Atrial Resynchronization Using a Single Lead: The New Concept of Septal Pacing Triggered by the Onset of Atrial Excitation

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Summary

We hypothesized that an increase in the distance between the tip- and ring electrodes of an atrial lead widens the sensing spectrum and allows earlier detection of the onset of intrinsic atrial excitation. Leads with an increased tip-ring distance of 8 cm, with the lead tip screwed into the low-posterior atrial septal region and the ring placed in the mid anterior part of the right atrium, were implanted in four women and six men with recurrent atrial fibrillation. Atrial low-posterior septal sensing conditions were not worse than those obtained during temporary positioning of the lead tip in the right atrial appendage or mid-coronary sinus, although the ratio of the sensed atrial and far-field ventricular amplitudes (A/V ratio) was the most favorable in the right atrial appendage position. Pacing thresholds (about 1 V) and impedance values were within the acceptable limits intra- and postoperatively, and did not change in the acute postoperative period. IEGM recordings performed in the bipolar sensing configuration indicated the presence of two separate atrial waves in all ten patients. The first atrial wave represented the potential of the high-RA anterior part, and the second one the local potential recorded from the tip electrode. The high RA potential of 1.6 mV was slightly lower in amplitude than the low-posterior septal potential (2.0 mV). Excellent pacing was obtained in the coronary sinus ostial region, which was triggered with the onset of atrial excitation in patients with recurrent atrial fibrillation (using simple SSI unit and SST mode). This concept worked perfectly in all the patients and with satisfactory clinical effect. Widening of the sensing dipole was not accompanied by deterioration of sensing and pacing conditions: A-wave amplitude, A/V ratio, pacing threshold, and impedance remained within acceptable limits. Our approach seems to be a new step toward more simple and effective atrium-resynchronizing pacing for the treatment of drug resistant atrial arrhythmias in patients with atrial conduction disturbances in the absence of chronotropic incompetence. The low-posterior atrial septal pacing triggered with the onset of the excitation in RA became feasible using a special bipolar lead with the indifferent ring electrode located in the upper part of the RA lumen.

Key Words

Atrial resynchronization, septal pacing, screw-in lead

Introduction

Especially in patients with atrial conduction disturbances, pacing to resynchronize the atria has become a widely accepted non-pharmacological method of preventing recurrent atrial arrhythmias [1-9]. Four different atrial pacing systems have been introduced in recent years for atrial resynchronization:

- Daubert's biatrial pacing (split-right atrial appendage (RAA) and coronary sinus (CS) leads) [4-8];
- Markewitz-Osterholzer's biatrial pacing (pacing both of atria using both channels of DDD pacemaker) [10-14];
- Saksena's dual site right atrial pacing (split-RAA and septal leads) [9,15-18]; and

- Padeletti's low posterior atrial septal pacing (using single lead) [19-24].

For anatomical and electrophysiological reasons, the tip of the lead located in the right atrial appendage (RAA) detects the atrial excitation 20 – 40 ms after the start of the P-wave [14,25-31]. This unavoidable delay in sensing of onset of atrial excitation delays pacing in the coronary sinus or its ostial region, and diminishes the effectiveness of triggered pacing modes. As shown in the literature, detecting spontaneous atrial activation (sinus or ectopic) as early as possible is crucial for resynchronizing the atria [1-9,12-14]. A pacing system for atrial resynchronization should have the following four characteristics:

- Simple and easy for implantation and explantation (single lead is preferred);
- Symmetrical activation of both atria;
- Continuous pacing of the triangle of Koch region (one of the most arrhythmogenic areas in the atria); and
- Early-as-possible sensing of atrial excitation (sinus and ectopic).

Through long-term experience with different resynchronizing atrial pacing systems [14] and a review of the literature we have concluded that single-lead, low-posterior atrial septal pacing seems to best meet these criteria, except for early sensing of the onset of atrial excitation. This last criterion is necessary for the triggered pacing mode. Our goal was to find a pacing system that was both simple and easy-to-implant (and explant if necessary), and which fulfilled most of the requirements for of an ideal resynchronizing atrial pacing system. We identified single-lead, low-posterior septal pacing as the most promising and hypothesized that the construction of a new screw-in lead, a first case report for which was recently published [32], allows for sensing of the onset of atrial excitation as well as for permanent low-posterior septal pacing triggered by high right atrial potentials. Data from ten patients are presented in this article, confirming the promising results from our case report [32].

Materials and Methods

Patients

We implanted the new designed lead in ten patients (five male, five female, aged 48 – 78; mean age 67 years) with recurrent atrial arrhythmias and moderate atrial conduction disturbances (P-wave < 140 ms). Patients with severe inter-/intraatrial conduction defects or with severe bradycardia received a classic biatrial pacing system. Patients with AV conduction disturbances presenting with first-degree AV block or a Wenckebach point under 130/min were excluded from the study and received three-chamber pacing systems with split bipolar atrial lead configuration.

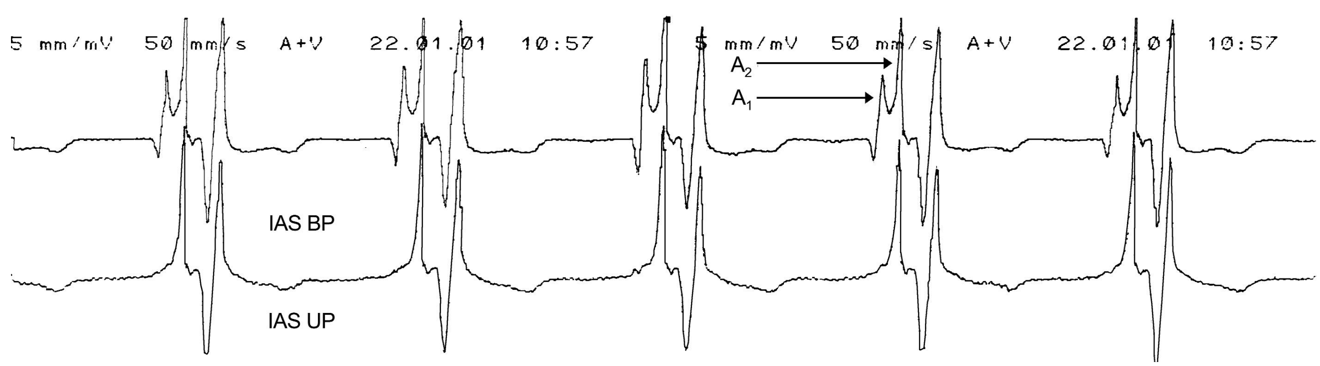


Figure 1. Intraatrial signals recorded using a threshold analyzer (ERA 300 B, Biotronik, Germany) during implantation of the new screw-in electrode designed for low-posterior septal pacing. Simultaneous recording of IEGM after screw in tip of lead in coronary sinus ostium region in bipolar (BP) and unipolar (UP) sensing configurations. The upper record indicates that the BP configuration (using the new lead) enables detection of atrial excitation 70 ms earlier than is possible during UP configuration (A_1 – A_2 delay).

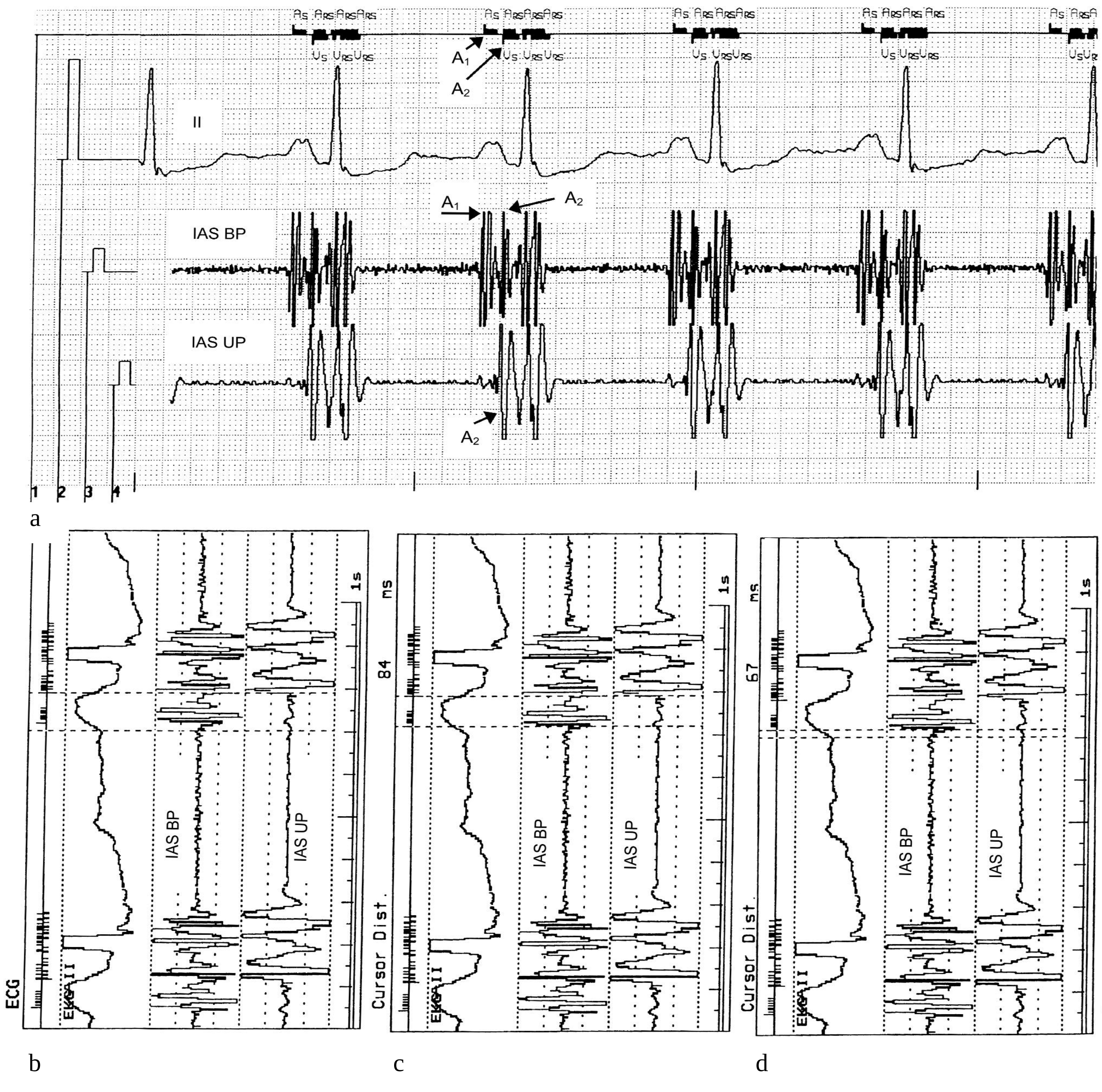
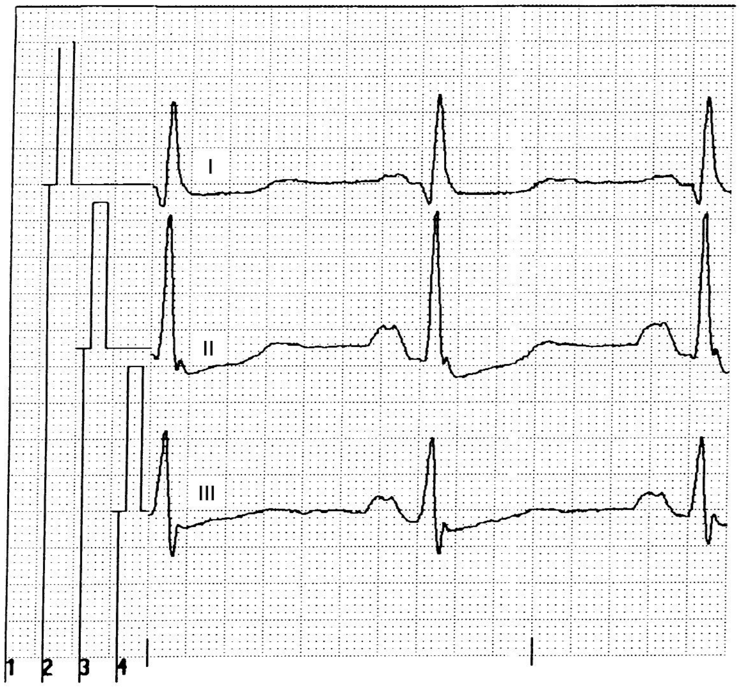


Figure 2. Intraoperative examination by an external DDD pacemaker (Actros D, Biotronik) and programmer (PMS 1000, Biotronik). Each panel shows the event marker, surface ECG lead II, intracardial signal from the atrial septum in unipolar (IAS UP) and bipolar (IAS BP) sensing configuration. Arrows indicate sensed A_1- and A_2-potentials (a). Screen snapshots enable exact measurement of atrial timing parameters using cursors: b) intraatrial conduction time = 84 ms, c) delay of activation of CS ostium region in comparison to detection of high right atrium potential = 67 ms, and d) delay of detection of high right atrium potential in comparison to onset of P-wave = 14 ms. Figure indicates the utility of the ring (indifferent) electrode located in the high right atrium for early sensing of atrial activation.

Leads and Pacemakers

All ten patients received bipolar screw-in leads (modification of Y 60 BP lead with an 80-mm separation between the tip and ring, Biotronik). The modified leads allowed for the ring electrode to be located in the inflow tract of the high right atrium. All patients received SSI(R) pacemakers (Actros SR, Biotronik). Rate-responsive function was only used in case of normal triggered pacing (SST program) not being teasible.



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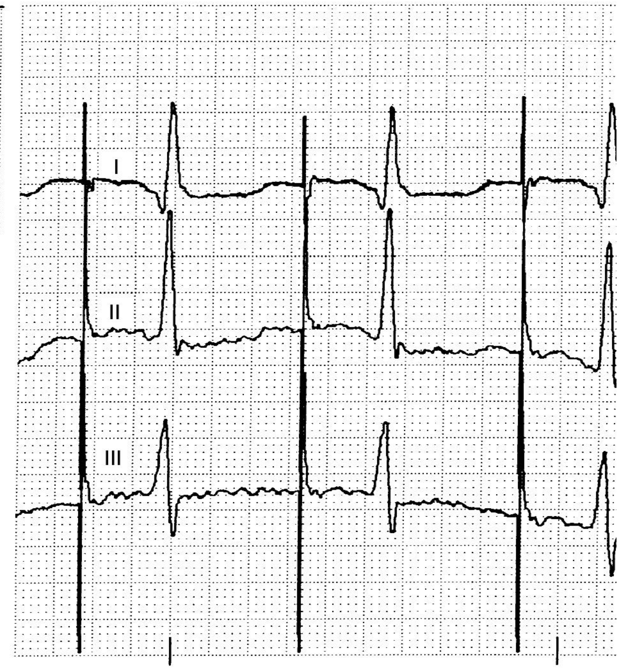

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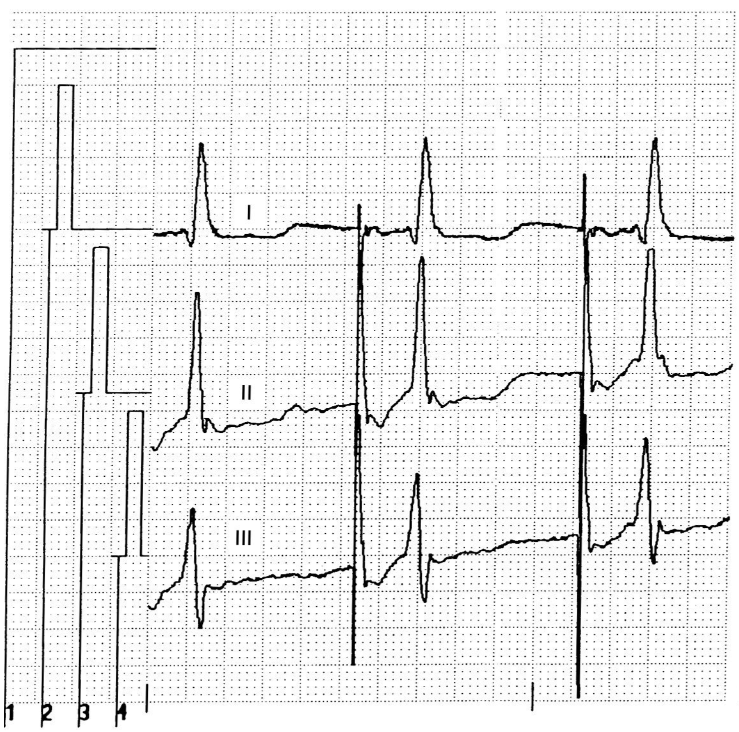

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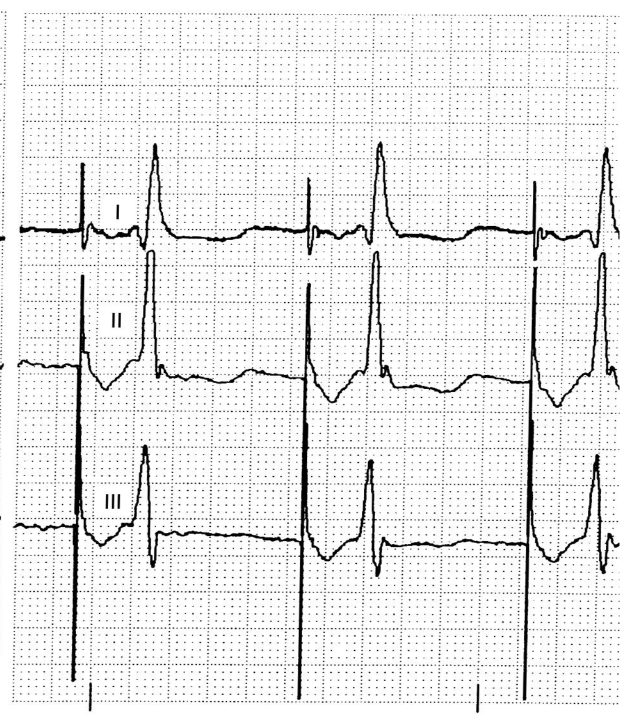

d

Figure 3. Surface ECG during intraoperative examination for a) sinus rhythm (SR), b) right atrial appendage (RAA) pacing, c) proximal part of coronary sinus (CS) pacing, and d) low-posterior septal pacing. Different values of P-wave duration during SR (100 ms), RAA pacing (160 ms), CS pacing (120 ms) and septal pacing (135 ms) are visible. Different values for the AV delay (start of P- or V-spike) during SR (150 ms), RAA pacing (200 ms), CS pacing (140 ms) and septal pacing (170 ms) indicates the different effects of the atrial pacing modes compared (see Table 5).

Implantation Procedure

The new screw-in lead was introduced into the venous system using subclavian vein puncture. Initially, the lead tip was temporarily positioned in the right atrial appendage (RAA). UP pacing/sensing conditions were examined. Subsequently the lead tip was carefully withdrawn and introduced into the mid-part of the CS; its location was confirmed with typical movement of the distal part of the lead and the morphology of the paced P-wave. Pacing and sensing conditions in UP configuration were evaluated as well. Subsequently the lead tip was carefully withdrawn, rotated back and screwed into the wall of the low-posterior part of the atrial septum, slightly posterior and slightly superior of the CS ostium.

Using a threshold analyzer (ERA 300 B, Biotronik) we recorded IEGMs in UP and BP configurations and measured the standard sensing/pacing conditions (Figures 1 – 4). For simultaneous IEGM recording using both UP and BP configurations and ECGs, we used both of the threshold analyzer channels and/or replaced the analyzer with an external standard DDD pacemaker, PMS 1000 programmer, and four-conductor sterile cable. IEGM snapshots on the monitor screen permitted exact measurement of timing parameters at a speed of 100 mm/s. Subsequently, the proximal end of the lead was connected with a standard SSI(R) pacemaker, which was implanted into the subcutaneous pocket in the left subclavian region.

Postoperative Examination

During the postoperative examination, pacing and sensing parameters were tested using both UP and BP configurations (Figures 5 – 8). Transmission of intracardiac electrograms (IEGMs) via the implanted pacemaker, simultaneous with ECG lead II, was an important part of the study. Finally, the pacemaker was programmed to triggered pacing mode (SST). The examination was repeated prehospital discharge, whereas some changes of pacing/sensing parameters were introduced.

Results

The results of the analysis of atrial septal sensing conditions, performed by manually measuring the amplitudes of potentials from paper recordings, are presented in Table 1. The table presents and compares the results of measurements taken on RAA and mid-CS sensing conditions. In eight out of ten patients, we found local (CS-ostium region) potentials with amplitudes over 1.5 mV using UP sensing configuration immediately after screwing in the lead. The recorded A-wave was followed by a slight "injury" elevation of the isoelectric line. Only in two patients, this potential has a smaller amplitude. What is most important, recordings performed in BP sensing configuration showed the presence of two separate atrial A-waves (Figures 1, 2, 5) in all ten patients. The first one probably represents the potential at the high anterior part of the right atrium (A_1 potential); the second one represents a local potential recorded from the tip electrode (A_2 potential).

Table 1 indicates, that the atrial potential recorded from the region of the CS ostium near the tip electrode shows (even at UP configuration) a sufficient amplitude (mean 2.0 mV, median 2.4 mV) and A/V ratio (median 1.3) for driving the pacemaker's functions. Sensing with the BP configuration shows the presence of two A-waves with similar amplitudes (about 2.0 mV) and even a slight improvement in the A/V ratio. The results indicate, that sensing of the right atrium with a large dipole offers the possibility of driving the pacemaker with the potential from the high-anterior part of the right atrium. The table also indicates, that atrial low-posterior septal sensing conditions are not worse than those obtained during temporary location of the lead tip at the RAA and mid-CS, although the measured A/V amplitude ratio was most favorable during RAA sensing.

Sensing conditions at the CS-ostial region were evaluated via telemetry in UP and BP configuration after implantation of the pacing system. Automatic measurement only allows for evaluation of the first detected atrial potential in a cardiac cycle. Thus the CS ostium potential (A_2) was measured automatically in the UP sensing configuration and the high-anterior part of the right atrial potential (A_1) was measured in the BP configuration. The results of telemetric, automatic measurements of A-wave amplitude performed directly after implantation of the pacing systems are presented in Table 2. These results confirm the findings of our intraoperative studies: an A-wave (i.e., HRA potential) recorded via a ring electrode located in the upper anterior part of the right atrium possesses an amplitude (2.1 mV), that is sufficient to trigger septal pacing.

This pacing system offers the possibility of noninvasive IEGM recording via telemetry using the UP and BP configurations (Figure 5). The automatic mea-

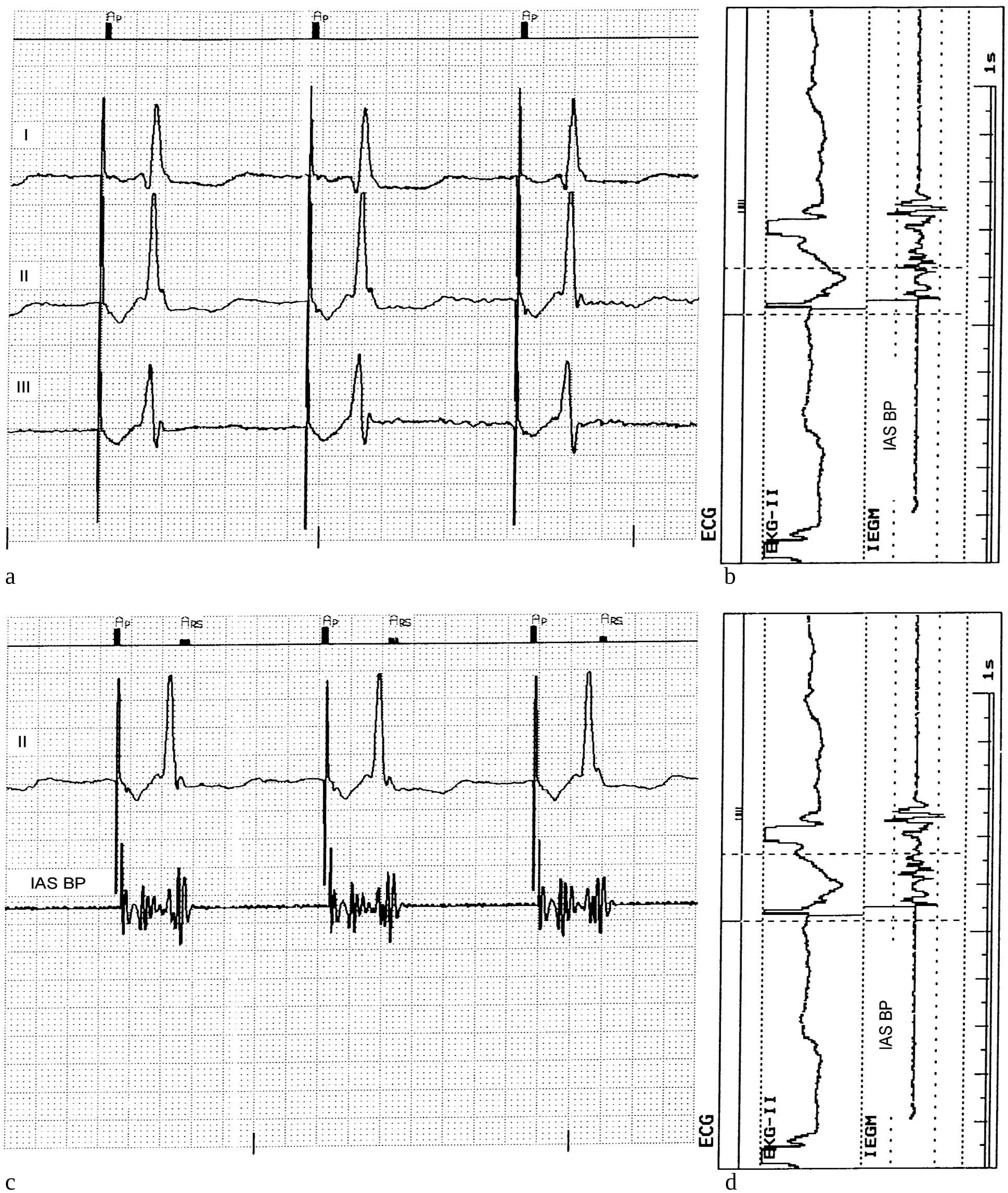

Figure 4. Data from intraoperative measurements; a) surface ECG; b) – d) event marker, the surface ECG lead II, and intracardial signal in bipolar sensing configuration (IAS BP). The figure shows effects of single site septal pacing. The location of the ring electrode enables detection of a delay in activation of the high right atrium during septal pacing. Paced P-wave duration and total time of activation of right atrium shows the same value = 137 ms (c); Intraatrial (retrograde) conduction time = 93 ms (b).

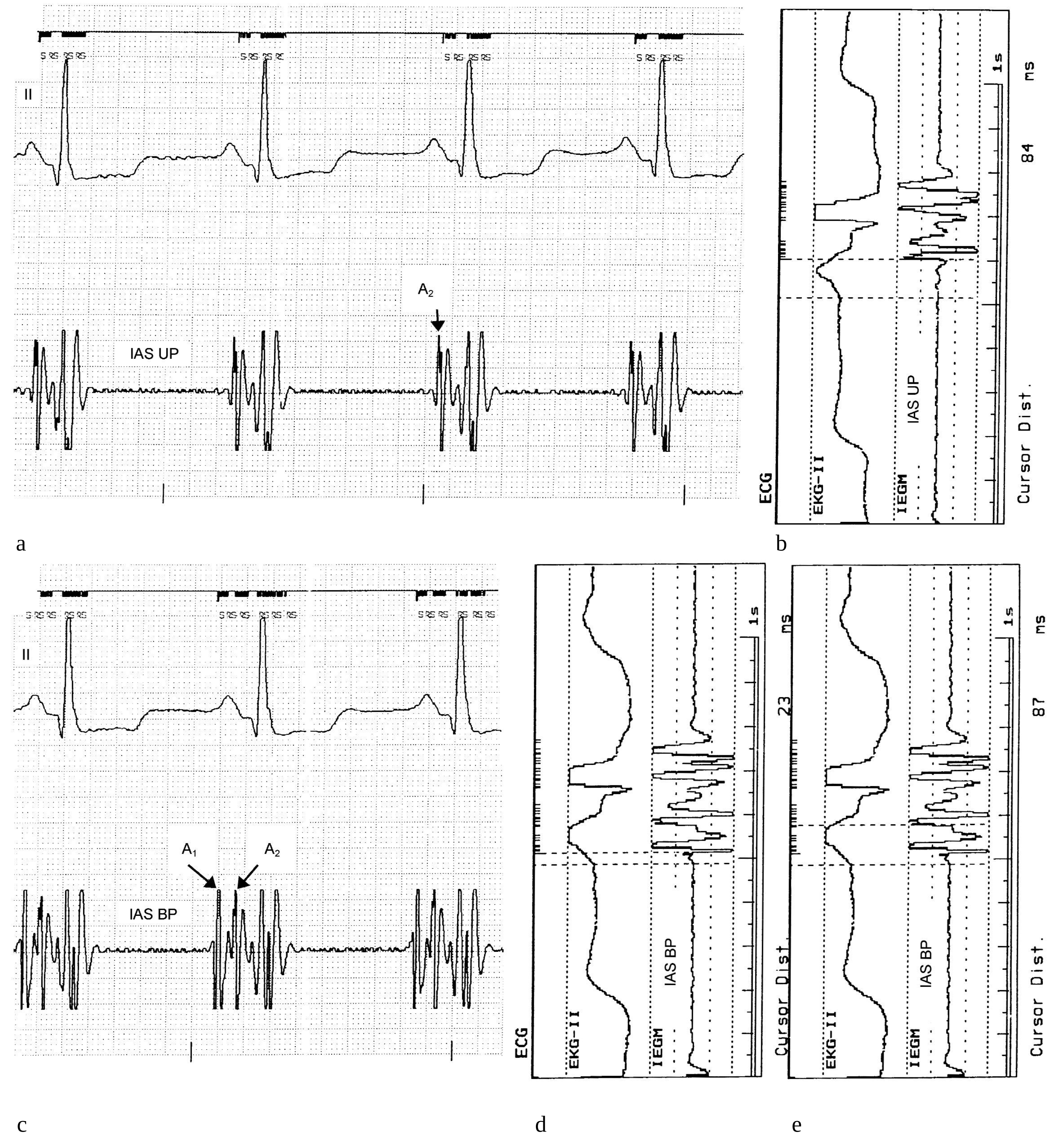

Figure 5. Postoperative measurements during sinus rhythm in the same patient as in Figures 3 and 4. Each panel shows the event marker, surface ECG lead II, and intracardiac signal from the atrial septum in the unipolar (IAS UP) or bipolar (IAS BP) sensing configuration. The local coronary sinus ostial region potential (A_2) is sensed 84 – 87 ms after onset of P-wave (b, e). This value represents the intraatrial conduction time. The location of the ring electrode (indifferent electrode) in the high right atrium enables the detection of a separate, additional A-wave (A_1) 80 ms earlier than the local potential in the coronary sinus ostial region (c, d, e), 23 ms delayed from the start of the P-wave (d). The amplitude of the first atrial (high right atrium) A-wave (A_1 potential) is equally suitable as the second A-wave for driving the pacer functions.

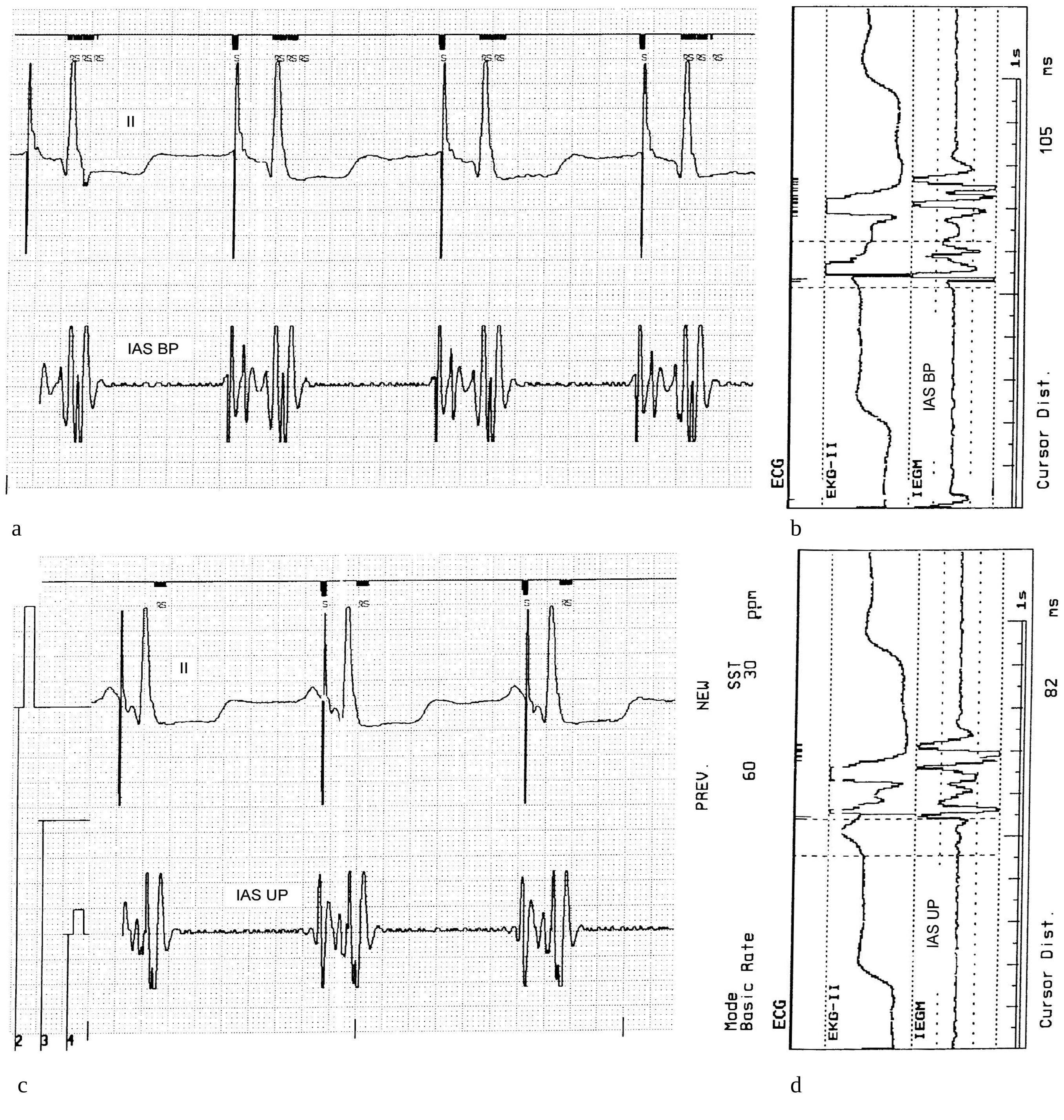

Figure 6. Postoperative measurements during triggered (SST) unipolar pacing mode in the same patient as in Figures 3 – 5. Each panel shows the event marker, surface ECG lead II, and intracardial signal from the atrial septum in unipolar (IAS UP) or bipolar (IAS BP) sensing configuration. The location of the spike indicates the moment of detection of excitation, in the high right atrium (a, b) and in the low-posterior septal region (c, d). Low-posterior septal pacing triggered by high right atrium potentials allows the attainment of a significant increase in atrial synchrony (see Figure 7 and Figure 8). The spike indicates the moment of detecting of excitation in the region of the coronary sinus os (c, d). Triggered pacing with local potential has no influence on atrial activation. The interval between the start of P-wave and the triggered pacemaker spike offers another means of evaluating the intraatrial conduction time (82 ms).

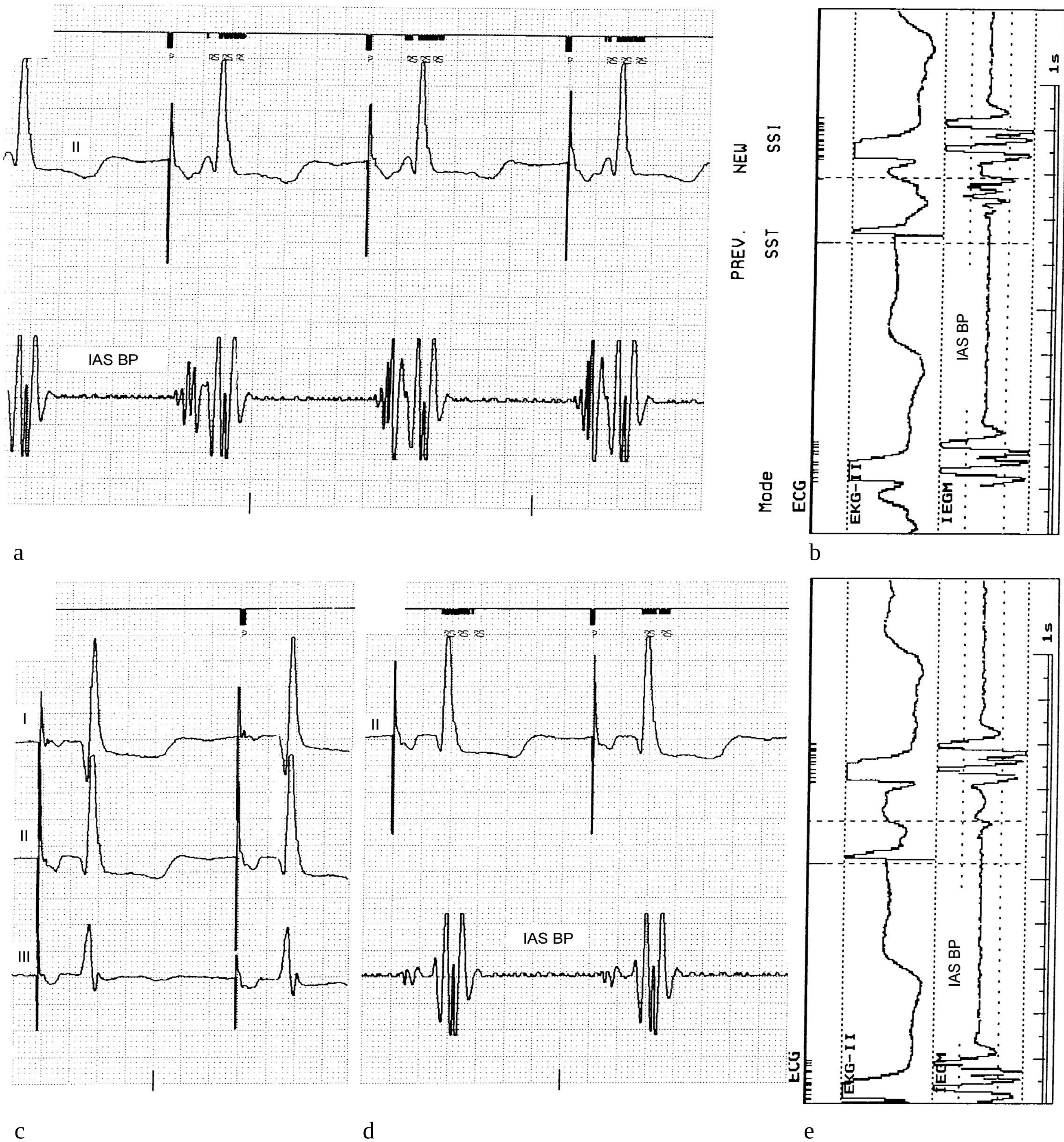

Figure 7. Postoperative measurement during septal unipolar pacing (85 beats/min) and bipolar (BP) sensing configuration in the same patient as in Figure 3. a) surface ECG. Other panels show event markers, surface ECG II, and intracardiac signals from the atrial septum in a bipolar sensing configuration (IAS BP). The location of the lead ring enables detection of intra-atrial delay during septal pacing (a). UP pacing P-wave duration and total time of activation of right atrium shows similar values of about 140 ms (b). Intraatrial (retrograde) conduction time = 70 ms. c), d) show different effects of pacing using BP configuration: bifocal pacing of right atrium. It was most libely due to the ring remaining in close contact to the atrial wall; these findings were found only in two out of ten examined patients. Bifocal RA pacing effected with very short duration of P-wave (90 ms) and total time of activation of right atrium (100 ms).

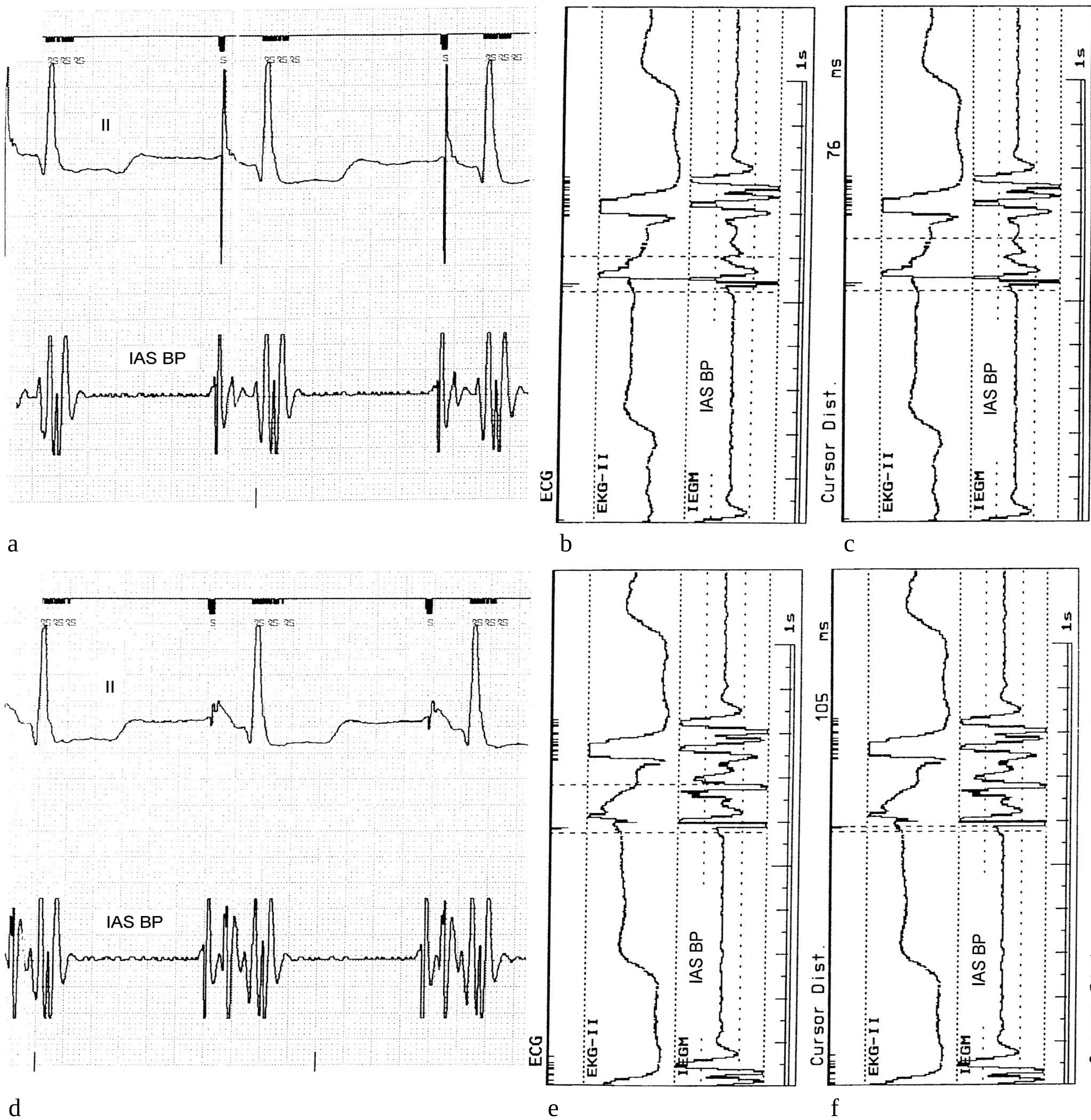

Figure 8. Postoperative measurements during triggerd (SST) unipolar pacing mode in the same patient as in Figures 3 – 7. In all panels event marker, surface ECG II, and intracardiac signal from atrial septum in bipolar sensing configuration (IAS BP) are shown. Capture (a, b, c) and non capture (d, e, f: unsuccessful pacing). The comparison of both panels clearly shows effects of low-posterior septal region pacing after detection of onset of atrial excitation. Different P-wave morphology and values of atrial timing parameters are visible. The figures confirm, that this pacing mode provides a more synchronous activation sequence of the atria in comparison to sinus rhythm.

surement allows only for the first potential in the cardiac cycle; during the first postoperative examination, we recorded IEGMs for manual measurement amplitudes both of atrial (A_1 and A_2) and ventricular (V) potentials. The analysis of the results is presented in Table 3. Postoperative examinations performed with IEGM recordings obtained via telemetry from the implanted pacing system generally confirmed the

		IAS UP A_2 amplitude (1)	IAS BP A_1 amplitude (2)	IAS BP A_2 amplitude (3)	RAA UP (4)	CS UP (5)
A amplitude (mV)	Mean	2.05	2.34	1.71	3.15	2.42
	SD	1.01	1.07	0.97	0.72	1.00
	Median	2.4	2.0	1.3	3.0	2.6
V amplitude (mV)	Mean	1.85	1.60	1.45	1.58	3.50
	SD	1.64	1.80	1.85	1.11	1.23
	Median	1.2	0.9	0.8	1.2	4.0
A/V ratio	Mean	2.5	3.32	2.43	4.60	0.78
	SD	3.64	4.48	3.00	6.16	0.39
	Median	1.3	1.8	1.0	2.2	0.9

a

		1 vs. 2	1 vs. 3	1 vs. 4	1 vs. 5	2 vs. 3	2 vs. 4	2 vs. 5
A amplitude	No. of pairs	7	7	6	7	7	6	7
	t	1.24	1.74	1.62	0.69	1.70	1.19	0.12
	P	0.259	0.131	0.144	0.513	0.139	0.285	0.903
V amplitude	No. of pairs	7	7	6	7	7	6	7
	t	1.33	1.52	0.62	4.46	1.00	0.23	3.94
	P	0.023	0.178	0.550	0.004	0.355	0.820	0.007
A/V ratio	No. of pairs	7	7	6	7	7	6	7
	t	2.16	0.20	1.95	1.29	1.38	1.55	1.53
	P	0.073	0.846	0.107	0.241	0.214	0.181	0.175

b

Table 1. Atrial potentials (panel a) and statistical evaluation (panel b) for different sensing locations: atrial septum in unipolar and bipolar configureation (IAS UP, IAS BP), right atrial appendage (RAA UP), and mid coronary sinus (CS UP) in unipolar sensing configuration.

results of our intraoperative measurements. Recorded as the first (in BP sensing configuration) HRA potential (A_1) shows a slightly lower amplitude (1.6 V) than that measured intraoperatively. Low-posterior septal potential (A_2) still shows an amplitude of about 2.0 mV during sensing in both UP and BP configuration. The A/V ratio remained sufficient in most pts (average > 2).

		UP (A_2 amplitude)	BP (A_1 amplitude)
A amplitude (mV)	Mean	2.00	2.06
	SD	0.72	0.92
	Median	2	2

		UP vs. BP
A amplitude (mV)	No. of pairs	9
	t	0.49
	P	0.633

Table 2. Postoperative automatically measured A-wave amplitudes (above) in unipolar (UP) and bipolar (BP) sensing configuration and statistical evaluation (below).

Table 3 presents the results of manual measurement of the A-wave amplitude from paper recordings. The results are comparable to those of the automatic measurement. Some differences between the analog results obtained using two different methods can be explained by the fact that in some of the records, parts of the A-waves recorded on paper were cut.

The important part of the study was evaluation of low-posterior septal atrial pacing conditions and the examination of whether the unconventional distance between the tip and ring of the modified lead deteriorates pacing conditions. Table 4 shows intra- and postoperative conditions of low-posterior septal region pacing. Intraoperative examinations were performed using a threshold analyzer, postoperatively via telemetry using a pacemaker programmer (threshold test and lead telemetry test). Table 4 indicates, that the values for the pacing threshold and impedance remained within acceptable limits (about 1 V) both intra- and postoperatively, and remained stable during the acute postoperative period. No significant differences between pacing characteristics in UP and BP configuration were

		UP	BP
A_1 amplitude (mV)	Mean		1.61
	SD		0.55
	Median		1.4
A_2 amplitude (mV)	Mean	2.04	1.96
	SD	0.35	0.37
	Median	2.2	2.1
V amplitude (mV)	Mean	1.61	1.10
	SD	0.69	0.62
	Median	1.8	1.0
A_1/V ratio	Mean	1.85	1.84
	SD	1.61	1.07
	Median	1.1	1.4
A_2/V ratio	Mean		2.22
	SD		1.04
	Median		2.4

	UP vs. BP	A_1 vs. A_2	A_1/V vs. A_2/V
A_1 amplitude			
No. of pairs		10	
t		1.92	
P		0.085	
A_2 amplitude			
No. of pairs	10		
t	1.80		
P	0.010		
V amplitude			
No. of pairs	10		
t	2.59		
P	0.028		
A_1/V ratio			
No. of pairs	10		10
t	0.02		1.92
P	0.984		0.086

Table 3. Postoperative measurement of atrial amplitudes (left) and statistical evaluation (right) from IEGM programmer print-outs.

observed. The results indicate that passing the ring electrode proximally into the inflow tract of the high part of the right atrium does not influence pacing conditions.

The last part of our examinations consisted of comparing the influences of different atrial pacing modes (RAA and CS pacing, low posterior septal pacing and low posterior septal pacing triggered with onset of atrial excitation) on intraatrial conduction and atrial activation parameters. Tables 5 and 6 show the analysis of the results which were obtained. During implantation of the atrial lead, its tip was temporarily introduced into the RAA and CS for evaluation and comparison of the effects of pacing before it was screwed into its final position in the CS-ostial region. Using the programmer's snapshot screen (gain 1 mV = 20 mm, speed 100 mm/s) we measured the P-wave duration and P-Q interval (spike-QRS interval respectively) intraoperatively using the cursors. The results and their statistical evaluation are presented in Table 5 (with examples in Figure 3). Table 5 shows, that low-posterior septal pacing does not prolong the P-wave duration in comparison to sinus rhythm (127 and 132 ms respectively). In contrast, RAA and CS pacing significantly prolong the paced P-wave duration (158 and 145 ms respectively) in comparison to both sinus rhythm and septal pacing. Atrial septal pacing significantly shortens AV conduction (spike-Q interval) in comparison to sinus rhythm (P-QRS interval) (144 and 171 ms respectively). In contrast, RAA pacing significantly prolongs the spike-Q duration (202 ms) in comparison to sinus rhythm, septal pacing, and CS pacing.

The study group consisted of patients with moderate atrial conduction disturbances. During sinus rhythm, the average P-wave duration was 129 ms (IACT), i.e., the interval from the start of the P-wave to the start of the A-wave recorded in the CS ostium region was 68 ms and the total time of activation of the right atri-

		Intra-operative		Post-operative	
		UP (1)	BP (2)	UP (3)	BP (4)
Pacing threshold (V)	Mean	0.8	1.1	0.9	0.9
	SD	0.3	0.8	0.6	0.4
	Median	0.9	0.8	0.8	1.0
Impedance (Ω)	Mean	395.1	477.9	381.2	452.5
	SD	81.1	95.1	66.4	70.5
	Median	420	504	376	465

	1 vs. 2	1 vs. 3	1 vs. 4	2 vs. 3	2 vs. 4	3 vs. 4
Pacing threshold						
No. of pairs	7	10	7	7	7	7
t	1.37	0.33	0.24	0.93	0.31	1.19
P	0.219	0.745	0.815	0.386	0.763	0.278
Impedance						
No. of pairs	7	10	7	7	7	7
t	2.36	2.35	0.07	1.13	1.10	2.47
P	0.055	0.042	0.943	0.3	0.313	0.048

Table 4. Acute and subacute interatrial septum pacing threshold and impedance values (left) and statistical evaluation (right) using screw-in leads.

	IAS UP pacing (1)	Sinus rhythm (2)	RAA UP pacing (3)	CS UP pacing (4)
P_{II} duration (ms)				
Mean	132.0	127.1	158.5	145.6
SD	16.3	10.8	28.3	14.5
Median	130	130	145	145
P-Q interval (ms)				
Mean	144.4	171.3	202.5	174.4
SD	22.6	12.5	28.3	39.4
Median	140	170	200	170

	1 vs. 2	1 vs. 3	1 vs. 4	2 vs. 3	2 vs. 4	3 vs. 4
P_{II} duration						
No. of pairs	8	8	8	8	8	8
t	0.61	2.81	1.88	2.89	2.91	1.10
P	0.550	0.026	0.100	0.023	0.022	0.306
P-Q interval						
No. of pairs	8	8	8	8	8	8
t	3.42	7.57	2.88	3.15	0.27	3.50
P	0.011	0.0001	0.023	0.015	0.79	0.009

Table 5. Intraoperative evaluation of electrophysiological effects of different atrial pacing modes. P-wave duration and P-Q interval duration (above) and statistical evaluation (below) of unipolar interatrial septum pacing (IAS UP), sinus rhythm (SR), unipolar right atrial appendage (RAA UP) pacing, and unipolar mid coronary sinus (CS UP) pacing.

um (TRAAT) was 132 ms. Figures 2 and 5 present typical examples of our findings. Low-posterior (UP) septal pacing causes a slight prolongation of the atrial conduction and activation times (Figures 4 and 7). Low-posterior septal pacing triggered by activation of the upper-anterior part of the right atrium (BP) resulted in significant shortening in comparison to sinus rhythm: P-wave duration (101 vs. 130 ms), P-Q interval and atrial pace spike-Q interval respectively (155 vs. 174 ms), and TRAAAT (114 vs. 131 ms) (Figures 6, 8, 9). The A_1-wave, which results from excitation of the anterior-superior part of the right atrium, was sensed approx. 14 ms after the start of the P-wave. After the next 4 ms, this potential showed sufficient amplitude to be detected with the pacemaker and to trigger delivery of an impulse (SST pacing with BP sensing configuration). Local low-posterior septal potential was detected at an average of 68 ms after the start of the P-wave (intraatrial conduction time); the potential within the next 9 ms showed a sufficient big amplitude to be detected by a pacemaker and to trigger an impulse (SST pacing with UP sensing configuration) (Figure 6). Table 6 indicates that low-posterior septal pacing triggered by activation of the upper-anterior part of the right atrium provides more synchronous atrial activation than can be observed during sinus rhythm or single-site low-posterior septal pacing (Figures 6 ,8, 9).

Discussion

All recent pacing systems for atrial resynchronisation have their own specific disadvantages [32-40]. The shared disadvantage of RAA-potential driven systems (Saksena's dual-site RA pacing, Daubert's and Markewitz-Osterholzer's biatrial pacing) is delayed sensing of atrial excitation (about 30 – 40 ms) and delayed pacing of the CS-ostial region or mid-CS [14,25-31,36,40]. Other disadvantages are the necessity of implanting two atrial leads, the inavailability of ventricular pacing in the Markewitz-Osterholzer system, and the necessity of "Y" connectors and potentially proarrhythmic anodal pacing [41-45] in Saksena's and Daubert's systems. Single-lead septal pacing systems (Padeletti) offer relatively symmetric atrial activation, but these systems work properly only during pacing [19-24]; new overdrive pacing algorithms ("consistent atrial pacing") can never provide 100 % paced beats and very early premature ectopic atrial excitations usually cannot trigger resynchronizing pacing [19-24]. "Missed" atrial premature beats are probably responsible for unsatisfied clinical effectiveness in some patients.

During the last 20 years, manufacturers of atrial leads concentrated on sensing the local atrial potential (in order to prevent accidental sensing of ventricular potentials) [46-48]. Narrowing of the sensing window was achieved by shortening the separation between the tip and ring of the atrial lead. Sensing of local RAA potentials is appropriate for driving ventricular pacing, but disadvantageous if atrial resynchronization is needed.

The pacing system proposed here seems to be very promising. It possesses the advantages of all multisite atrial pacing systems (triggered pacing with improved synchronisation of atrial activation) with the simplicity of single site pacing system. This system permits for early detection of atrial excitation, even slightly better than can be obtained in multisite pacing systems. The system allows for permanent pacing of the triangle of Koch region – the most common arrhyth-

	Sinus rhythm (1)	IAS UP pacing (2)	IAS BP SST pacing (3)	IAS UP SST pacing (4)
P_{II} duration (ms)				
Mean	129.6	134.2	101.0	
SD	13.0	14.2	16.6	
Median	130	135	100	
P-Q interval (ms)				
Mean	173.9	163.3	155.0	
SD	16.5	27.5	19.4	
Median	170	160	150	
$(P\text{-}A_1)/(P\text{-}S)$ ratio				
Mean	13.7		18.9	77.0
SD	6.8		12.1	25.4
Median	15		20	80
IACT (ms)				
Mean	68.0			
SD	22.5			
Median	70			
T_{RA} AT (ms)				
Mean	131.7	136.5	114.3	135.7
SD	24.3	25.4	15.1	23.6
Median	130	140	120	130

	1 vs. 2	1 vs. 3	1 vs. 4	2 vs. 3	2 vs. 4	3 vs. 4
P_{II} duration						
No. of pairs	10	10		10		
t	0.77	4.67		5.57		
P	0.460	0.001		0.0003		
P-Q interval						
No. of pairs	9	9		9		
t	1.33	4.38		1.41		
P	0.218	0.002		0.194		
$(P\text{-}A_1)/(P\text{-}S)$ ratio						
No. of pairs		10	10			10
t		1.30	7.73			6.74
P		0.224	0.00002			0.00008
IACT						
No. of pairs						
t						
P						
T_{RA} AT						
No. of pairs	10	10	10	10	10	10
t	0.65	2.88	0.61	2.55	0.09	3.75
P	0.528	0.018	0.555	0.030	0.925	0.004

Table 6. Postoperative evaluation of electrophysiological effects of different atrial pacing modes: sinus rhythm, unipolar atrial septum pacing (IAS UP), and atrial unipolar and bipolar septum pacing in SST pacemaker mode (IAS UP SST, IAS BP SST). P-wave duration, P-Q interval duration, $P\text{-}A_1$ interval/P-S interval ratio, intraatrial conduction time (IACT), and total time of activation of right atrium (TRAAT) are presented on the left and statistical evaluation on the right.

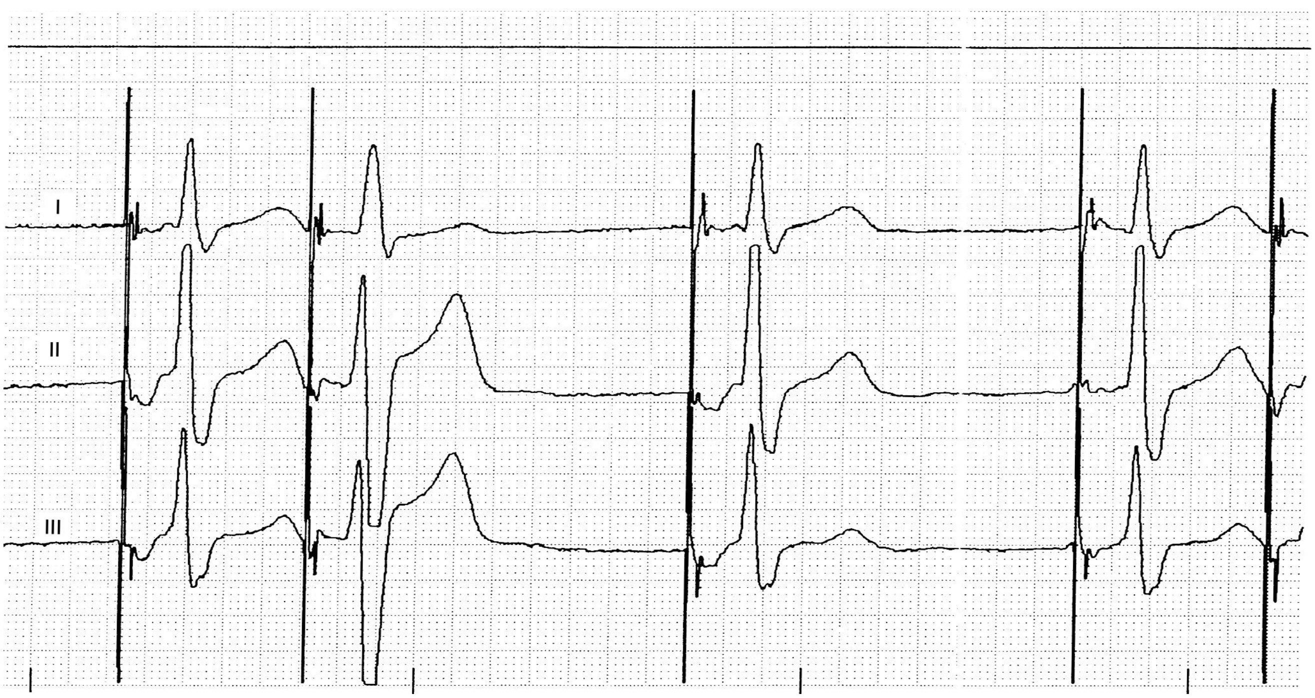

Figure 9. Surface ECG during postoperative examination in another patient (significant sinus bradycardia, numerous atrial premature beats) for triggered (SST) pacing with 60 beats/min. First beat: septal or more probably – bifocal RA pacing. Second beat: premature atrial beat excellently resynchronised by triggered (potentially bifocal) pacing. Third beat: septal pacing. Fourth beat: sinus excitation correctly triggering septal pacing. Last beat: premature atrial beat excellently resynchronised by triggered septal (potentially bifocal of right atrium) pacing.

mogenic area in the atria. And – what is more important – these effects can be obtained using units which only offer triggered pacing (SST). There are a lot of data showing that it can be as effective as Saksena's dual-site RA pacing system. Increasing the tip-to-ring separation did not lead to deterioration of sensing or pacing characteristics. Our first very promising experiences will have to be confirmed during EPS studies and in bigger groups of permanently paced patients.

Conclusion

- It is possible to obtain low-posterior atrial septal pacing triggered with onset excitation of right atrium using a single, special BP-lead with an indifferent (anodal) ring electrode located in the upper part of the inflow tract of the right atrium.
- Low posterior atrial septal pacing triggered with the onset of excitation of the right atrium offers better synchrony of atrial excitation than standard pacing in this region.

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