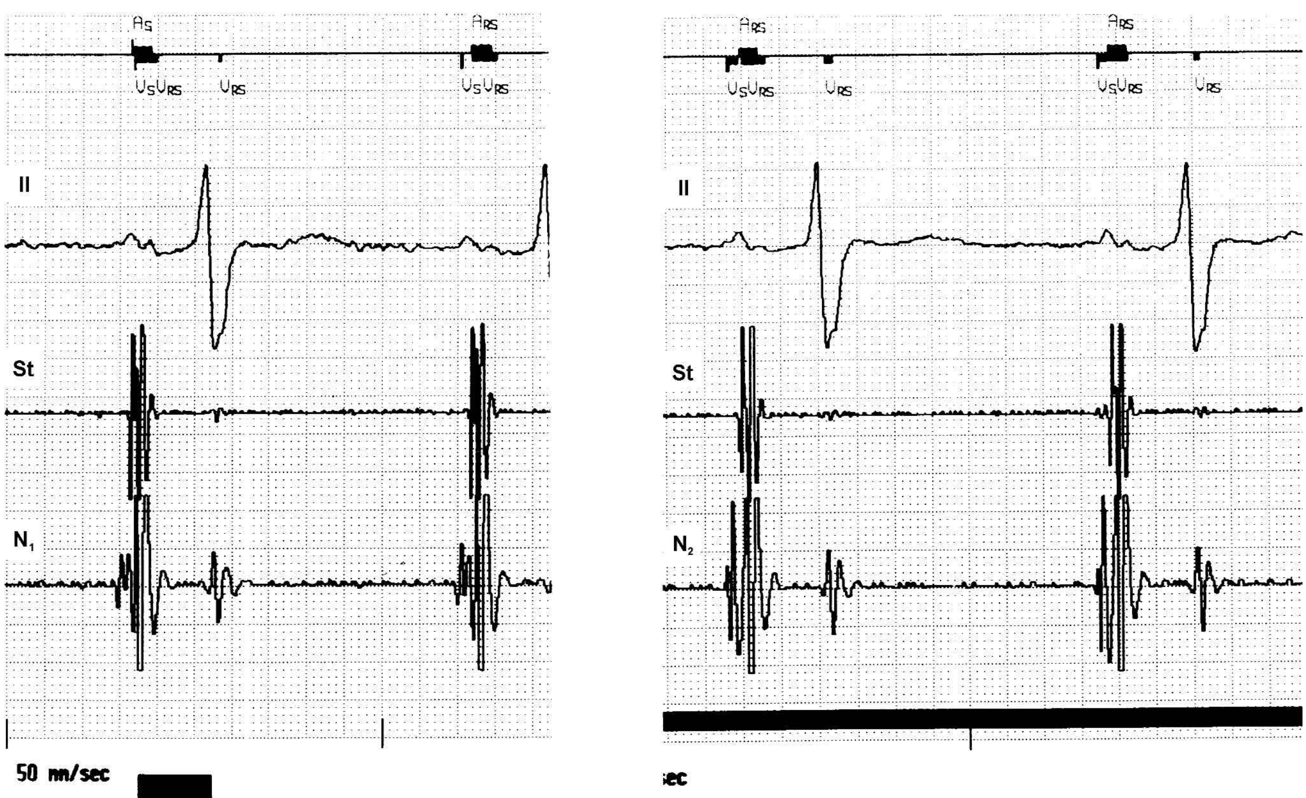

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Figure 10. IEGM recordings in another patient. Atrial channel: standard lead recording; ventricular channel: recordings in non-standard configurations (N_1 and N_2). Significantly earlier (20 – 40 ms) detection of an excitation wave in the non-standard (N_1 and N_2) IEGM.

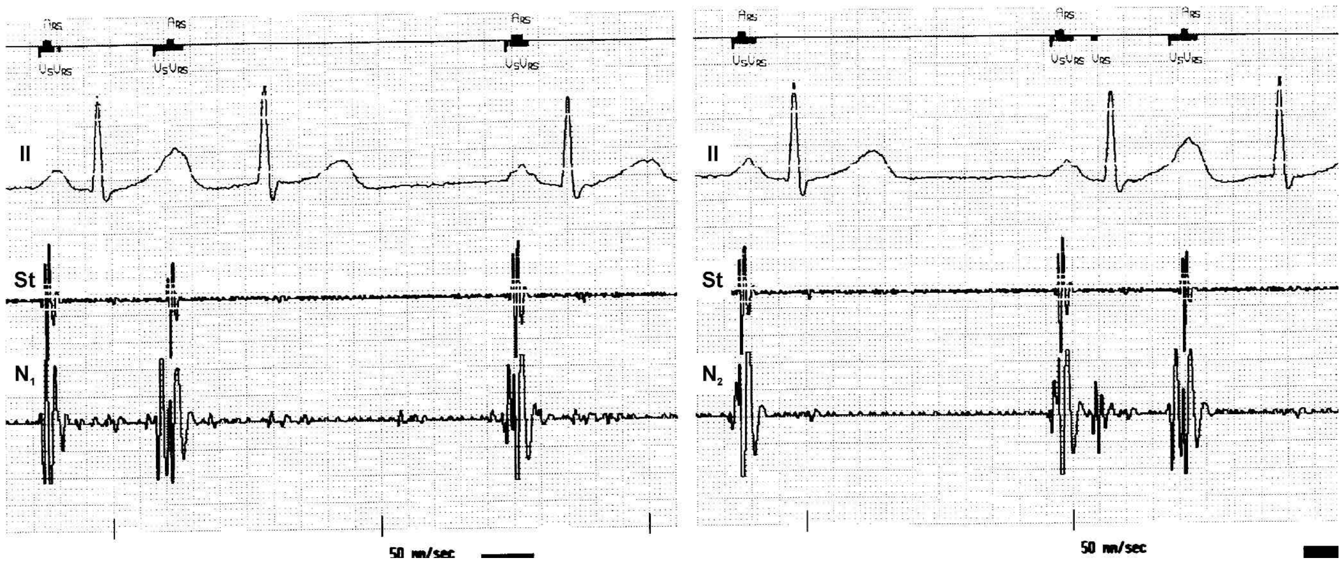

Figure 11. ECG and IEGM of a patient with premature atrial beats. Atrial channel: standard lead recording; ventricular channel: recordings in non-standard configurations (N_1 and N_2). Slightly earlier (20 ms) detection of an excitation wave in the non-standard (N_1 and N_2) IEGM. The difference is much greater (about 60 ms) during premature atrial beats.

Conclusion

Our work has led to the following conclusions:

- The lead with its tip in the right atrial appendage (cathode) and its ring located in the central-superior part of the right atrium (anode) detects the beginning of the atrial activation about 19 ms earlier than the standard lead.
- Increasing the distance between the tip and ring of the atrial lead does not significantly worsen sensing conditions, nor influences the pacing parameters.
- Adding a second ring positioned in the central-inferior region of the right atrium for earlier detection of premature beats originating in that part of the atrium does not change sensing and pacing conditions compared to the single-ring configuration.

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