A New Lead Connection Configuration for the Possibility of Biatrial Pacing Triggered by Left Atrial Events Using a Dual-Chamber Pacemaker

A. KUTARSKI, M. WÓJCIK
Department of Cardiology, University Medical Academy, Lublin, Poland

M. SCHALDACH
Department of Biomedical Engineering, Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany

Summary

A biatrial pacing system that is based on a DDD pacemaker has many advantages such as its effectiveness and safety of pacing; however, the impossibility of resynchronization in the event of left atrial premature beats, i.e. the impossibility of resynchronizing "left to right", is its main disadvantage. We hypothesized that "widening the sensing spectrum" of the atrial channel (with left atrial potentials) may be achieved by simply positioning the indifferent (anodal) lead of the right atrial channel eighter in the ostium or in the proximal part of the coronary sinus – i.e., the ussual position of the proximal ring of the coronary sinus lead. We decided to use this ring as the common anode for both channels of the pacemaker. The aim of the study was to evaluate the non-standard connection of leads intended for left atrial potentials detection in the (right) atrial channel of DDD pacemakers that are specially designed for biatrial pacing. The study was performed during biatrial system implantation in ten patients. The results showed that the modified lead connections clearly changed the intracardiac potential recordings in the right atrial channel of the pacemaker. The recordings contain left atrial potentials of similar amplitudes (2.59 and 2.47 mV) that appear following right atrial potentials. Only a slight deterioration of sensing conditions (deterioration of A-wave to V-wave ratio from 13.8 to 4.8) was observed. The pacing conditions in both the right and the left atrium did not change significantly. The results of the study confirmed the hypothesis regarding the possibility of sensing the left atrial potential in the right atrial channel of the DDD pacemaker (the one specially designed for biatrial pacing), in which the "ventricular" channel is specified for left atrial pacing. The proposed leads connection allows one to retain all advantages of bipolar coronary sinus pacing from a separate channel. The results of the study seem to show a new direction in designing biatrial pacing systems that might be applied in truly three-chamber pacemakers with an additional channel for left atrium pacing.

Key Words

Biatrial pacing, atrial resynchronization, connection of electrodes for biatrial pacing

Introduction

Biatrial pacing is not only gaining acceptance, it is becoming a more and more common non-pharmacological method of preventing atrial arrhythmia in patients with interatrial conduction disturbances [1-30]. This new, but still under development, method of pacing has several unsolved problems with respect to maximum effectiveness of pacing, energy consumption optimalization, optimal sensing characteristics, and effective pacing resynchronization during cardiotopic atrial beats [6,17,23-27, 31,32,42]. Due to the lack of special pacemakers for biatrial pacing, there are four basic systems that are being used with standard pacemakers (Figure 1) [31-42].

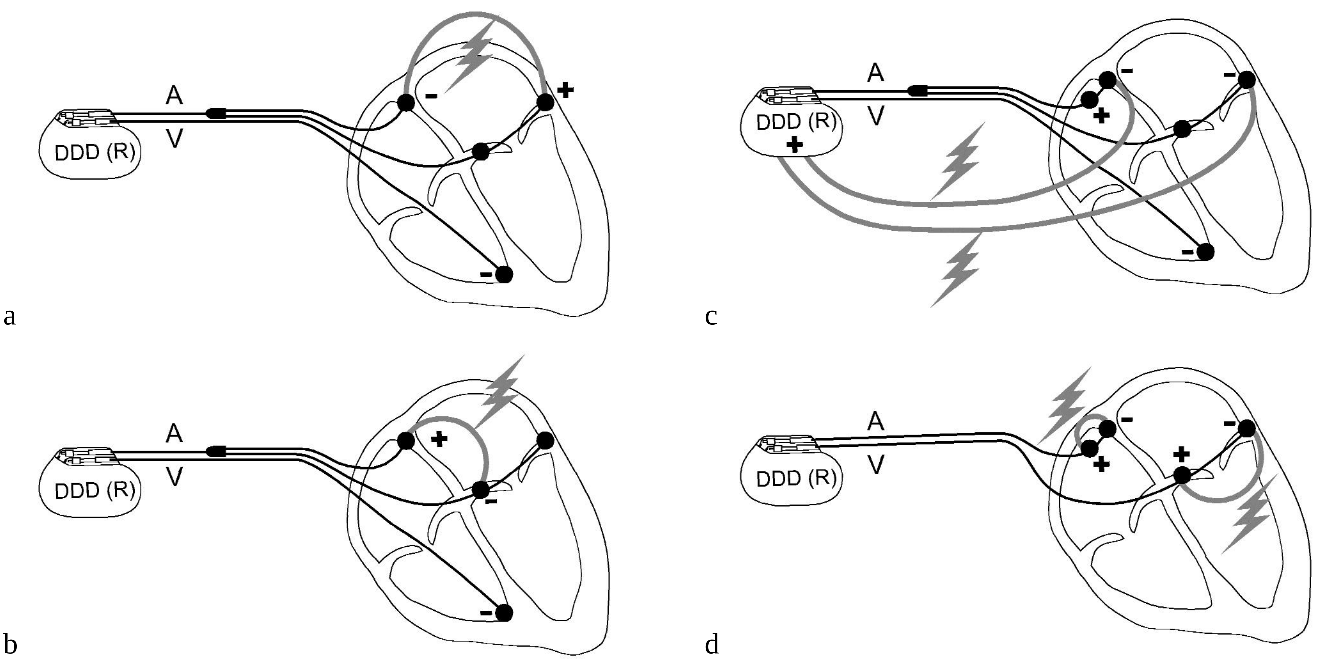

Figure 1. a) Split bipolar configuration proposed by Daubert in 1991 in which both atria are paced from a single pacemaker port via the Y-connector (anodal coronary sinus pacing). b) Inverted hybrid split-bipolar configuration where the coronary sinus is paced with cathodal current from the ring of a standard lead, or from the proximal ring of a bipolar lead specially designed for coronary sinus pacing. c) A system of parallel lead connections where both atria are paced with cathodal current and the common anode is localized on a pacemaker housing (dual cathodal unipolar configuration) or on the ring of the right atrial lead (dual cathodal bipolar configuration). d) The use of a dual chamber DDD pacemaker for biatrial pacing; its ventricular port is connected with the lead in the coronary sinus for left atrial pacing. A = atrial channel; V = ventricular channel.

- Split-bipolar configuration proposed in 1991 by Daubert, where both atria are paced from one port (channel) of the pacemaker using the "Y" connector [7-16].
- Inverted hybrid split-bipolar configuration (author`s modification) [43-45].
- System of parallel leads connections with both atria pacing with cathodal current, with the common anode either on the pacemaker housing (dual cathodal unipolar configuration) or on the ring of the right atrial lead (dual cathodal bipolar configuration) [31-42].
- System with a standard DDD pacemaker, using its ventricular channel for left atrial pacing [18-30].

Each of these systems has its advantages and disadvantages (Table 1); however, the biatrial pacing system based on the DDD pacemaker seems to be most promising. Its advantages are as follows:

(1) Effectiveness: Bipolar pacing of the coronary sinus from the independent (ventricular) port of the pacemaker allows for left atrial pacing with energy values only slightly exceeding the pacing threshold. Simultaneous pacing of the right atrium (keeping the standard safety margin) assures *(2) Safety of pacing* [23-25]. Relatively *(3) moderate energy consumption* is achieved due to the possibility of bipolar pacing of the left atrium (higher resistance), and mainly as a result of the possibility of programming sole energy values for left atrial pacing [23-25,34,35,39,42]. The use of independent channels for pacing each atrium makes the system *(4) independent of the global* (summed) *impedance* of the atrial leads [23-25,34,35,39,42]. Sensing of (relatively "local") atrial potentials in bipolar configuration allows one to obtain *(5) the most favorable sensing conditions* (i.e., the most desirable A-wave to V-wave ratio) [26,42], while independent atrial potential recording (i.e., IEGM) *(6) makes the diagnostics of atrial arrhythmias more precise and easier* [26]. Pacing systems of this type allow for *(7) triggering of left atrial pacing* by right atrial (sinus or ectopic) beats, i.e., resynchronization of sinus beats and premature right atrial beats. The system offers a *(8) safe triggered pacing* (DDD mode with an

		SBP (Daubert's)	Inverted SBP (Kutarski's)	DC BP (dual cathodal BP)	DDD (AV delay = 0 – 15 ms)
Pacing	Pacing with anodic current	CS	RAA	No	No
	Effectiveness	++	+++	++	+++
	Energy consumption	++	+	+++	+
	Electrode impedance dependence	++	+	+++	-
Sensing	A/V ratio	++	++	++	+++
	Separate RA and LA sensing	No	No	No	Yes
Resynchronising pacing (resynchronisation)	Sinus rhythm	++*	++*	++*	++
	RA extrasystoles	++*	++*	++*	++
	LA extrasystoles	++*	++*	++*	No

Table 1. Comparison of advantages and disadvantages of different biatrial pacing systems. SBP = split bipolar pacing; BP = bipolar pacing; CS = Coronary Sinus; RAA = right atrial appendage; No = not possible; Yes = possible; "+++" = high; "++" = mid; "+" = low; "-" = non; A/V ratio = A-wave to V-wave ratio; RA = right atrial; LA = left atrial; "" = triggered pacing mode necessary.*

AV delay of 0 ms) because of the minimal risk of pacemaker tachycardia caused by undesirable triggering of atrial pacing by V-waves (QRS complexes), which may occur in other systems. The system also allows one to (9) avoid (potentially proarrhythmic) *anodal pacing*. The system allows one to benefit from the unique advantages of bipolar pacing of the coronary sinus, i.e., with specific resynchronizing and antiarrhythmic effects as well [49-56].

As Table 1 shows, biatrial pacing systems based on DDD pacemakers seem to have many advantages (very important ones) and only two disadvantages:

- Impossibility of additional ventricular pacing in the event of AV conduction disturbances.
- Impossibility of resynchronizing to premature, left atrial beats, i.e., the impossibility of resynchronizing "left to right" [23-27].

Experience gained over a few years with 50 patients with implanted biatrial pacing systems based on DDD pacemakers, and several months' experience with ten patients with pacemakers specially designed for biatrial pacing (Logos DS, Biotronik, Germany) [6,17-26] convinced us of the need for studies focused on looking for better effectiveness of that method of pacing. The triggering of right atrial pacing by premature left atrial beats posed a challenge for us. We opted for the easiest solution: (1) working out the atrial lead configuration that allows sensing of premature left atrial beats in the (right) atrial channel and (2) introduction of the algorithm of triggered right atrial pacing (DDTA) into pacemaker memory. The last one should work similarly to the one proposed by Daubert for the Chorus 7034 pacemaker (ELA Medical, France) 8 years ago [7-16].

Materials and Methods

The aim of the study was to evaluate non-standard lead connections for sensing of left atrial potentials in the (right) atrial channel of DDD pacemakers specially designed for biatrial pacing. We performed the study according to the following principles:

- Standard, bipolar, J-shaped leads were used for right atrial pacing and bipolar leads for coronary sinus pacing (all currently available leads for this purpose are bipolar) [57-59].
- All advantages resulting from bipolar pacing of the coronary sinus were included [49-56,60-65].
- The standard site for right atrial lead fixation was maintained, i.e., the right atrial appendage.

The technical conditions and the previously mentioned principles showed that the only way that left atrial potentials could be sensed in the (right) atrial channel is if the pacing/sensing configuration were changed. We decided to move the indifferent electrode (anode) in that channel. We hypothesized that we could "widen the sensing spectrum" of the atrial channel (with left atrial potentials) by positioning the indifferent (anodal)

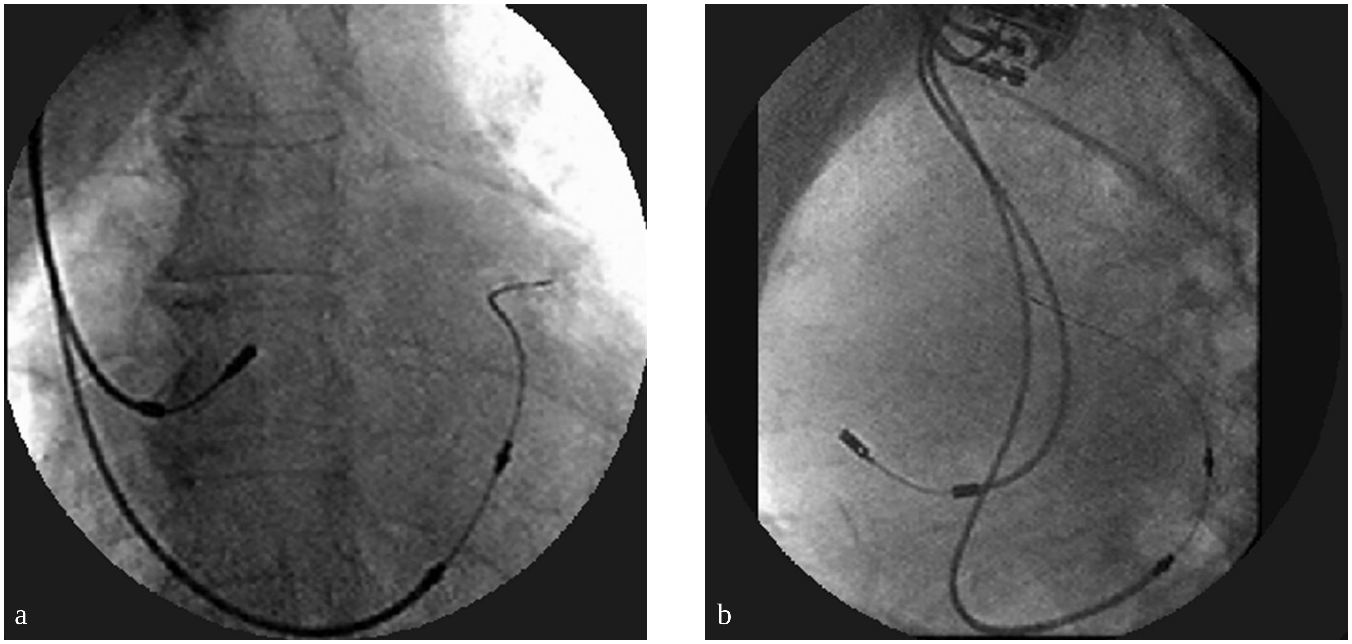

Figure 2. Biatrial pacing system based on a dual chamber DDD pacemaker. The bipolar lead for left atrial pacing (Corox V 375, Biotronik) is positioned in the coronary sinus; only the two rings are used for pacing, whereas its distal part being anchored in a proximal part of a great cardiac vein, plays the role of a stabilizer. Posterior-anterior view (a) and lateral view (b).

electrode of the right atrial channel in the ostium or proximal part of the coronary sinus, i.e., on the proximal ring of the coronary sinus lead. The use of the ring as the common indifferent electrode (anode) for both channels seemed to be the easiest option.

Patients

The study was performed in ten patients (four males, six females; average age 65 years) during the procedure of biatrial system implantation (Figure 2). Along with the classical indications for permanent pacing, all patients appeared to have generally accepted indications for biatrial pacing [1-30].

Study Procedures

In all patients, access was obtained by puncturing the left subclavian vein. The standard, J-shaped, bipolar lead (CSX 53 BP, Biotronik) was implanted into the right atrial appendage, and the other bipolar lead (Corox V 375, Biotronik) was implanted into the coronary sinus [58-59] (Figure 3). With the stable position of the leads in view under fluoroscopy, the standard pacing and sensing characteristics of both leads in the classical bipolar configuration were checked both for the right and left atrium (Figure 4a). Next, the indifferent lead (anode) was disconnected from the ring of the J-shaped lead and was linked to the proximal ring of the bipolar lead implanted into the coronary sinus, and the measurements of the pacing and sensing conditions, as well as the recording of intracardiac potentials (IEGM), were repeated (Figure 4b). After all measurements and recordings were completed, the leads were connected in a standard way to the sterile pacemaker and the implantation procedure was finished routinely.

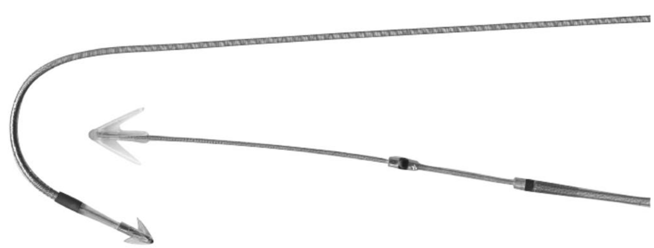

Figure 3. Standard J-shaped lead for right atrium appendage pacing (SX 53 BP, Biotronik) and bipolar lead for coronary sinus pacing (Corox V 375, Biotronik) with its distal ring as an active electrode (cathode) and proximal ring as a passive electrode (anode). The clearly visible difference between the surface areas of the leads' anodal rings explains the observed differences between pacing thresholds in the atrial channel.

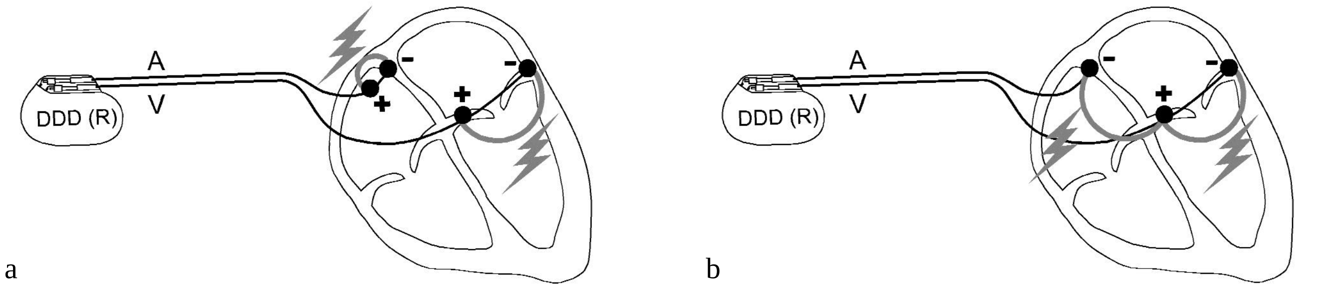

Figure 4. a) Sensing and pacing performance was first evaluated in classical lead configuration. b) Refined configuration of the atrial input. Sensing and pacing performance was assessed for a lead configuration with the tip of the right atrial lead as the different pole, and the proximal ring of the coronary sinus lead as the indifferent pole. The AV delay was programmed to the shortest value, which is 0 ms or 15 ms for Logos or Actros pacemakers (Biotronik), respectively. A = atrial channel; V = ventricular channel.

Details on Measurement Recording Tools and Protocols

The main research tools consisted of a sterile, four-wired cable, two "Y" connectors, a non-sterile DDD pacemaker, and a pacemaker programmer (PMS 1000, Biotronik). The leads were successively connected to the pacemaker according to the diagram in Figure 5; the measurements of available pacing and sensing conditions (pacing threshold, A-wave potential) were performed in both the (right) atrial and "ventricular" (left atrial) channels. After all measurements were completed, intracardiac recordings were made simultaneously with the recording of a standard surface ECG (lead II) at the paper speed of 50 mm/s, and the measurements of timing parameters were made using cursors on the frozen recording (at the speed of 100 mm/s) on the programmer screen. The measurement of the pacing threshold was finished by short pacing with the maximal energy (9.6 V/0.5 ms) to evaluate the possibility of phrenic nerve stimulation.

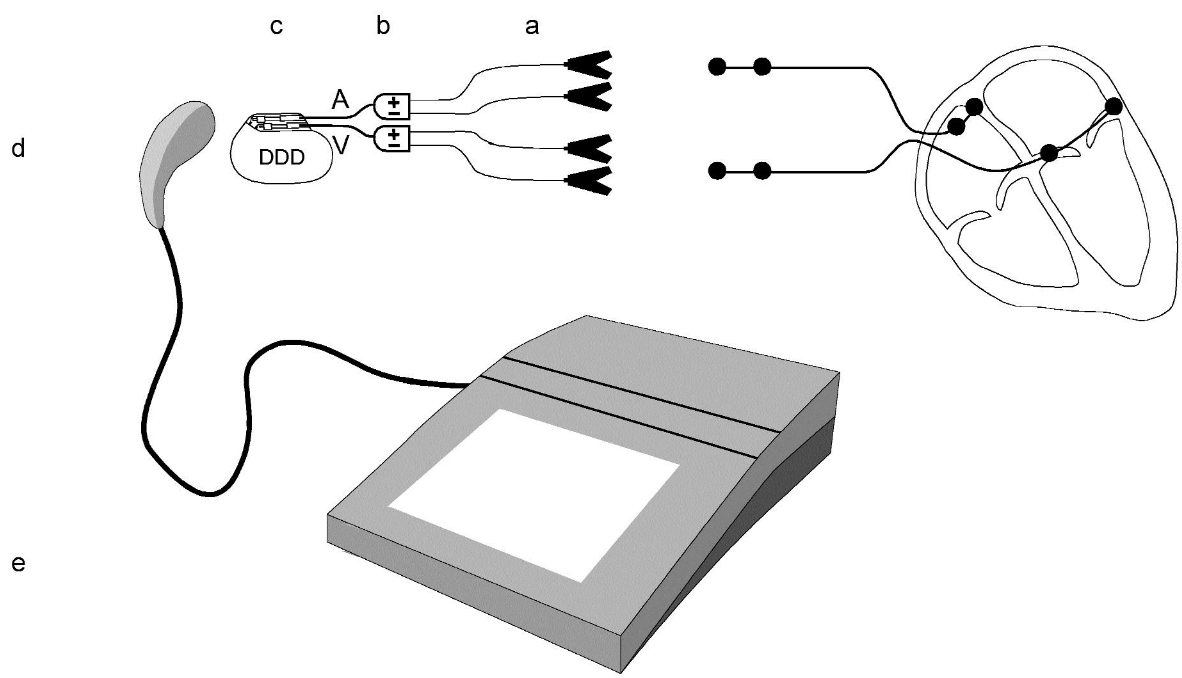

Figure 5. The main research tools: a) a sterile four-wired ECG cable; b) two "Y" connectors (A1-A-BP, Biotronik); c) a non-sterile DDD pacemaker (Actros D, Biotronik); d) a pacemaker programmer head; e) a pacemaker programmer.

Pacing/sensing configuration			Automatic measurement		Manual measurement from paper recordings					
			A-wave amplitude (mV)	Pacing threshold (V)	A-wave amplitude (mV)	V-wave amplitude (mV)	A/V ratio	Amplitude A (LA) in atrial channel (mV)	A (RA)/ A(LA) in atrial channel	P_{II}-onset A(RA) (ms)
Standard connection	Test I Channel "A" (RA)	Mean	2.89	0.81	2.42	0.18	13.84			32.2
		SD	1.16	0.35	0.80	0.28	10.7			6.7
		Range	1.8 – 5.0	0.4 – 1.5	1.7 – 4.6	0.1 – 0.8	2.4 – 23.0			20 – 40
	Test II Channel "V" (CS)	Mean	3.37	1.12	3.80	2.23	3.93			
		SD	1.37	1.09	2.41	2.18	5.98			
		Range	1.7 – 6.2	0.4 – 4.0	2.2 – 9.5	0.3 – 8.0	1.0 – 20.0			
New connections	Test III Channel "A" (RA + LA)	Mean	3.45	1.07	2.59	0.81	4.85	2.47	1.07	45.5
		SD	1.94	0.52	0.86	0.56	3.57	0.82	0.19	12.6
		Range	0.9 – 7.7	0.5 – 1.8	1.9 – 4.2	0.3 – 1.9	1.1 – 10.5	1.6 – 4.6	0.9 – 1.4	30 – 65
	Test IV Channel "V" (CS)	Mean	3.51	1.08	3.75	2.74	2.38			
		SD	1.29	0.99	2.82	3.14	1.95			
		Range	2.0 – 6.2	0.1 – 3.0	1.2 – 9.5	0.3 – 9.0	0.9 – 7.7			

Statistical evaluation of mean difference using Student's pair test		Automatic measurement		Manual measurement from paper recordings					
		A-wave amplitude	Pacing threshold	A-wave amplitude	V-wave amplitude	A/V ratio	Amplitude A (LA) in atrial channel	A (A)/ A(LA) in atrial channel	P_{II}-onset A(RA)
Test I versus test III	t	0.824	2.685	0.834	3.051	3.903			4.000
	P	0.431	0.025	0.426	0.014	0.0036			0.0039
Test II versus test IV	t	0.562	0.245	0.018	0.722	1.159			
	P	0.588	0.811	0.952	0.488	0.276			

Table 2. Right atrial (RA) and left atrial (LA) sensing/pacing conditions (bipolar configuration) in biatrial pacing system using different anode connections. All measurements were performed in ten patients; P_{II} onset was measured in only nine cases. A = atrial; V = ventricular; CS = coronary sinus.

Justification of the method

In order to minimize the time required for measurement and recording, we used the most universal hardware set, which reduced the number of maneuvers required during measurements and recordings. The use of a standard pacemaker allowed us to eliminate the influence of different technologies for filtering and recording intracardiac potentials on hardware designed for electrophysiological studies. Our hardware set allowed for simultaneous recording of lead II of the standard ECG (for estimation of the onset of the P-wave) and intracardiac potentials (IEGM). The paper recordings of intracardiac potentials were used to measure A- and V-wave amplitudes despite the known inaccuracy of that method, i.e., quite often the maximum amplitude of the A-wave may be cut off. However, this was the only way we could obtain even approximate values of the most precise parameter for atrial sensing – the ratio of A-wave to V-wave amplitude.

Results

As seen in Table 2, the right atrial appendage clearly offers more favorable sensing conditions than the coronary sinus when using standard bipolar configuration. The differences are related not so much to the absolute values of the sensed atrial potentials (A-waves), which do not differ significantly (2.42 versus 3.80 mV), but rather primarily to the amplitude of the ventricular potentials (V-waves) and secondarily to the A/V ratio (13.84 versus 3.93). However, the acceptable values of left atrial sensing parameters have been achieved. The results of examining the pacing parameters of both atria are comparable to those observed by the majority of authors [7-30].

By moving the indifferent lead (anode) from the ring of the right atrial lead to the proximal ring of the left atrial lead in the coronary sinus and using this ring as the common indifferent lead (anode) for both channels, the picture of the intracardiac potential record-

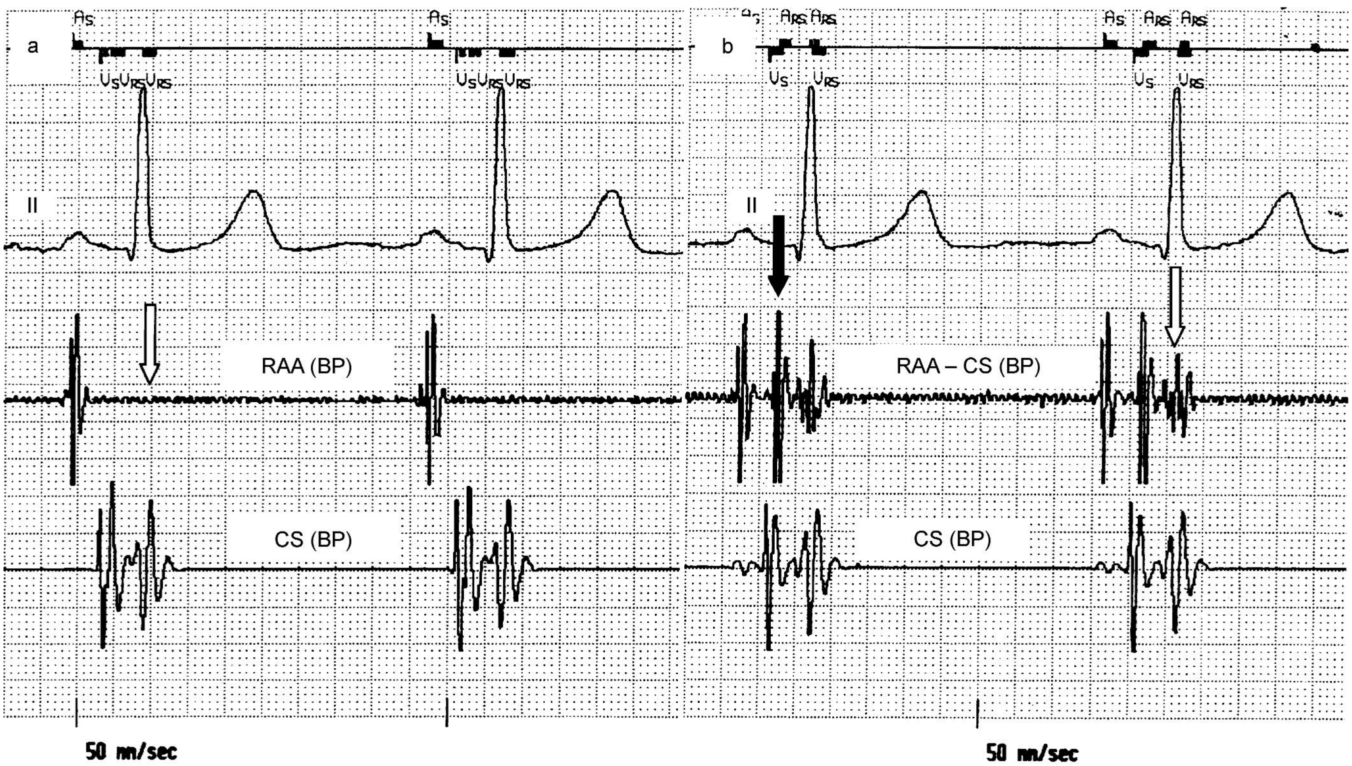

Figure 6. Intraoperative ECG and intracardiac potentials (i.e., IEGM) recordings. a) standard lead connections. b) non-standard lead connections; the proximal ring of coronary sinus lead is the common passive electrode (anode). The change of configuration results in recording left atrial potentials in the atrial channel (a black arrow) and a slight increase in V-wave amplitude in that channel (a white arrow). RAA = right atrial appendage; CS = coronory sinus; BP = bipolar configuration.

ings in the atrial channel was changed significantly. In these recordings, after the right atrial potentials, there are left atrial potentials that appeared at amplitudes that were similar (average amplitude ratio: 1.07) to right atrium potentials (2.47 mV) (Figures 6-12). The use of new lead connections, which allows for recordings of left and right atrial potentials in the atrial channel, was connected with slight deterioration of sensing parameters, i.e., the increase in the amplitude of the V-wave (from 0.18 to 0.81 mV) recorded in that channel (Figures 6-12) and the deterioration of A-wave to V-wave ratio (from 13.84 to 4.85). The described change of the lead configuration does not influence the amplitude of an A-wave recorded in the "atrial" (right atrial) channel of a pacemaker (2.42 and 2.59 mV) nor in the "ventricular" (left atrial) channel (3.80 and 3.75 mV). The pacing (threshold) conditions in both the right (0.81 and 1.07 V) and left (1.12 and 1.08 V) atrium did not change considerably. Pacing of the phrenic nerve could not be achieved in any of the patients.

Discussion

The results of the study confirmed the hypothesis regarding the possibility of detecting the left atrial potentials in the right atrial channel of a DDD pacemaker specially designed for biatrial pacing, in which the "ventricular" channel is specified for left atrial sensing/pacing. In the proposed lead connection configuration, the active electrode (cathode) consists of the tip of the lead classically placed in the right atrial appendage, with the passive electrode (anode) connected to the proximal ring of the lead for coronary sinus pacing. This electrode positioning results in diminished detection of "local" potentials.

It also allows for sensing a slightly earlier right atrial A-wave (a very positive phenomenon), and a left atrial A-wave (the delay in recording this value depends on the degree of conduction disturbances within atria). Detection of higher amplitude values of ventricular potentials (V-wave) in the (right) atrial channel is the disadvantage. However, the sensing conditions in that channel remain acceptable (mean AV ratio: 4.85).

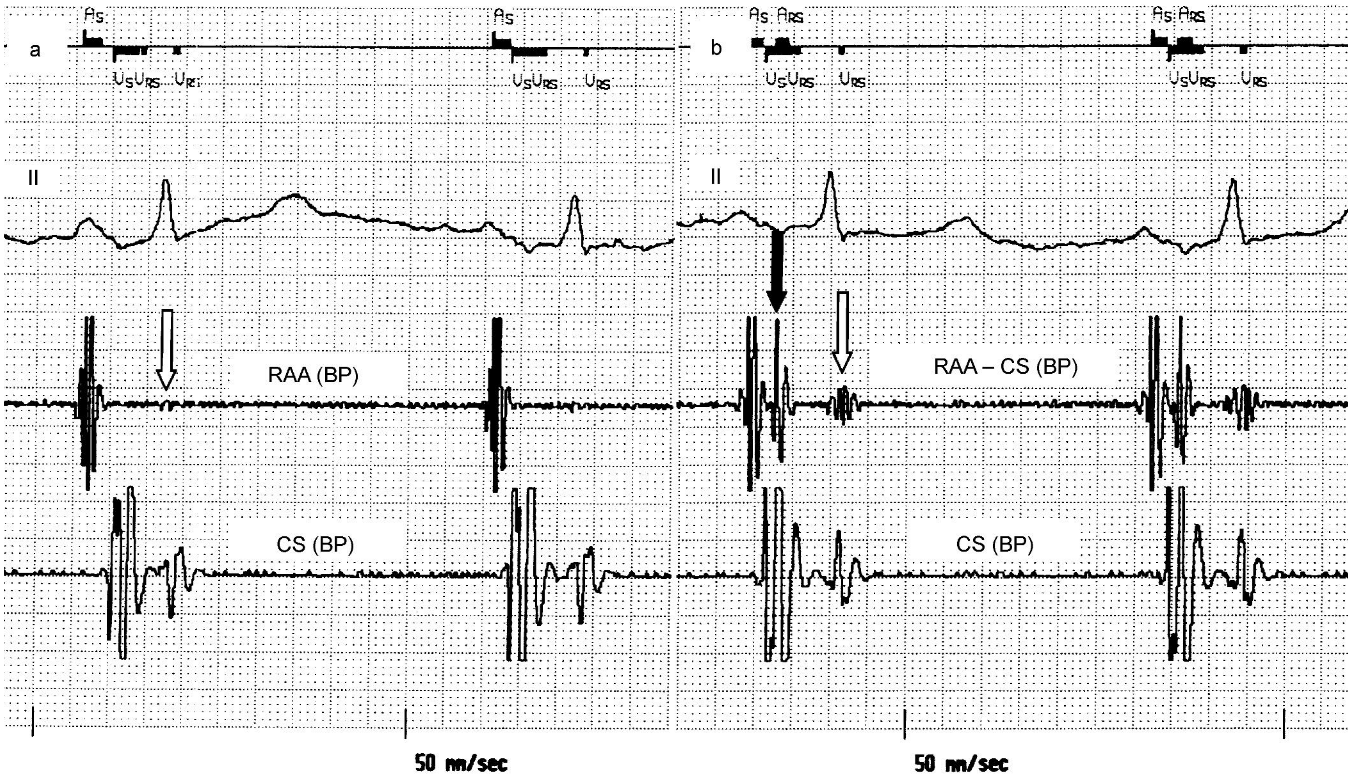

Figure 7. See legend to Figure 6. Intraoperative ECG and intracardiac potentials recordings. a) standard lead connection. b) non-standard lead connection. Black arrows marks left atrium potential recorded in atrial channel using unconventional lead connection. Only a little increase of V-wave amplitude may be noted (white arrows).

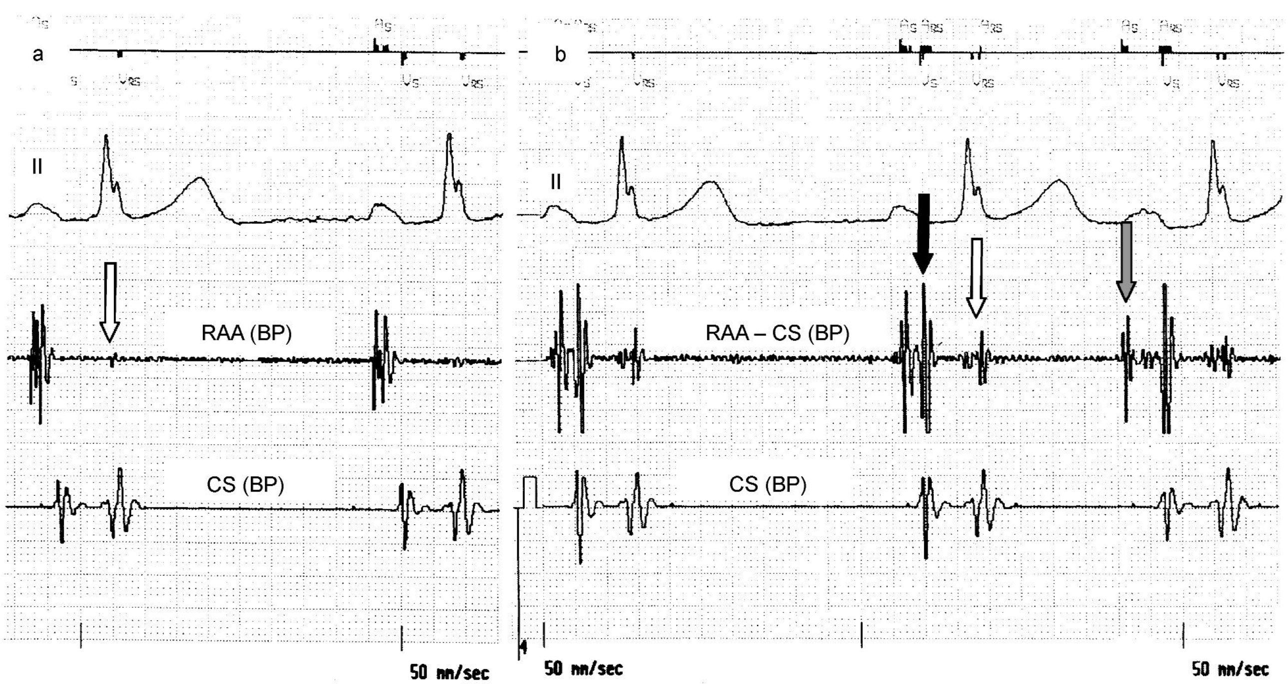

Figure 8. See legend to Figure 6. Intraoperative ECG and intracardiac potentials recordings. a) standard lead connection. b) non-standard lead connection. The proposed configuration allows for left atrium potentials recordings in atrial channel (a black arrow) and only slightly increases V-wave amplitude (white arrow). The interatrial conduction disturbances are relevantly increased by right atrium premature beats (a grey arrow).

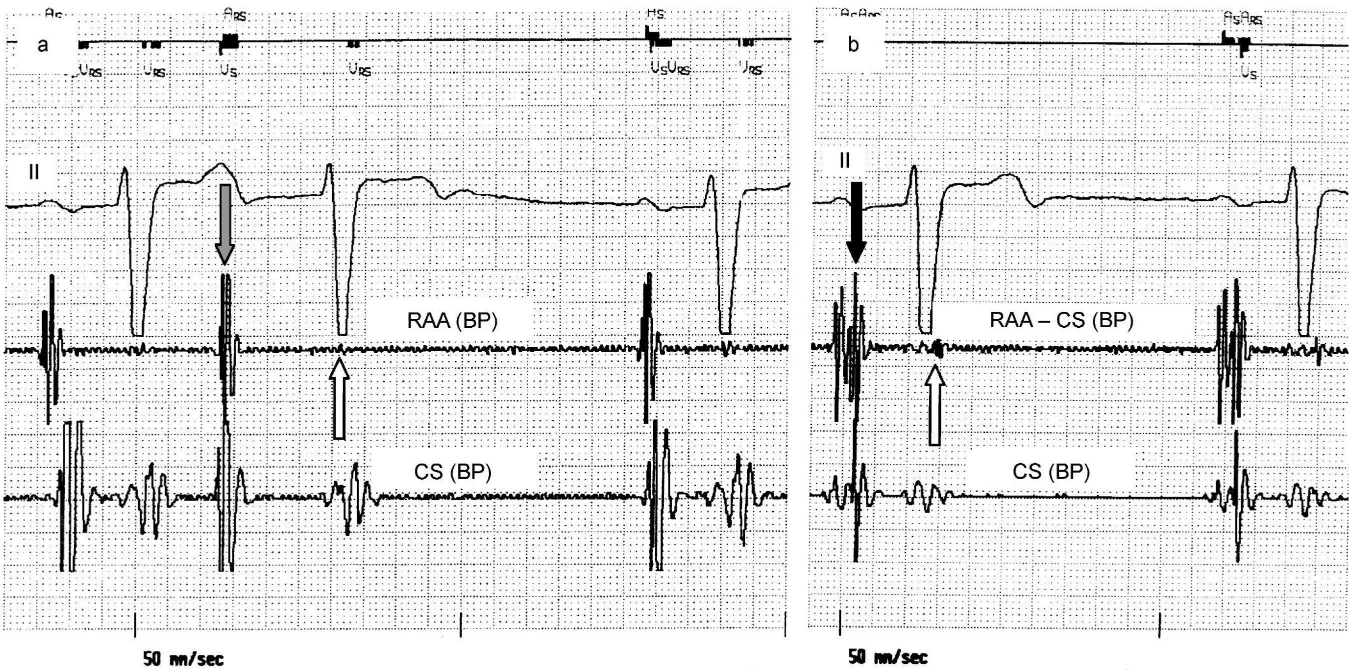

Figure 9. See legend to Figure 6. Intraoperative ECG and intracardiac potentials recordings. a) standard lead connection. b) non-standard lead connection. Non-standard lead configuration does not change significantly the V amplitude detected in (right) atrial channel (white arrow). Premature left atrial beats (grey arrows), which has been recorded in standard connection blocks both pacemaker's channel and as a result the resynchronization pacing is impossible.

Slightly higher values for pacing thresholds in the right atrial channel may be explained by an increased impedance in the circuit related to the use of the ring of the coronary sinus lead that is significantly narrower (with a few times smaller area) than the classical J-shaped lead designed for pacing of the right atrial appendage. The examinations were performed during implantation of the biatrial pacing system in a way that did not stress the patients at all (without the need for additional lead insertion for more precise electrophysiological studies). Unfortu-nately, left atrial premature beats were not recorded in any of the patients during the evaluation of the new lead configuration. As a result, we can only assume (to a very high degree of probability) that the proposed right atrial lead connection should allow for significantly earlier detection of premature beats (a very advantageous phenomenon), including those originating in different areas of the right atrium and mainly within the triangle of Koch, which is the most arrhythmogenic area [62-66].

The proposed connection configuration for right atrial leads allows one to benefit from all advantages of coronary sinus pacing in bipolar configuration from separate channels in both electrophysiological [49-56,62-66] and technical [6,17,22,25] aspects. The possibility of triggered pacing in the atrial channel is indispensable to more fully using the advantages of that connection [7-16]. Premature beats detected in the atrial channel should trigger not only instantaneous left atrial pacing (DDD mode with AV delay of 0 ms), but also pacing of the right atrium (AAT mode); this is similar to the algorithm of the Chorus 7034 pacemaker (ELA Medical). The results of the study seem to illustrate a new direction in designing both biatrial and three-chamber pacing systems.

Conclusions

During biatrial pacing with the DDD pacemaker, moving the indifferent electrode (anode) from the ring of the right atrial lead to the proximal ring of the coronary sinus lead, which then serves as the common indifferent lead (anode) for both channels, makes left atrial potentials detectable (of similiar amplitude) in the right atrial channel, too. Using this configuration causes only slight deterioration of sensing conditions (reduction of the A- to V-wave amplitude ratio), but the pacing conditions of both the right and left atria do not

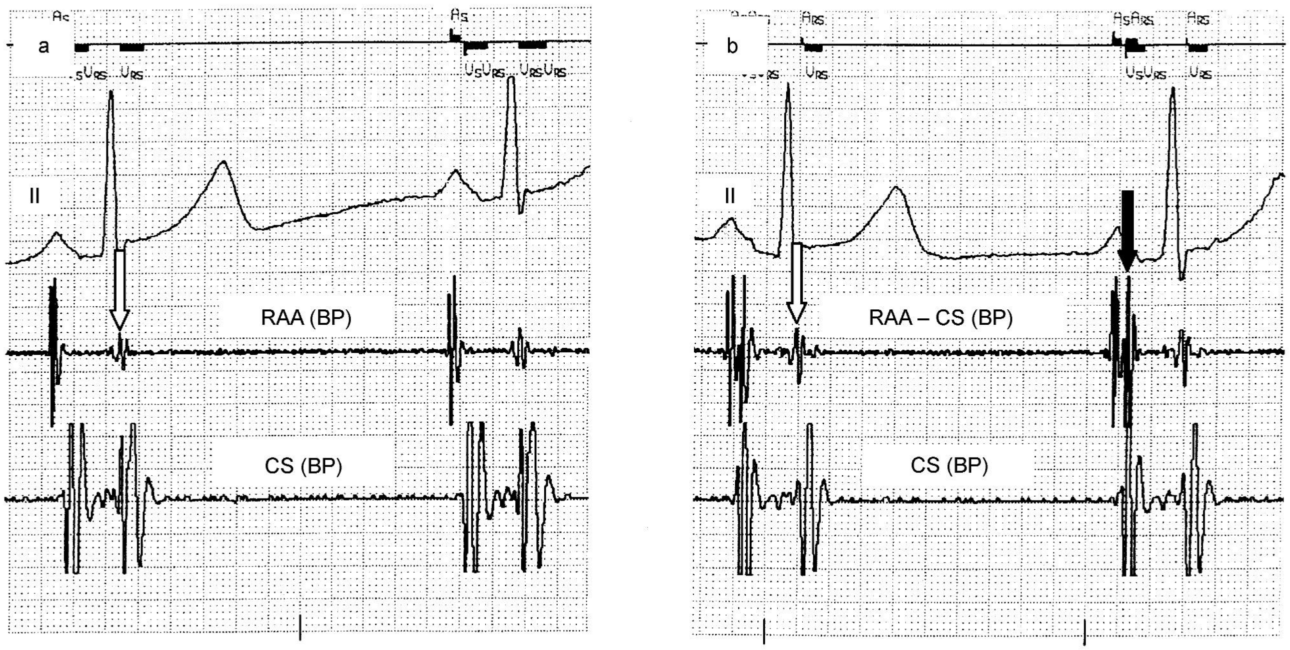

Figure 10. See legend to Figure 6. Intraoperative ECG and intracardiac potentials recordings. a) standard lead connection. b) non-standard lead connection. Non-standard configuration did not deteriorated sensing conditions in (right) atrial channel (not signifikant in A/V ratio (white arrow)). "Low" position of the tip of right atrial lead in the right atrium appendage (disadventageous effect) and the localisation of proximal ring of left atrial lead close to the ostium of coronary sinus results in the misleading picture of the lack of interatrial conduction disturbances.

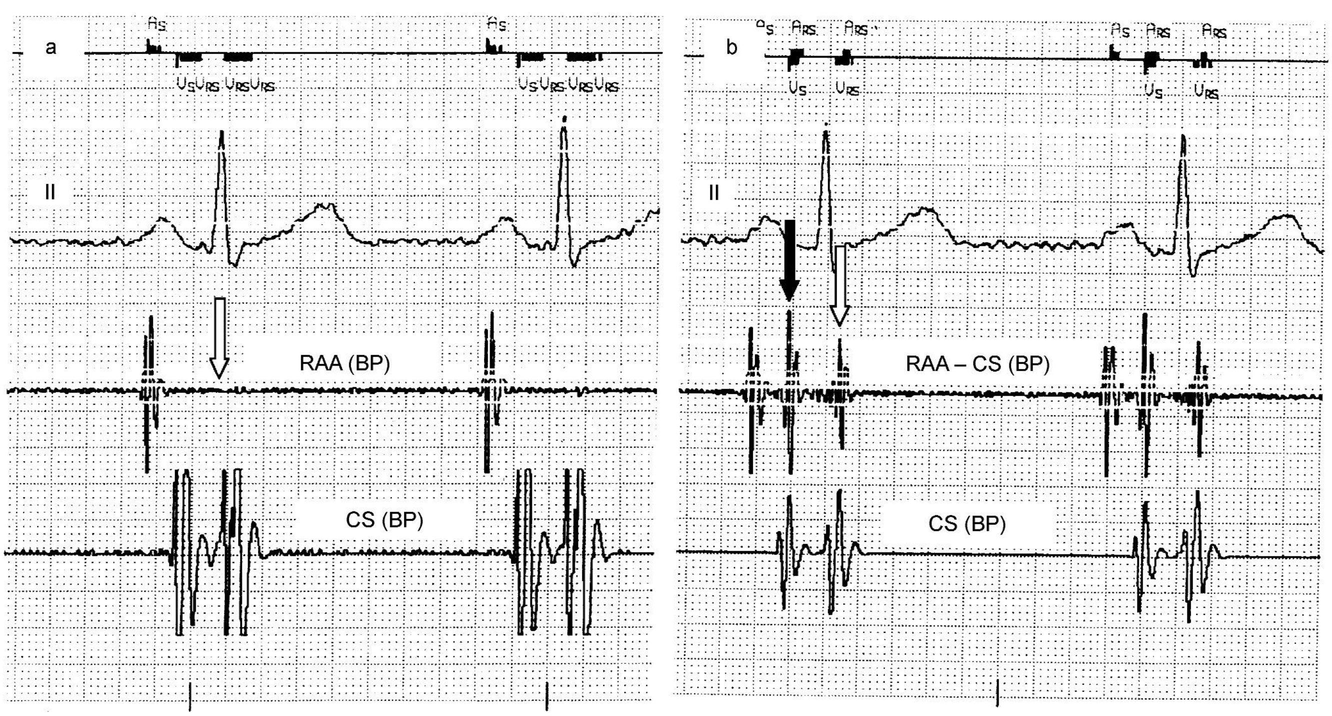

Figure 11. See legend to Figure 6. Intraoperative ECG and intracardiac potentials recordings. a) standard lead connection. b) non-standard lead connection. Here, there was a marked increase in V-wave amplitude in atrial channel (white arrow) in unconventional lead connection. The recordings present the results of positioning the tip of the right atrial lead in the high right atrium (the right atrial wave is recorded simultaneously to the onset of P-wave – an advantageous effect).

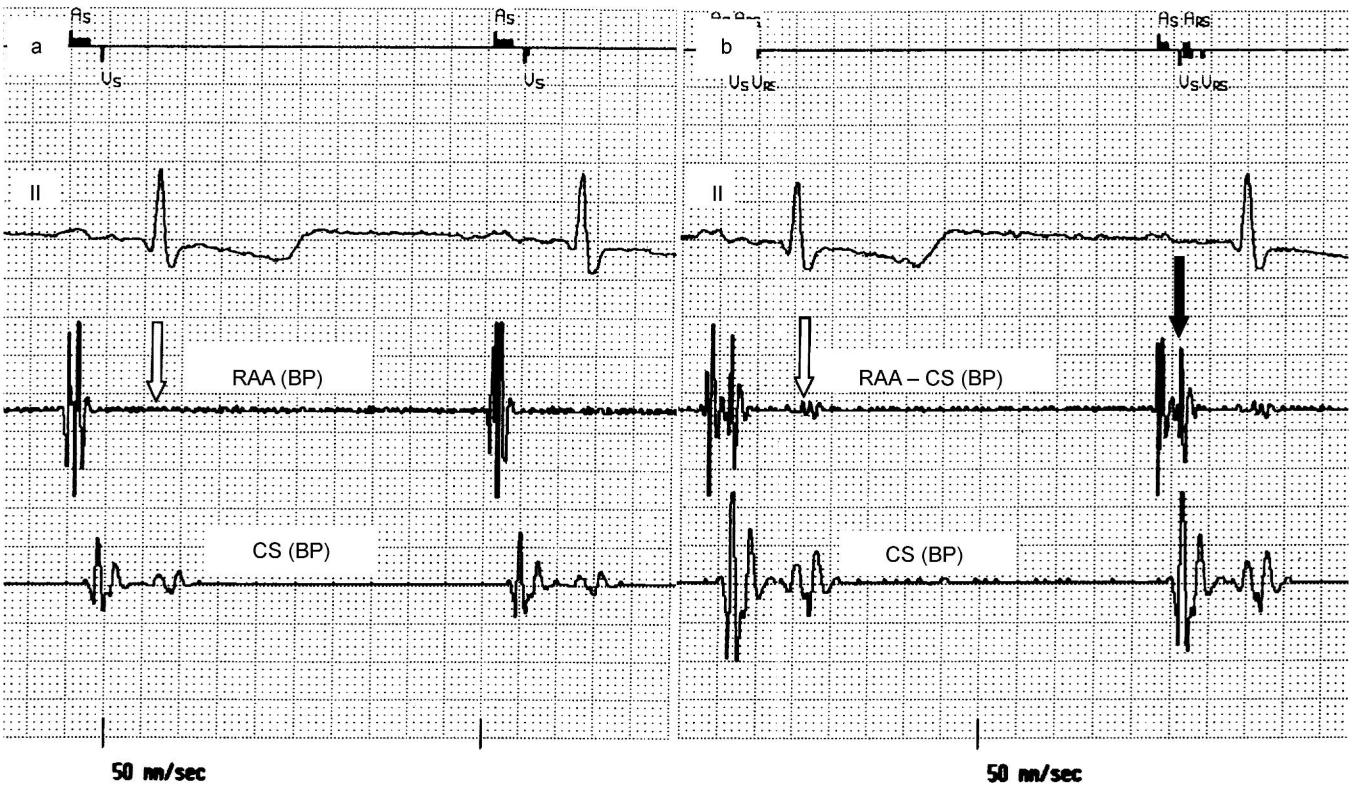

Figure 12. See legend to Figure 6. Intraoperative ECG and intracardiac potentials recordings. a) standard lead connection. b) non-standard lead connection. Non standard leads connection allows detection of left atrium potential in atrial channel (black arrow). Only very mild deterioration of sensing conditions in (right) atrial channel (white arrow) might be seen (and as a result slightly lower A/V ratio).

change. The proposed lead connection configuration allows one to receive all advantages of coronary sinus pacing from the isolated channel. The results of the study seem to show a new direction in biatrial pacing system design that might be applied in three-chamber pacemakers with additional atrial port for left atrium pacing.

Acknowledgements

This paper was supported by a grant from the Polish State Committee for Scientific Research No 4 P05B 005 18.

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Contact
Andrzej Kutarski, MD, PhD
Department of Cardiology
University Medical Academy
ul. Jaczewskiego 8
20-090 Lublin
Poland
Telephone: +48 81 742 54 71
Fax: +48 81 742 54 71
E-mail: a_kutarski@yahoo.com