Cathode or Anode in Coronary Sinus for Split Bipolar Biatrial Pacing?

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Summary

In the split bipolar atrial configuration for biatrial pacing, the right atrial appendage is paced with the cathodal current (-) and the coronary sinus (left atrium) is paced with the anodal current (+). Unsatisfactory clinical results in many patients implanted with these systems were mostly caused by excessively high pacing threshold or exit block in the coronary sinus lead, resulting in permanent or temporary loss of atrial resynchronization despite stable lead fixation. The aim of the present study was to evaluate whether inverted polarity in the split bipolar atrial configuration (placement of the cathode in the coronary sinus and of the anode in the right atrium) could ensure left atrial pacing and thus improve the effectiveness of biatrial pacing. The measurements performed in 47 patients during pacemaker implantation demonstrated that anodal pacing thresholds in either atrium were higher than the corresponding cathodal thresholds by about 0.5 V and almost 1 mA. The study also showed that the inverted lead polarity did not influence pacing impedance and sensed atrial signal. The observed effect of the "mirror reflex" in the sensed intracardiac signal appeared irrelevant. Biatrial pacing system with the split bipolar atrial configuration was implanted in a total of 145 patients at our institution. The first 20 (14 %) received pacing systems with standard atrial lead connections; the remaining 125 patients were implanted with identical pacing systems with the reversed lead polarity. In the patient group with conventional lead connections, problems to accomplish satisfactory left atrial pacing (biatrial pacing) were encountered in 12 % of the patients at the 1-month follow-up and in 25 % of the patients at the 1-year follow-up. The incidence of problems was significantly lower in the patient group with inverted lead connections: 3 % at the 1-month follow-up and 2 % at the 1-year follow-up. Mean A-wave amplitude in the right atrium fluctuated within the 2.6 – 3.0 mV range in either patient group. The right atrial pacing threshold was 2 – 3 V, or significantly lower than the left atrial pacing threshold (5 – 6 V), independently from the choice of connection (conventional or inverted). Mean pacing impedance in the split bipolar lead configuration fluctuated within the range from 650 – 800 W and did not differ for the two patient groups. Beside other advantages, the inverted connection system allows for accurate measurement of pacing and sensing values in the left atrium, which will be of particular interest in future clinical evaluations of new lead models specifically designed for coronary sinus application.

Key Words

Effectiveness of biatrial pacing, split bipolar configuration, cathodal and anodal pacing, lead polarity

Introduction

The advent of biatrial pacing created new therapeutic options for patients with conduction disturbances within the atria and recurrent atrial arrhythmias [1-5]. Two teams of French investigators from Rennes [6-8] and Saint Cloud [9-11] led by Daubert, the inventor of biatrial pacing [12,13], and our own clinical results [14-18] have demonstrated that the underlying reasons for unsatisfactory results of biatrial pacing in many patients are technical problems to achieve permanent atrial resynchronization despite stable lead fixation.

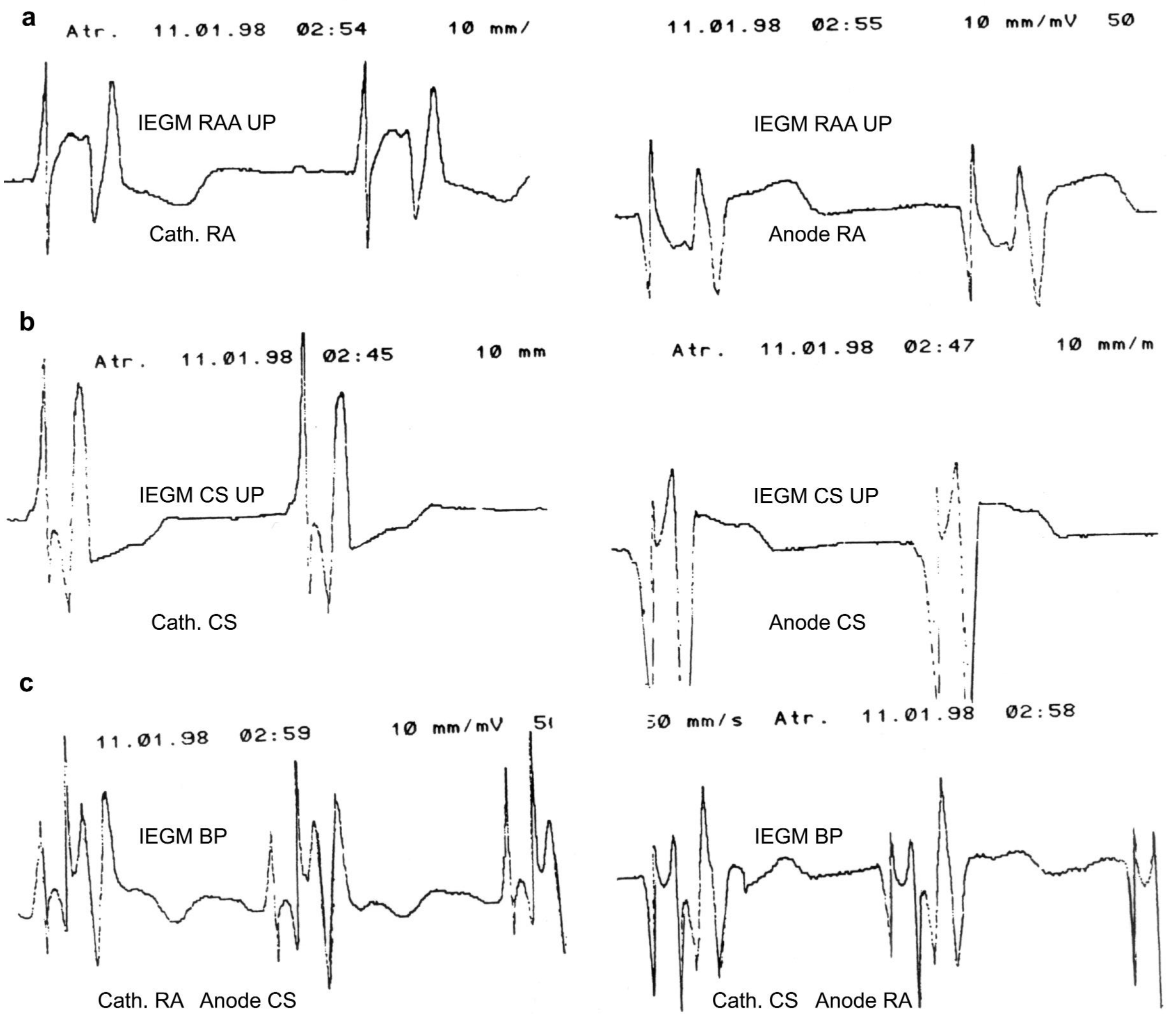

Figure 1. Intracardiac electrocardiograms (IEGMs) recorded during the implantation procedure in a 58-year-old female patient with a history of recurrent atrial flutter rapidly degenerating into atrial fibrillation. Left panels stand for conventional lead configuration and right panels for a reversed lead connection, where the cathode (Cath.; active electrode) and the anode (passive electrode) were inverted. a) IEGM recorded from the right atrial appendage (RAA). b) Left atrial IEGM. c) Biatrial IEGM. The recordings in the unipolar (UP) configuration (a and b) were obtained with an electrode placed in the right atrium (RA) or coronary sinus (CS) and the other electrode being represented by a surgical tool located in a previously prepared pacemaker pocket. In the bipolar (BP) sensing configuration (c), the cathode was placed in one atrium and the anode in another atrium. The "mirror reflex" effect appeared to be the only result of the reversed lead polarity.

The most common failure is excessively high pacing threshold or exit block in the coronary sinus lead intended for left atrial pacing [10,14-23].

To compensate for the unavailability of specifically designed pacemakers for biatrial and biatrial-ventricular (tri-chamber) pacing, Daubert [12,13] proposed in 1991 the use of a "Y" connector for split bipolar lead configuration, where the right atrial appendage is paced with the cathodal current (-) and the coronary sinus is paced with the anodal current (+). A similar lead configuration was advocated four years later by Saksena for bifocal pacing of the right atrium [24]. Both authors are active in further considerations of system of connections [4,25]. Due to the limitation of the application of biatrial pacing with conventional dual-chamber pacemakers to patients without atrioventricular conduction disturbances [14-18,26], our team has been employing since 1997 biatrial pacing with two atrial leads connected via the "Y" adapter (A1-ABP) to the atrial port of a dual-chamber pacemaker or to the

sole port of a single-chamber pacemaker [15,16,27].
During the first year of biatrial pacing implementation in our clinic, the system of lead connections recommended by Daubert was used. The outcome was neither promising nor satisfying, i.e., the energy level needed to pace both atria was difficult or even impossible to attain with standard pacemakers. Only the right atrium could be paced effectively, while frequent failure to pace the left atrium had a negative impact on the overall success of the antiarrhythmic therapy.
Our extensive results on left atrial pacing in the period between 1996 and 1998 [16,28-30] corroborated earlier observations of Moss [31], Greenberg [32] and Daubert [6-10,12] that coronary sinus is a valuable but difficult place for pacing due to substantially higher pacing thresholds and increased battery energy consumption compared to the right atrial appendage position. An additional limitation of the system proposed by Daubert was dependency of the global impedance on both leads, where too high global impedance often limited the possibility of delivering higher energies to ensure coronary sinus pacing [11,19-23,27,33-36].
Due to unavailability of an additional port for left atrial pacing, the atrial port of conventional dual-chamber pacemakers will continue to be used for connecting both atrial leads to the pulse generator, and the choice of connection system will play a key role in achieving maximum effectiveness of biatrial pacing. The connection system introduced by Daubert [12,13] and Saksena [24] offers many advantages and will remain the most acceptable technical solution for a while. The challenge will be to improve the effectiveness of this connection system in terms of safety and economy of energy consumption.
The available literature suggests that ventricular pacing threshold is typically > 30 % lower for cathodal than anodal current [37-41]. No comparison between cathodal and anodal pacing was made in the atrium, and even no report analyzed in depth anodal pacing in the left atrium. We hypothesized that in pacing systems comprising two leads in one circuit to pace two distant points of the heart, the supposedly "more effective" cathodal current should be applied to the cardiac site which is "more difficult" to pace (associated with a higher pacing threshold) and the "less effective" anodal current should be applied to the cardiac site offering a lower pacing threshold.

Goals of the present study were:

- to investigate to what extent the reversed pacing polarity (anode: lead tip; cathode: pacemaker case) changes pacing conditions in the right and left atrium;
- to verify that this change does not have a negative impact on sensing conditions;
- to find out whether the reversed polarity in the split bipolar atrial configuration can reduce threshold for left atrial pacing and thus improve the effectiveness of biatrial pacing.

Materials and Methods

Intraoperative Evaluations

Intraoperatively, we evaluated the influence of the inverted lead polarity on sensing and pacing values in the right and left atria during unipolar pacing. The measured sensing value was A-wave amplitude and pacing values were represented by pacing impedance and voltage and current pacing thresholds. 47 patients (18 male and 29 female, mean age 65.2 years, range 36 – 76) underwent a coronary sinus lead implantation for different reasons. Unipolar J-shaped leads were predominantly implanted in the right atrium, as the system of connections did not allow the use of the lead ring. Conventional bipolar ventricular leads were inserted in the coronary sinus, with one or two lead tines removed to improve contact between the lead tip and the coronary sinus wall [14-16,18,28-30].
Proper lead position was confirmed by X-rays before measuring pacing and sensing parameters of both atrial leads in the unipolar configuration, pacing system analyzer ERA 300 (Biotronik, Germany) was used in the measurements. A surgical tool placed in a prepared pacemaker pocket served as the indifferent electrode (anode). Evaluation of pacing and sensing values of the tip and ring electrode on the coronary sinus lead was a part of our routine procedure for the selection of optimal electrode configuration [11,19-23,27,33-38]. In the studied patient group, measurements of pacing and sensing values were repeated with the inverted active electrode (cathode) and passive electrode (anode) connections (Figure 1 – 4).

Clinical Observations

Biatrial or biatrial-ventricular pacing systems using split bipolar atrial lead configuration were implanted in a total of 145 patients (85 males and 60 females, mean

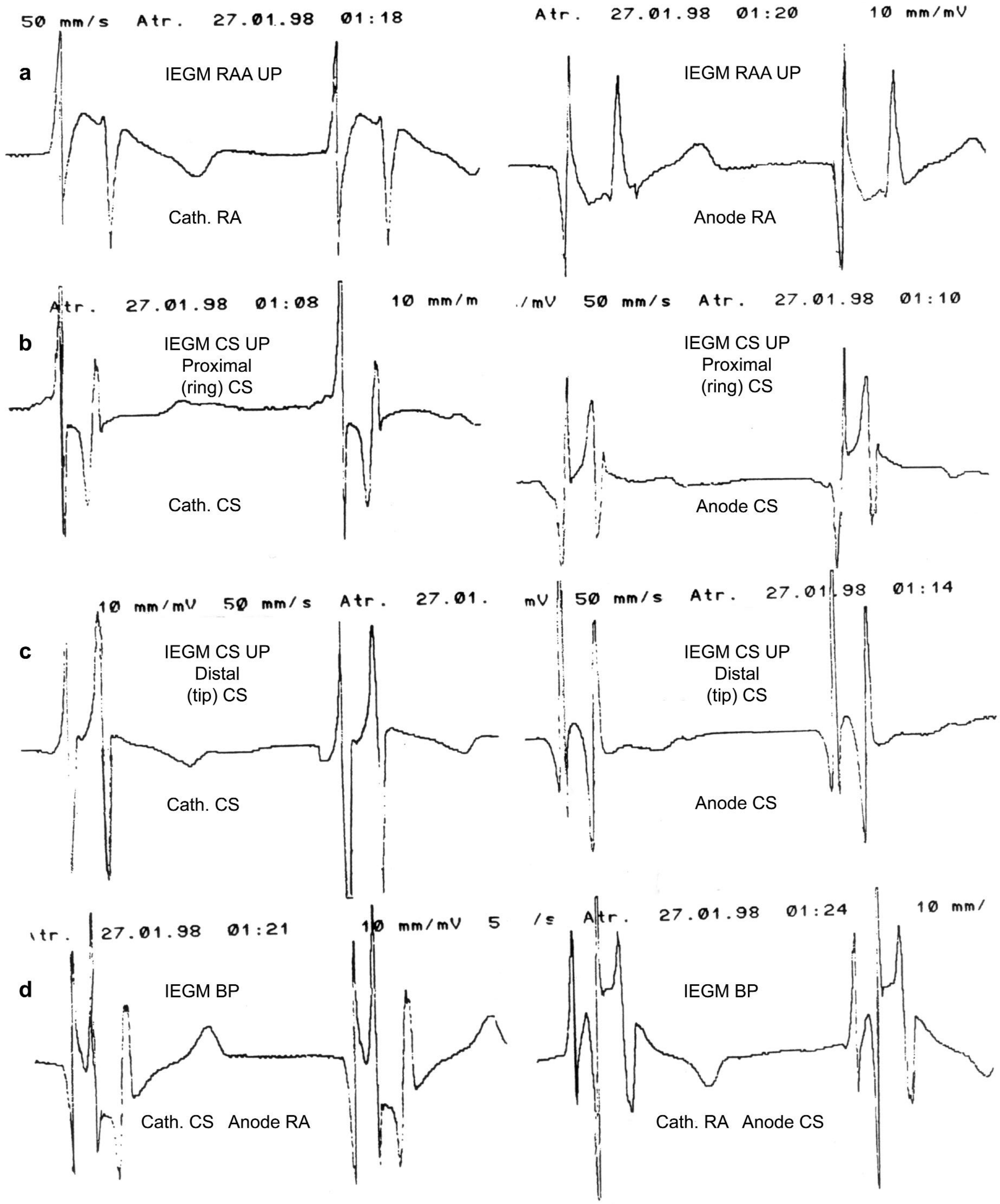

Figure 2. Intracardiac electrocardiogram (IEGMs) recorded during the implantation procedure in a 64-year-old female patient with bradytachy syndrome. Left panels stand for conventional lead configuration and right panels for a reversed lead connection, where the cathode (Cath.; active electrode) and the anode (passive electrode) were inverted. a) IEGM recorded from the right atrial appendage (RAA). b) Left atrial IEGM recorded from the ring electrode of the coronary sinus (CS) lead. c) Left atrial IEGM recorded from the tip electrode of the CS lead. d) Biatrial IEGM. The recordings in the unipolar (UP) configuration (a – c) were obtained with an electrode placed in the right atrium (RA) or CS and the other electrode being represented by a surgical tool located in the previously prepared pacemaker pocket. In the bipolar (BP) sensing configuration (d), the cathode was placed in one atrium and the anode in another atrium. The "mirror reflex" effect appeared to be the only result of the reversed lead polarity.

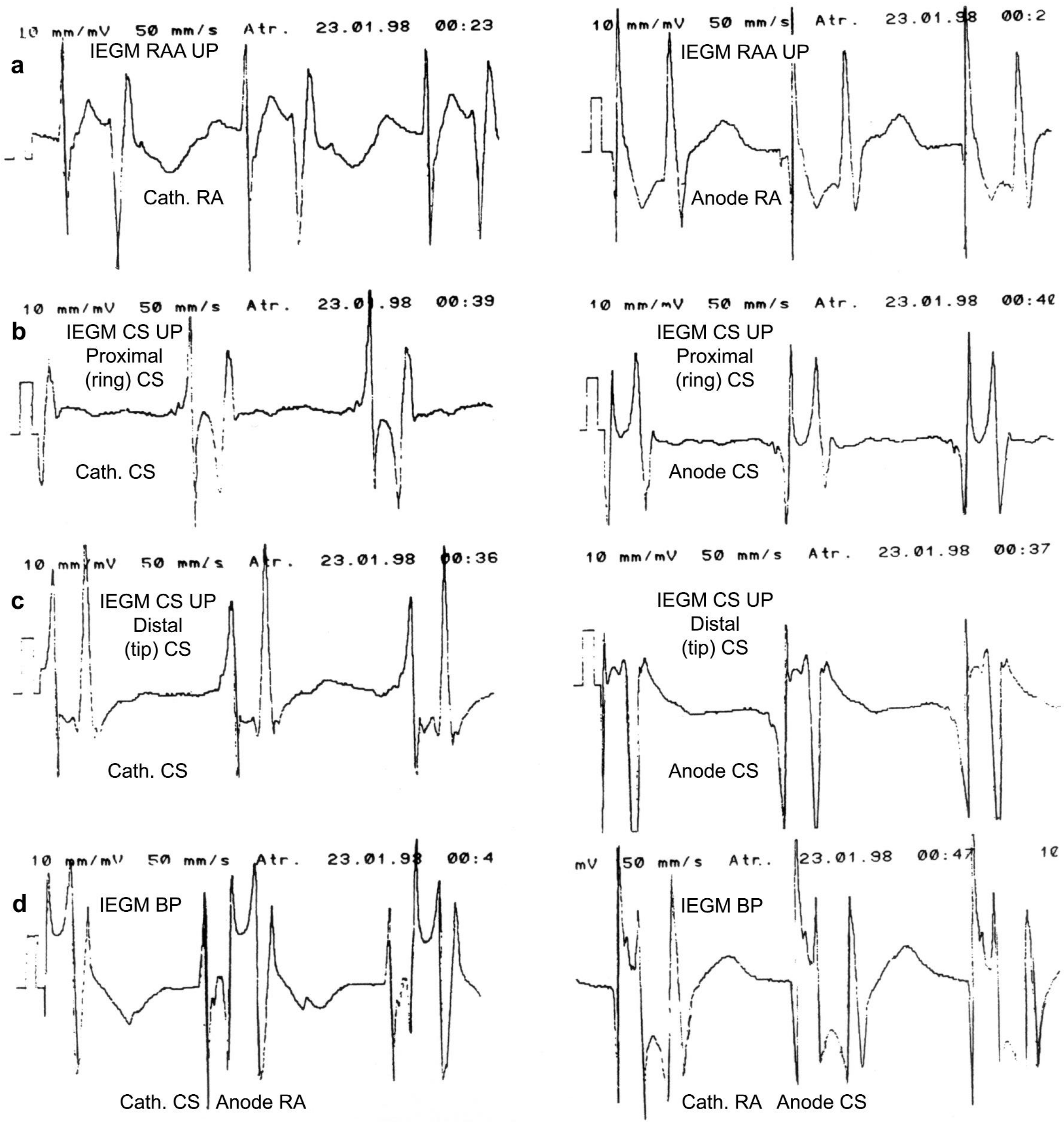

Figure 3. Intracardiac electrocardiograms (IEGMs) recorded during the implantation procedure in a 64-year-old female patient with a history of frequent recurrences of atrial flutter. The remaining of the legend is identical to that below Figure 2.

age 67.8 years, range 42 – 89). The first 20 patients (14 %, mean age 69.4 years, range 52 – 84) received pacing systems with standard connections proposed by Daubert [1-13,25], where the tip of the right atrial lead is the cathode and the tip of the left atrial lead is the anode. Due to frequent technical problems, mostly loss of left atrial pacing and a lack of resynchronizing effect, the next 125 patients (mean age 67.7 years, range 42 – 98) received identical pacing systems with the inverted lead polarity. This was achieved by exchanging connections at the "Y" connector. During the implantation procedure, complete measurement sets described above were performed (Figure 1 – 4).

All patients received standard TIJ or SD pre-shaped leads for right atrial pacing as well as standard TIR or SD straight bipolar leads for left atrial pacing (Biotronik, Germany). Leads with higher impedances (e.g., Synox or Polyrox, Biotronik, Germany) were not used due to the application of split bipolar

Sensing/Pacing Conditions of RAA Lead

	A wave amplitude		Pacing threshold		Impedance		Current	
	Cth	An	Cth	An	Cth	An	Cth	An
No. of data	47	47	46	46	47	47	46	46
Mean	2.8 mV	2.7 mV	0.7 V	1.3 V	688 Ω	702 Ω	1.15 μA	2.09 μA
± SD	1.7 mV	1.8 mV	0.8 V	0.9 V	217 Ω	233 Ω	1.47 μA	1.81 μA
P <	0.428		0.001		0.463		0.001	

Sensing/Pacing Conditions of CS Lead Ring

	A wave amplitude		Pacing threshold		Impedance		Current	
	Cth	An	Cth	An	Cth	An	Cth	An
No. of data	44	44	48	48	47	47	47	47
Mean	2.2 mV	2.2 mV	2.2 V	2.4 V	314 Ω	306 Ω	7.8 μA	8.4 μA
± SD	2.3 mV	2.8 mV	1.5 V	1.7 V	71 Ω	95 Ω	3.7 μA	4.1 μA
P <	0.905		0.018		0.058		0.085	

Sensing/Pacing Conditions of CS Lead Tip

	A wave amplitude		Pacing threshold		Impedance		Current	
	Cth	An	Cth	An	Cth	An	Cth	An
No. of data	441	41	41	42	38	39	37	38
Mean	2.4 mV	2.3 mV	5.5 V	6.0 V	601 Ω	588 Ω	8.8 μA	9.6 μA
± SD	2.3 mV	2.4 mV	3.4 V	3.5 V	195 Ω	214 Ω	5.3 μA	5.2 μA
P <	0.287		0.141		0.804		0.035	

Table 1. Acute effects of the inverted left and right atrial lead polarity on pacing/sensing conditions. Cth = cathode, An = anode, RAA = right atrial appendage, CS = coronary sinus.

configuration. Special leads for coronary sinus pacing were not available at the time of study performance.

Results

Study results are presented in Tables 1 – 3 and selected examples of intracardiac electrograms are illustrated in Figures 5 – 9. Table 1 compares pacing and sensing values for the right atrial appendage and coronary sinus lead positions, in the conventional unipolar configuration (cathode: atrial electrode; anode: surgical tool placed in the pacemaker pocket) and with the inverted polarity connections. The inverted connections did not influence A-wave amplitudes and pacing impedance. The cathodal pacing was much more effective than the anodal pacing, offering about 0.5 V and 1 mA lower voltage and current thresholds.

Table 2 illustrates the incidence of technical problems in conventional split bipolar atrial lead connections (proposed by Daubert) and the inverted connections (author's modification). Lead dislocations were not mentioned in the table, as the connection system could not play any role in it. In the patient group with conventional lead connections, satisfactory left atrial pacing (biatrial pacing) was not possible to accomplish in 12 % of the patients at the 1-month follow-up and in 25 % of the patients at the 1-year follow-up. The inci-

	Cathode: RA (–), anode: CS (+) "Conventional"	
	Follow-up point	
	1 month	1 year
Patient number	16	16
No problems with pacing or sensing	14 (87 %)	11 (68 %)
RA pacing or sensing problems	-	1 (6 %)
CS pacing, sensing, or resynchronisation problems	2 (12 %)	4 (25 %)

a

	Cathode: CS (–), anode: RA (+) "Inverted"	
	Follow-up point	
	1 month	1 year
Patient number	113	71
No problems with pacing or sensing	107 (95 %)	67 (94 %)
RA pacing or sensing problems	3 (3 %)	2 (3 %)
CS pacing, sensing, or resynchronisation problems	3 (3 %)	2 (3 %)

b

Table 2. A review of pacing, sensing, and atrial resynchronization problems in patients with implanted biatrial pacing systems. RA = right atrium, CS = coronary sinus. Problems were defined as unfavorable pacing or sensing conditions without the need for reoperation, corrected by pacemaker reprogramming or resulting in temporary or permanent loss of synchronized biatrial pacing. In the conventional split bipolar atrial lead configuration (a), four patients were reoperated within 1 month after implantation. In the inverted split bipolar configuration (b), four patients were reoperated within 1 year after implantation, ten patients were lost to follow-up, seven developed chronic atrial fibrillation and 15 patients developed other arrhythmia.

dence of problems was significantly lower in the patient group treated with inverted lead connections: 3 % at the 1-month follow-up and 2 % at the 1-year follow-up.

While interpreting follow-up results, one should have in mind that in split bipolar atrial configuration successful pacing is possible with one atrial lead in conditions when the other atrial lead is ineffective due to high pacing threshold. Thus, the loss of the desired outcome – simultaneous pacing of both atria – will not require surgical intervention as long as it is transient. From 20 patients treated with conventional split bipolar atrial configuration, four were withdrawn 1 month after implantation due to the inversion of lead connection to treat permanent exit block at the left atrial site and frequent recurrences of atrial arrhythmia. In these four patients, the global impedance exceeded 900 Ω. Effective biatrial pacing in these cases was achieved simply by inverting the lead polarity (in 2 cases) or by using the ring electrode instead of the tip electrode on the coronary sinus lead, in conjunction with the inverted polarity (other 2 cases).

Mean A-wave amplitude in the right atrium (left atrial A-wave amplitudes could not be measured in the split bipolar lead configuration) fluctuated within the 2.6 – 3.0 mV range in either patient group, without significant differences. Pacing threshold in the right atrium was 2 – 3 V, or significantly lower than that in the left atrium (5 – 6 V), which was independent from the choice of connection (conventional or inverted). Mean pacing impedance in the split bipolar lead configuration fluctuated within the range from 650 – 800 Ω and did not differ for the two groups of patients (Table 3).

Discussion

The intraoperative results confirmed the hypothesis that left atrial pacing with the cathodal current is generally more efficient than the anodal pacing that is associated with higher pacing thresholds and increased energy consumption. While several groups of authors have previously demonstrated this effect in the ventricle [37-41], our study confirmed the same relationship in the atrium. The inverted lead polarity did not influence pacing impedance and sensed atrial amplitudes. The observed effect of "mirror reflex" in the sensed intracardiac signal appeared irrelevant. These findings, largely expected from the laws of physics, empowered us to modify conventional split bipolar atrial configuration in the way described in the article. Favorable intraoperative and follow-up results with the modified connections made us use this solution routinely in all patients.

Relatively high biatrial pacing thresholds reported in this study are caused by unavailability of specifically designed coronary sinus leads at the time of study performance. With standard leads placed in the coronary sinus, nominal output settings of 4.8 V/0.5 ms were not sufficient to not ensure biatrial pacing in almost half of the patients (only the right atrium could be paced with

	Lead polarity		post operative	1 month	3 months	6 months	12 months
RAA (A-wave) amplitude	"Conventional"	Number	17	13	7	9	9
	Cathode: RA (–)	Mean (mV)	2.97	2.85	2.63	2.53	2.78
	Anode: CS (+)	± SD (mV)	2.12	1.53	1.72	1.96	1.20
	"Inverted"	Number	123	92	45	60	42
	Cathode: CS (–)	Mean (mV)	2.98	2.92	2.92	3.07	2.93
	Anode: RA (+)	± SD (mV)	1.56	1.69	1.44	1.72	1.59
		t	0.0170	0.1450	0.4850	0.8570	0.2800
		P	0.9863	0.8846	0.6290	0.3940	0.7799
RAA pacing threshold 0.5 ms pulse width	"Conventional"	Number	19	13	5	6	9
	Cathode: RA (–)	Mean (V)	1.32	2.40	1.80	1.31	1.38
	Anode: CS (+)	± SD (V)	1.26	2.66	0.92	0.40	0.63
	"Inverted"	Number	114	84	41	63	47
	Cathode: CS (–)	Mean (V)	1.91	3.27	2.78	2.64	2.46
	Anode: RA (+)	± SD (V)	1.15	2.41	1.74	1.81	1.25
		t	2.0370	1.2010	1.2340	1.7830	2.5250
		P	0.0435	0.2320	0.2230	0.0791	0.0145
BiA pacing threshold 0.5 ms pulse width	"Conventional"	Number	15	10	4	8	10
	Cathode: RA (–)	Mean (V)	5.97	6.44	6.65	6.70	5.25
	Anode: CS (+)	± SD (V)	2.87	2.75	3.39	3.15	3.32
	"Inverted"	Number	116	94	51	63	48
	Cathode: CS (–)	Mean (V)	5.03	5.33	5.49	5.28	5.29
	Anode: RA (+)	± SD (V)	2.11	2.02	1.85	2.14	1.86
		t	1.5490	1.1120	1.1320	1.6720	0.0550
		P	0.1237	0.2574	0.2623	0.0991	0.9561
Impedance	"Conventional"	Number	16	10	4	8	11
	Cathode: RA (–)	Mean (Ω)	682.50	697.80	480.00	800.10	796.30
	Anode: CS (+)	± SD (Ω)	204.10	183.00	233.7	281.10	241.90
	"Inverted"	Number	125	99	51	66	49
	Cathode: CS (–)	Mean (Ω)	654.40	712.50	736.30	719.10	788.20
	Anode: RA (+)	± SD (Ω)	190.70	299.70	292.40	234.30	305.00
		t	0.5510	0.1520	1.7070	0.9040	0.2300
		P	0.5826	0.8790	0.0936	0.3689	0.8182

Table 3. Right atrial appendage (RAA) and biatrial (BiA) sensing and pacing parameters obtained with the aid of pacemaker telemetry in the bipolar (BP) configuration. Paired t-tests were used in statistical evaluations. RA = right atrium, CS = coronary sinus.

the 100 % energy safety margin), while the output of 6.2 V/0.5 ms was effective in the vast majority of cases. Other studies have shown that high pacing impedance (700 – 900 Ω) of biatrial systems almost doubles total current drain in comparison to conventional pacing with standard impulse energy [11,19-23,27,33-38]. Our

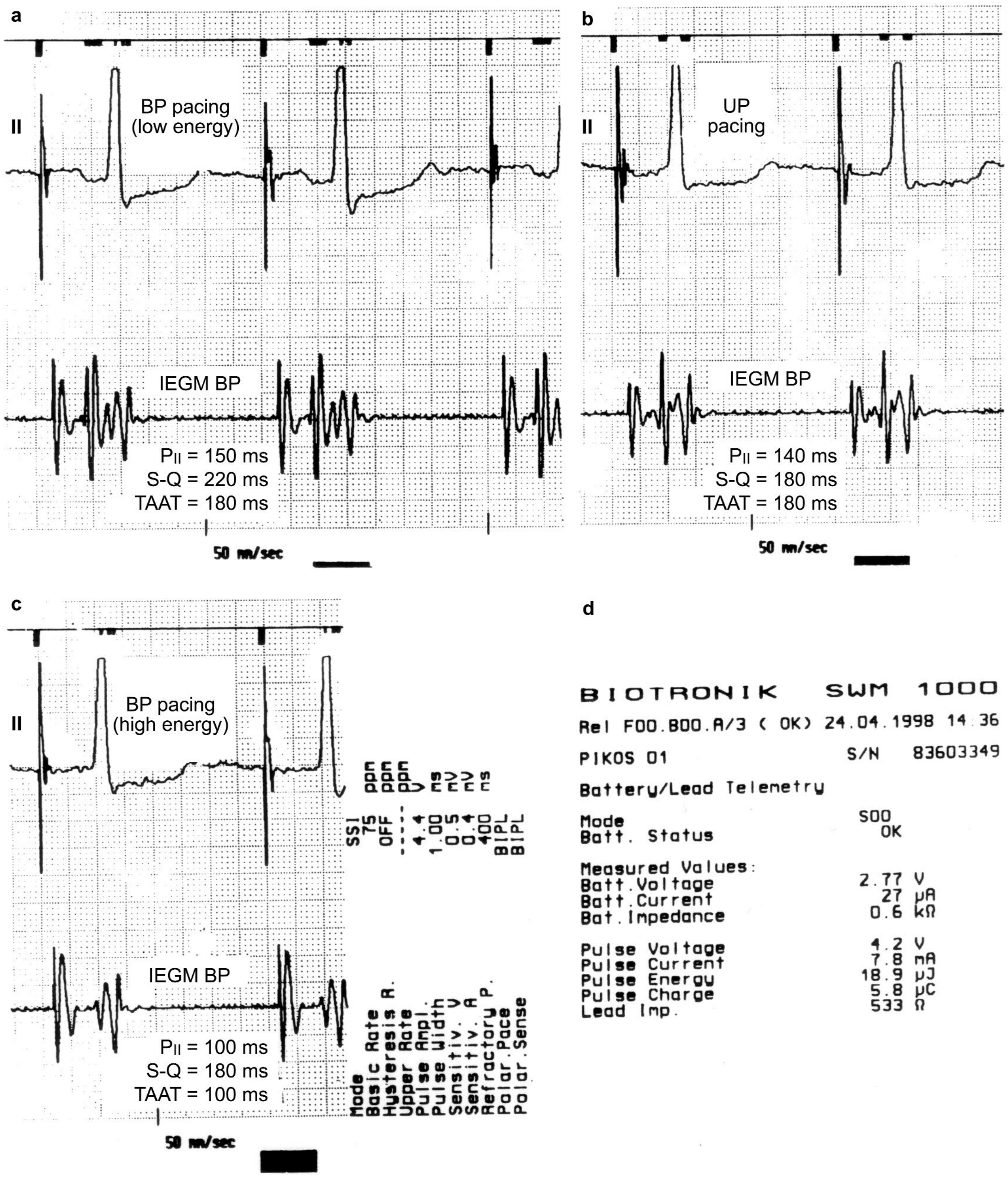

Figure 6. ECG and intracardiac electrocardiograms (IEGMs) recorded in the male patient from Figure 5. a) Bipolar (BP) pacing with the impulse energy programmed below the coronary sinus pacing threshold (2.0 V/0.5 ms). The impulses were captured only at the right atrial site, prolonging P-wave duration by 20 ms. S-Q duration = interval from the atrial paced spike to the Q-wave; TAAT = total atrial activation time. b) Unipolar (UP) stimulation resulted in the left atrial capture that significantly shortened S-Q duration in comparison to the right atrial pacing. c) BP pacing with a higher impulse energy captured by both atria. The presence of only one A-wave in the IEGM proves the effectiveness of biatrial pacing. d) The impulse energy and battery current drain after final pacemaker programming, showing that 19 mJ energy was sufficient for effective biatrial pacing with a standard safety margin.

previous research indicated that pacing systems featuring high pacing impedance and high pacing thresholds should be programmed to longer pulse duration to decrease current drain [42]. Despite relatively high pacing thresholds, the amplitude of 4.8 V in conjunction with pulse duration of 0.75 – 1.0 ms resulted in

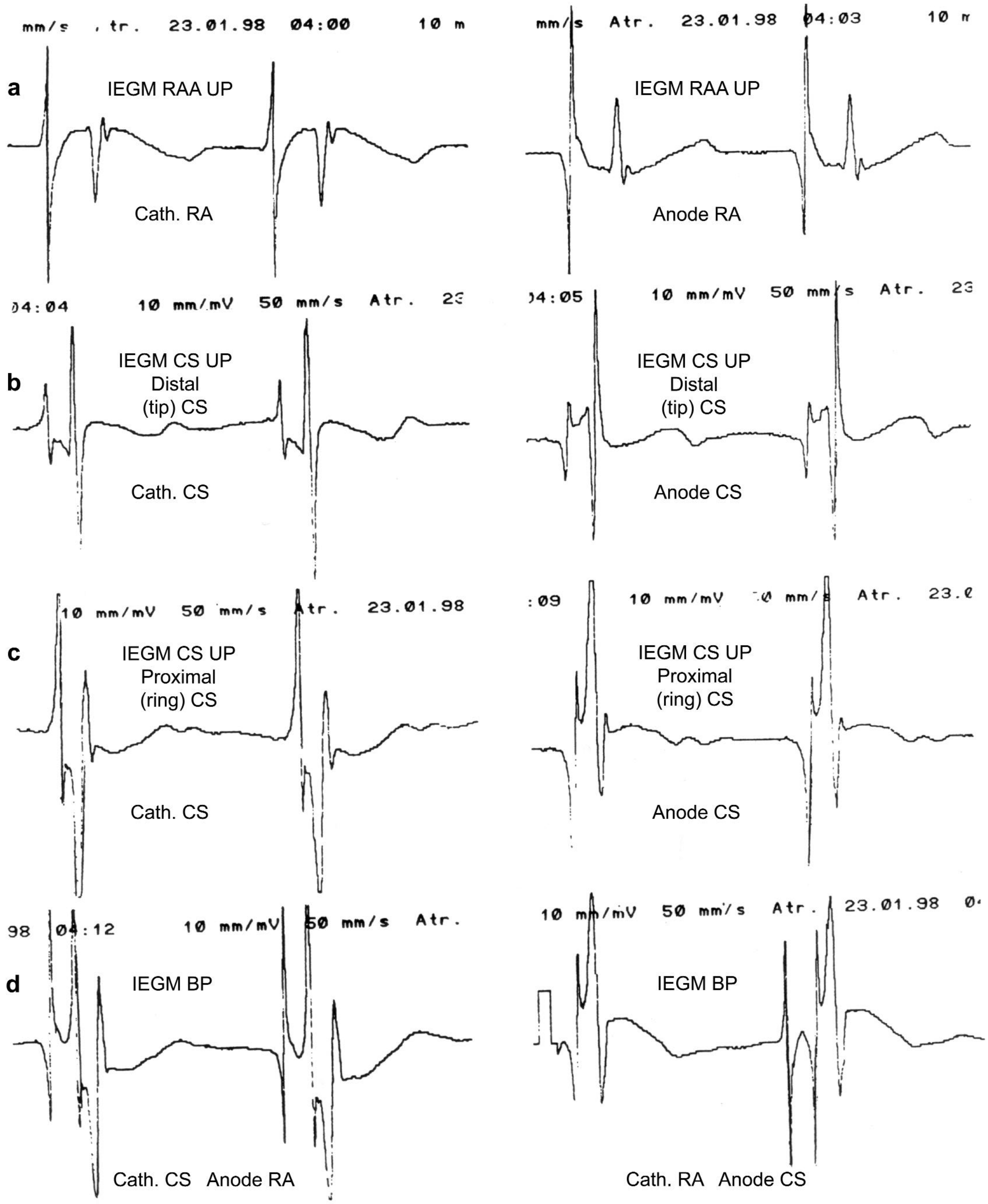

Figure 4. Intracardiac electrocardiograms (IEGMs) recorded during the implantation procedure in a 70-year-old male patient with recurrences of drug resistant atrial flutter. The remaining of the legend is identical to that below Figure 2.

successful biatrial pacing in the vast majority of patients.

The present study and earlier observations [43-44] demonstrated several advantages of the inverted split bipolar configuration. The first advantage is eliminated risk of accidental, potentially pro-arrhythmic anodal pacing in the ventricle. It has been known that both left atrium and left ventricle may be paced from the distal coronary sinus using medium- and high-energy pulses, respectively [10,16,28-30]. Placing the lead tip in a far distal position may cause danger from the equalization of atrial and ventricular pacing

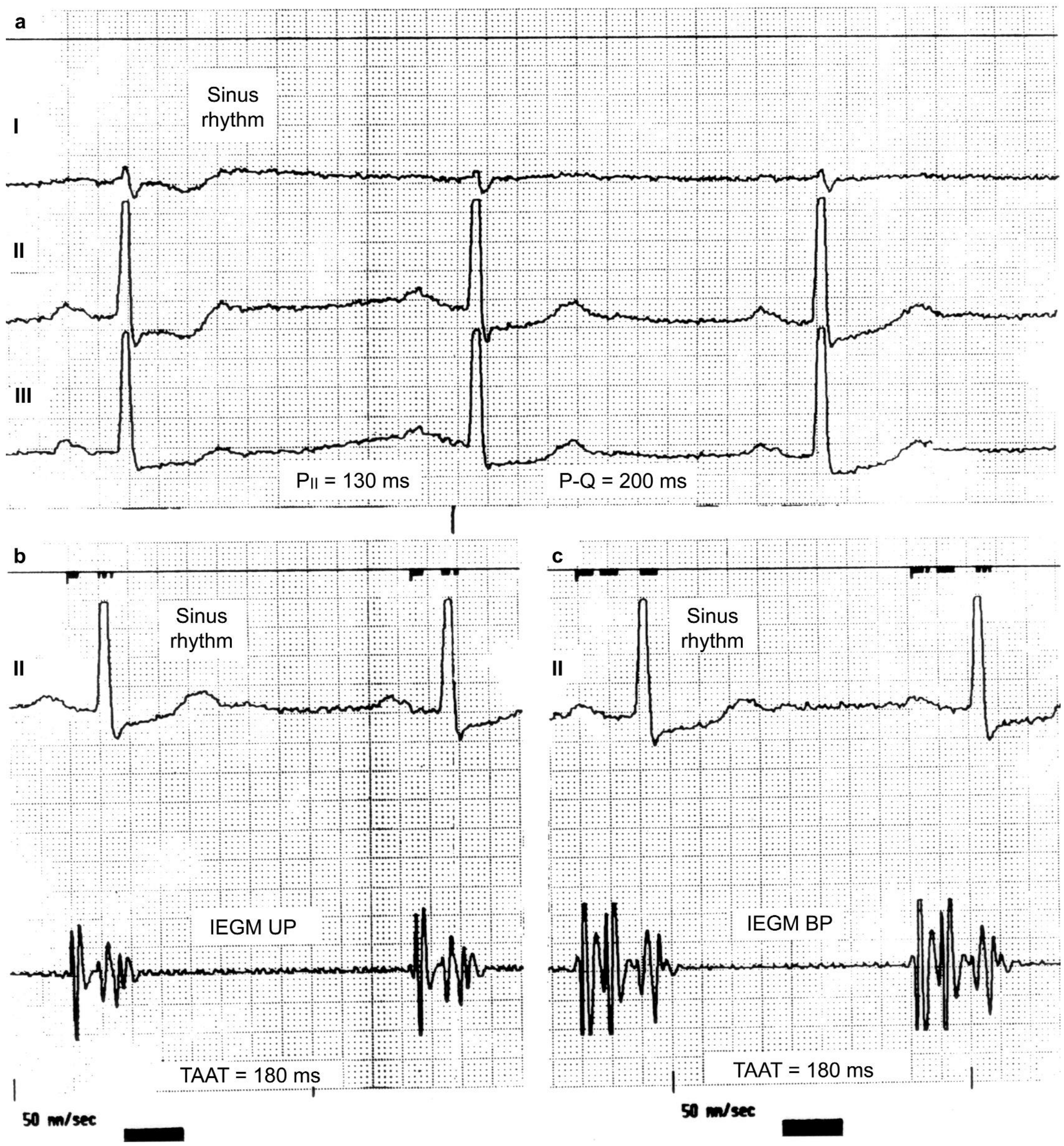

Figure 5. ECG and intracardiac electrocardiograms (IEGMs) recorded in a 72-year-old male patient with a biatrial pacing system (split bipolar atrial configuration) implanted due to interatrial conduction disturbances, recurrent atrial flutter (over 12 - 24 hours in the 24-hour ECG monitoring) and sinus bradycardia. a) Sinus rhythm at 52 beats/min. b) Pacing rate programmed below the sinus rate. c) IEGM in the bipolar (BP) configuration indicated the presence of both right and left atrial depolarization waves. In the unipolar (UP) IEGM, only the left atrial depolarization was present, disappearing 180 ms after the onset of the P-wave. The recording allowed estimation of the total atrial activation time (TAAT).

thresholds. Twenty years ago, it was demonstrated that ventricular pacing is possible with anodal current during effective ventricular refractory period, as a consequence of a collapse of the strength-interval curve [37-41,45-46]. There are no such risks for the anodal pacing within the right atrium, even for high energy levels.

The second, very important advantage of the inverted split bipolar configuration is feasibility of the unipolar atrial pacing, where the left atrium is paced in the unipolar configuration and the right atrium is paced by means of low-energy bipolar pacing. Present study and 90 % of other studies in larger patient groups indicate that anodal pacing threshold in the right atrium is

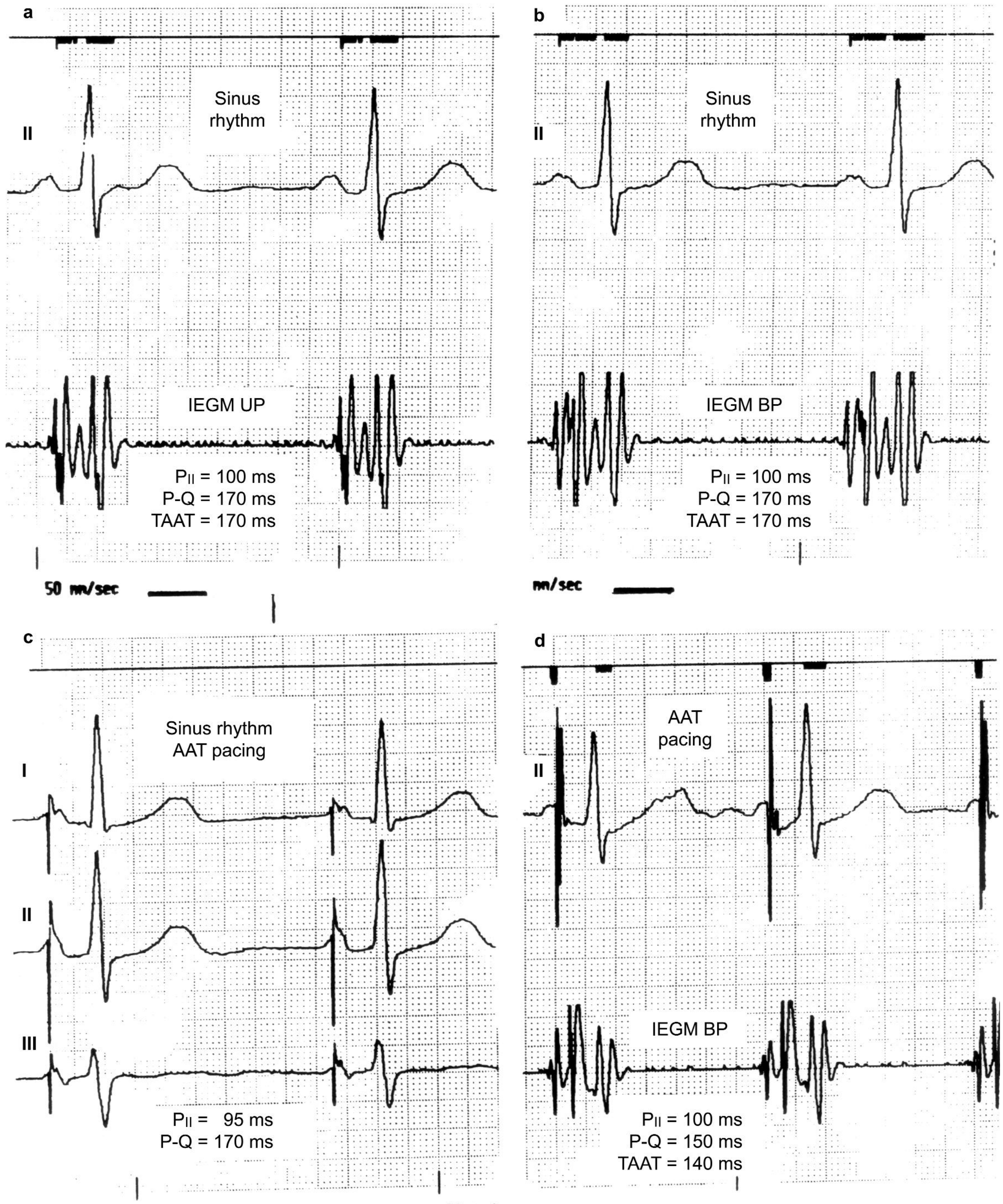

Figure 7. ECG and intracardiac electrocardiograms (IEGMs) recorded in a 52-year-old female patient with a biatrial pacing system (split bipolar atrial configuration) implanted due to bradytachy syndrome. Although P-wave morphology was regular, IEGMs indicated the presence of interatrial conduction disturbances. a) Sinus rhythm recorded in the unipolar (UP) configuration showed a delayed activation of the left atrium. The total atrial activation time (TAAT) was 170 ms. b) Sinus rhythm recorded in the bipolar (BP) configuration showed activation of both right and left atria. c) Triggered pacing (AAT pacemaker mode) with the pacing rate equal to the sinus rate. d) AAT pacing in the BP configuration. A moderate resynchronizing effect was present due to a delayed detection of the right-atrial A-wave. The delay was imposed by the conduction time between the region of sinus node and the tip of the right atrial lead. The sensing markers of atrial excitation show a delayed sensing of the left atrial A-wave by 180 ms (a) and of the right atrial A-wave by 45 ms (b and d), in comparison to the onset of P-wave.

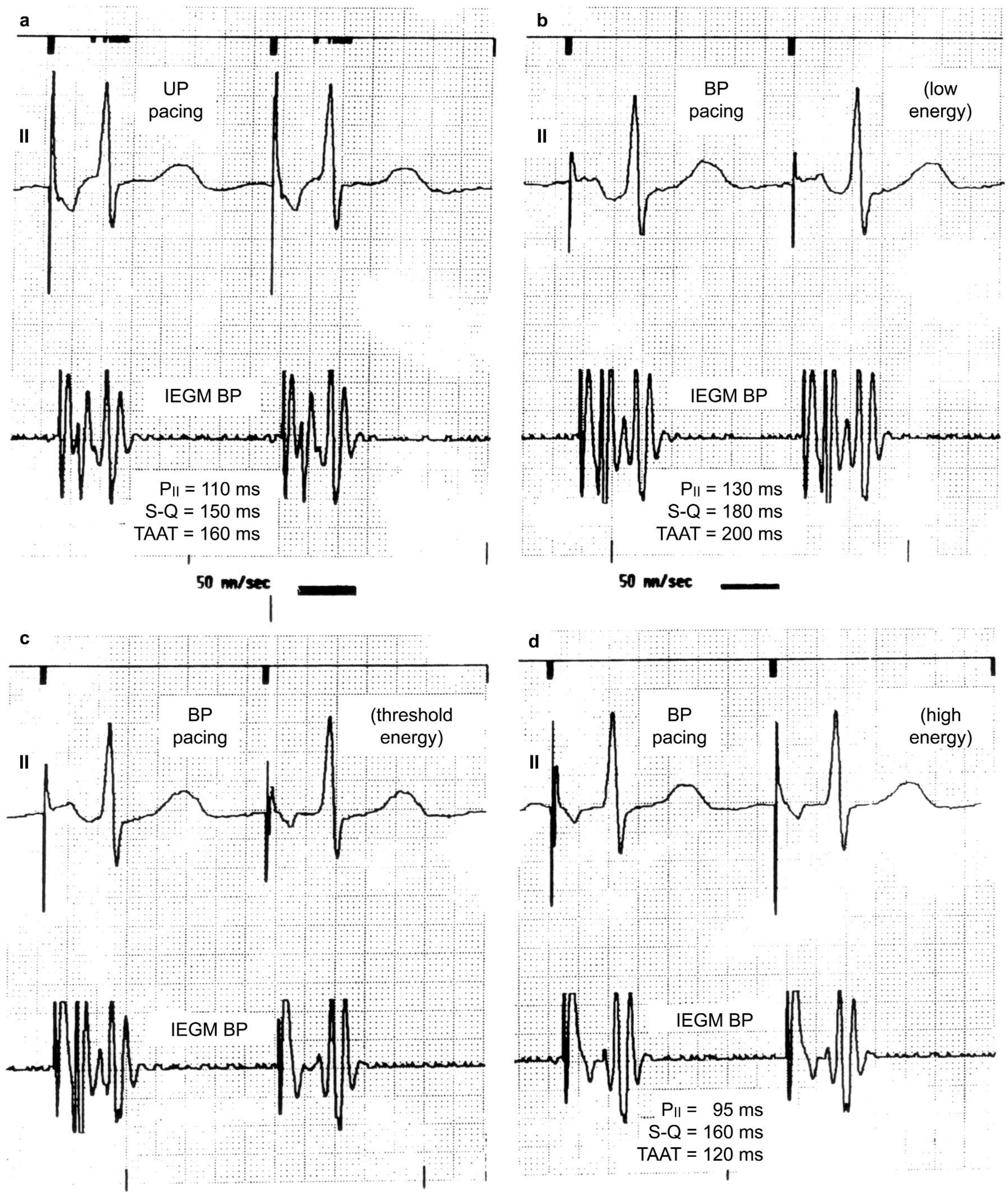

Figure 8. ECG and intracardiac electrocardiograms (IEGMs) recorded in the female patient from Figure 7. a) left atrial pacing in the unipolar (UP) configuration. The S-Q duration (interval from the atrial paced spike to the Q-wave) was shorter by 30 ms than in the right atrial pacing. TAAT = Total atrial activation time. b) Bipolar (BP) pacing configuration with the impulse energy programmed below the coronary sinus pacing threshold (2.4 V/0.5 ms). This low energy pacing was captured only by the right atrium and associated with a 20-ms prolongation of P-wave duration. c) BP pacing with the impulse energy above the left atrial threshold. The electrophysiological consequences of an alternative right and left atrial pacing can be compared. d) BP pacing with the impulse energy captured by both atria (biatrial pacing). P-wave duration was shortened to 95 ms, S-Q interval to 160 ms and TAAT to 120 ms. The presence of only one A-wave in the IEGM proves the effectiveness of biatrial pacing.

lower than the cathodal pacing threshold in the left atrium [15-16,21-23,27,34-35]. Positioning of the cathode in the coronary sinus enables the physician to monitor threshold changes in the coronary sinus and to attain left atrial pacing with a pulse energy slightly exceeding the threshold value. Conversely, anodal pacing of the right atrial appendage is successful and safe [21-23,27,34-35]. The proposed inverted system of connections allows for accurate evaluation of pacing and sensing values at the left atrial site, which will be of particular interest in future clinical evaluations of new leads specially designed for coronary sinus application.

All systems for biatrial pacing have certain disadvantages [15-16,20-22,33-35,43-44,47-48]. Disadvantages of the system proposed by our team are the phenomenon of lead impedance summation (which applies also for the conventional system proposed by Daubert) and loss of atrial pacing in case of coronary sinus lead dislocation. A relative advantage of the Daubert system is that left atrial lead dislocation (encountered in 8 % – 12 % of patients [8-10,35-36,47-48]) causes only loss of atrial resynchronization without failure to capture the right atrium with cathodal stimulation. In our system, dislocated coronary sinus lead must be repositioned.

Conclusions

- Cathodal pacing in the right atrium or in the coronary sinus is associated with significantly lower pacing threshold/energy than anodal pacing.
- Anodal pacing in the coronary sinus in a biatrial pacing system with the split bipolar lead configuration is associated with relatively high energy requirements and a significant risk of exit block at the left atrial site.
- Inverted electrode polarity in the split bipolar atrial configuration (with the cathode placed in the coronary sinus and the anode in the right atrium) does not influence pacing impedance and sensed atrial amplitudes.
- Inversion of lead polarity improves left atrial pacing conditions and system efficacy.

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