Resynchronizing and Antiarrhythmic Effects of High-Energy Bipolar Coronary Sinus Pacing

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Summary

Standard bipolar leads were implanted in the coronary sinus (CS) of 248 patients for left atrial or biatrial (BiA) pacing/sensing in combination with different pacing systems. The study showed that unipolar pacing from a mid CS position prolonged the P_{II}-wave duration (mean values from three different sets of measurements: 140 ms, 141 ms, 153 ms) when compared with the P_{II}-wave duration during sinus rhythm (mean values: 123 ms, 126 ms, 152 ms, respectively). High-energy bipolar CS pacing had a reverse effect – a reduced P_{II}-wave duration, with the mean values for the 2nd and 3rd set of measurement of 113 ms and 136 ms, as well as reduced total atrial activation time. These results suggest the possibility of real bifocal pacing (pacing the left atrium from the electrode tip and the basis of the right atrium from the ring electrode of the bipolar lead located in the CS ostium or the proximal part of the CS). Unexpectedly good clinical results reveal antiarrhythmic effect of high-energy bipolar CS pacing in recurrent atrial arrhythmias. In some patients with recurrent atrial arrhythmias and different degrees of interatrial block, only a partial resynchronization may be sufficient to achieve a satisfactory antiarrhythmic effect. These interesting bipolar CS pacing effects seem to indicate the future direction for atrial resynchronizing pacing modes in patients with interatrial block and/or recurrent atrial arrhythmias.

Key Words

Atrial resynchronization, coronary sinus permanent pacing, pacing energy effects

Introduction

Introduced in the late 1960s, the coronary sinus (CS) was the first site of permanent atrial pacing [1-5]. In the early 1970s, CS pacing was replaced (for a very long time) by right atrial appendage (RAA) pacing. However, some interesting observations about the electrophysiologic effects of CS pacing were made during this pioneer period. Moss et al. showed a shorter P-Q duration (the interval from P-wave to Q-wave for sinus rhythm, or from atrial pacing spike to Q-wave for CS pacing, respectively), if the CS was paced. The P-Q duration exhibited stable values during long-term CS pacing [1-3]. They recorded intracardiac electrograms (IEGMs) intraoperatively from the tip and ring electrodes of a bipolar (BP) CS lead and concluded that the distal IEGM (from the tip of the BP lead) represented terminal (presumably left atrial and ventricular) depolarization, whereas the proximal (ring) IEGM reflected the period of early repolarization [1]. To illustrate this, Figure 1 shows IEGM in different sensing configurations recorded in one of our patients. Moss' observations were confirmed by Greenberg's group several years later [4]: "Patients with normal spike-R interval tended to remain normal; those with prolonged intervals tended to remain the same or decrease to normal" [4]. Their very important conclusion (unfortunately forgotten for the next 20 years) was: "In patients with intermittent atrial fibrillation (AF), CS pacing can provide an atrial impulse that minimizes the tendency to return to AF" [4]. Both groups of authors used BP leads and non-programmable BP pacemakers of that time.

Atrial-based pacing modes and antiarrhythmic therapy lead to a significant reduction in atrial arrhythmia recurrences in most patients with brady-tachy syndrome. However, some papers reported cases where RAA stimulation was ineffective in the prophylactic

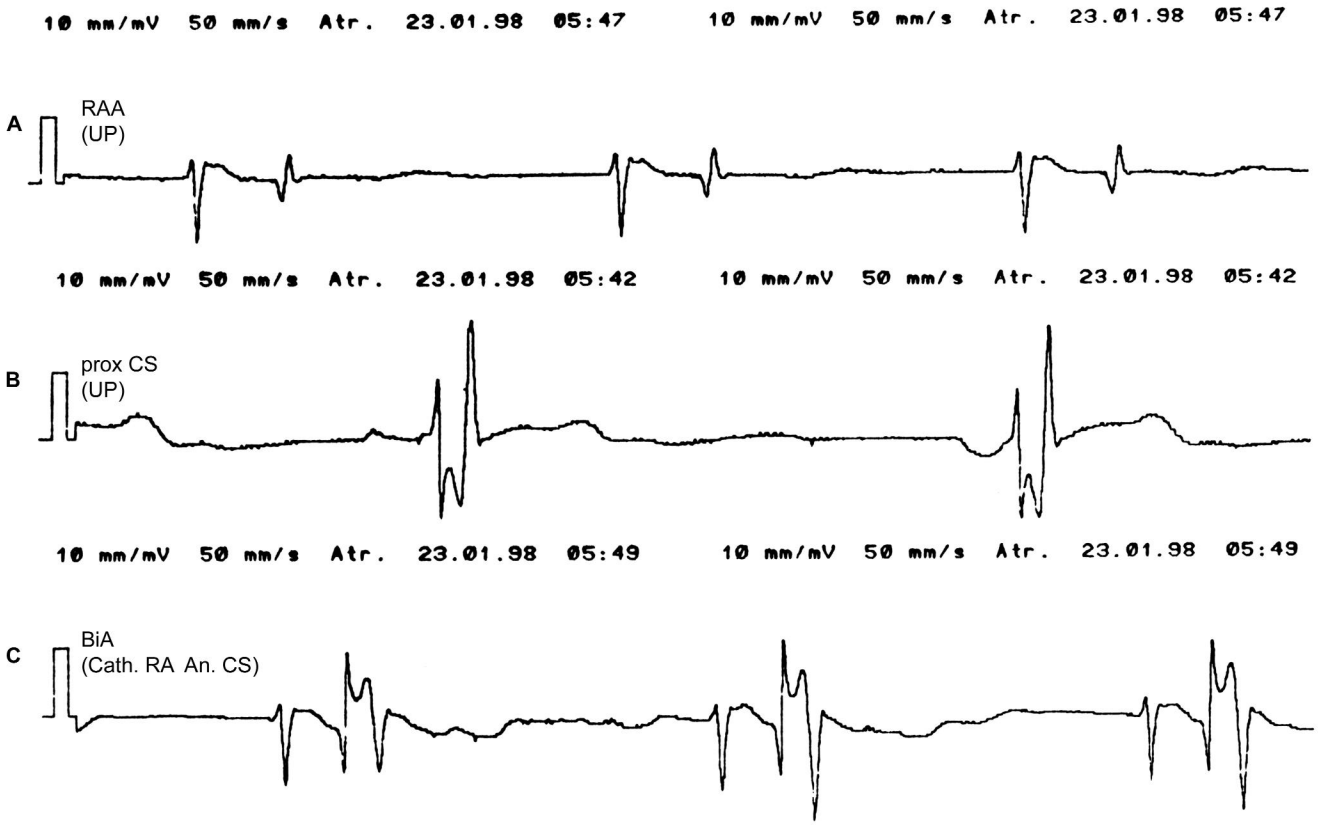

Figure 1. IEGM recorded during CS BP lead implantation in a patient with severe interatrial block. A: UP RAA IEGM. AV block I° is seen (only in the right heart). AV delay = 260 ms. B: UP proximal (ring) IEGM. Ultra short AV delay in the left heart (60 to 80 ms). C: BiA IEGM–BP sensing configuration. Interatrial conduction delay 140 ms.

treatment of arrhythmia or even increased arrhythmia recurrence [6-8]. A better understanding of the role of intraatrial and interatrial conduction disturbances as an underlying cause of atrial arrhythmias [9,10] promoted the use of pacing modes enabling atrial resynchronization [11-20]. Recently, it was shown that RAA pacing significantly increases interatrial conduction disturbances, expressed as prolongation of the P-wave duration in comparison to sinus rhythm [14,15,20-25]. From an intra- and interatrial conduction point of view, the lateral wall of the right atrium proved to be the least favorable place for atrial pacing [8,26-28]. For a more synchronous atrial activation, Daubert proposed biatrial (BiA) pacing as early as 10 years ago [11-12]. Later, Saksena suggested bifocal pacing in the right atrium [14-16]. Recently, Sopher [17], Spencer [18], and several other groups [19-21] proposed atrial anterior septal pacing, while Padetti [19] suggested posterior atrial septum pacing as the next resynchronizing mode of permanent atrial pacing. Our own group previously proposed two modifications of BiA pacing systems:

- to use a DDD pacemaker for BiA pacing from two separate pacemaker ports [22,23], or
- to use a modified Daubert's pacing system - the inverted split BP pacing system [24-26].

It is interesting that synchronizing BiA pacing with a DDD pacemaker was first introduced by Markewitz and co-authors [27] for recipient and donor atrial resynchronization in patients undergoing heart transplantation. All atrial resynchronizing pacing modes shorten the P-wave duration and significantly reduce atrial arrhythmia recurrence [10-23].

During the last 30 years, different leads have been used for permanent CS pacing. In the era of non-programmable pacemakers, Moss' and Greenberg's groups used mainly standard BP leads [1,2] or special CS Medtronic BP leads [3,4]. It was impossible to compare the effects of unipolar (UP) and BP CS pacing. Twenty years later, Daubert showed the feasibility of permanent CS pacing with standard J shaped BP leads

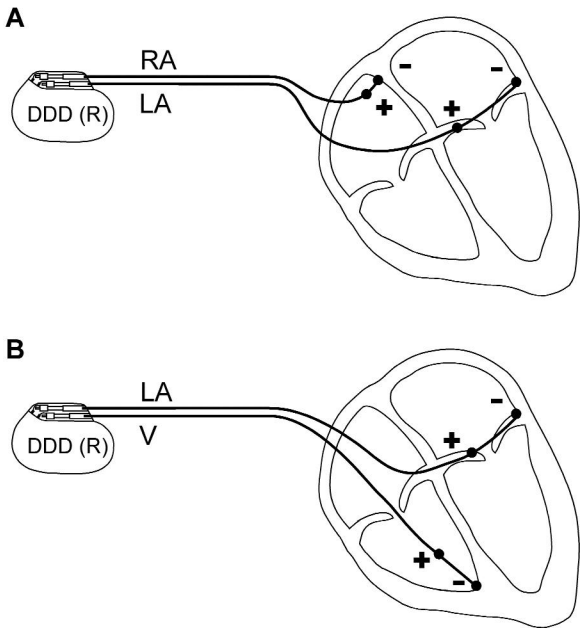

Figure 2. Two different atrial pacing systems allowing evaluation for UP and BP CS pacing and their effects evaluation and comparison.
A: BiA pacing system with DDD pacemaker. Separate atrial BP leads connected to atrial and ventricular pacemaker channel (AV delay 0 or 15 ms). RAA and left atrium (LA) can be paced in UP and BP configuration individually and its effects can be compared. This system allows simultaneous recording IEGM of both atria in separate channels during sinus rhythm and RAA (UP or BP), CS (UP or BP) or BiA pacing. Possible evaluation of timing from IEGM of opposite to paced atrium (TAAT). This connections allows more accurate "high-energy" BP CS pacing evaluation (Table 4, Figure 5 to 8).
B: DDD (AAI) pacing system with BP and UP CS pacing possibilitys. The CS lead is connected to atrial channel. Only left atrial (CS) IEGM in both sensing configuration can be recorded in atrial channel.

[28] connected to the BP port of a standard pacemaker, but he did not evaluate the differences in the effects of UP and BP CS pacing. During the following years, Daubert's group [11-13] used the split BP pacing system. Its technical configuration (the cathode and the anode of the same pacemaker port paced two different sites simultaneously [7]) made lone CS pacing impossible, and the effects of BP CS pacing could not be evaluated.

For the last 2 to 3 years, we have been using only standard (usually straight) leads for permanent CS pacing, conventionally connected to an SSI pacemaker or, sporadically, to the ventricular or atrial port of a DDD pacemaker [22,23]. This allowed CS pacing using UP and BP configurations (Figure 2). During ECG analysis of our first 20 patients, we found that the P_{II}-wave duration was shorter during BP than during UP pacing (average 117 ms vs. 138 ms), and that the P_{II}-wave amplitude of the negative phase was larger (0.11 mV and 0.16 mV, respectively) [29,30]. These interesting initial observations inspired us to compare electrophysiologic and clinical effects of permanent CS pacing in BP versus UP configuration. A secondary goal of this investigation was to evaluate the influence of pacing energy on the electrophysiologic and clinical aspects of lone BP CS pacing.

Materials and Methods

We complied with generally accepted indications for permanent CS pacing, such as technical problems with RAA pacing/sensing, hemodynamic indications (avoidance of DDD pacemaker syndrome in severe interatrial conduction disturbances), or/and antiarrhythmic indications [25, 31]. Three to four years ago, we preferred to implant a CS lead primarily due to technical reasons ("Y" connectors were not available on our market and CS lead dislocation occurred relatively frequently). Only in case it showed no antiarrhythmic effect, an additional RAA lead was implanted and permanent BiA pacing was introduced. In the last few years, we have been implanting BiA pacing systems more frequently as long as the indications were present [23,32].

We implanted BP leads into the CS in three groups of patients (Table 1):

Group I 97 patients without atrial arrhythmias, with an atrial lead implanted into the CS due to technical or hemodynamic indications (avoidance of pacemaker syndrome during DDD pacing due to interatrial block);

Group II 104 patients with recurrent (usually more than one per month) atrial arrhythmias and interatrial conduction disturbances (P_{II} > 125 ms);

Group III 47 patients with recurrent atrial arrhythmias, interatrial conduction disturbances, and normal AV conduction; all of them received BiA pacing systems with the CS lead connected mostly to the ventricular channel of the DDD pacemaker.

In cases of coexisting AV conduction disturbances, patients received DDD pacemakers with both atrial

Patients group	Group number	Number of patients	Gender		Age		Predominant indications for pacing			Kind of atrial arrhythmia		Pacing mode		
			m	f	range	mean (SD)	SND	BRT	AV block	AFL	AF	AAI	DDD	BiA
Only CS atrial lead atrial arrythmias-absent	I	97	51	46	21 - 79	70.1 (10.5)	40	-	54	-	-	37	60	-
Only CS atrial lead brady-tachy syndrome	II	104	41	63	40 - 93	71.2 (10.8)	-	104	-	37	67	66	38	-
RAA and CS leads brady-tachy syndrome	III	47	25	22	52 - 89	69.6 (8.3)	-	47	-	32	15	-	-	47
Summary of groups		248	117	131	21 - 93	70.0 (7.2)	40	151	54	69	82	103	98	47

Table 1.General information about the three groups of patients studied. Predominant indications for pacing were sinus node dysfunction (SNS), brady-tachy syndrome (BRT), and AV Block. Atrial arrythmias were divided into atrial flutter (AFL) and atrial fibrillation (AF). Pacing modes were AAI, DDD, and biatrial (BiA).

leads connected to the atrial port via the split BP configuration [32]. This connection made CS pacing in the BP configuration impossible [26], and all these patients had to be excluded from the study.

The examinations (excluding follow-up) were mainly performed several days after implantation of the pacing system and during the patient's stay in hospital. We examined the P_{II} or P_{III} duration manually from paper recordings (gain 0.05 mV/mm, paper speed 50 mm/s) or automatically on the monitor screen using cursors (frozen picture of 100 mm/s recordings). Simultaneously with the ECG, we telemetered the IEGM from the left atrium or from both atria; the latter was possible only in patients with BiA pacing systems. Simultaneous sensing of both atria allows evaluation of the total atrial activation time (TAAT), i.e. the time from the recorded onset of spontaneous atrial excitation or from an atrial pacing spike to the end of the atrial propagation wave.

Results

Table 2 shows electrophysiologic effects of UP and BP CS pacing using ordinary pacing energy levels in 221 patients (usually, pacing output was programmed to a double value of pacing threshold). The results were obtained from patients in all three groups. The data indicate that CS pacing in the UP configuration significantly prolongs P_{II}-wave duration and compare the

	Number of patients		P_{II}-wave duration (ms)	P-Q interval (ms)	P_{II}-wave amplitude of negative phase (mV)
Sinus rhythm	221	mean	123.4	197.6	-
		± SD	25.9	43.7	-
		median	120	190	-
Unipolar CS pacing	221	mean	140.0	211.9	1.10
		± SD	29.8	53.0	0.69
		median	140	200	1.0
Bipolar CS pacing	221	mean	125.8	196.5	1.64
		± SD	32.2	51.6	0.74
		median	120	185	1.5

		P_{II}-wave duration	P-Q interval	P_{II}-wave amplitude of negative phase
Sinus rhythm versus unipolar CS pacing	No. of pairs	219	195	-
	t	8.256	6.542	-
	P <	0.00000	0.00000	-
Sinus rhythm versus bipolar CS pacing	No. of pairs	217	198	-
	t	1.530	1.102	-
	P <	0.127	0.919	-
Unipolar CS pacing versus bipolar CS pacing	No. of pairs	208	190	171
	t	9.102	11.307	13.152
	P <	0.00000	0.00000	0.00000

Table 2. Data and statistical analysis in 221 patients from all groups I to III for routine unipolar and bipolar coronary sinus (CS) pacing. The P-Q interval is measured from P-wave to Q-wave for sinus rhythm, and from atrial paced spike to Q-wave otherwise.

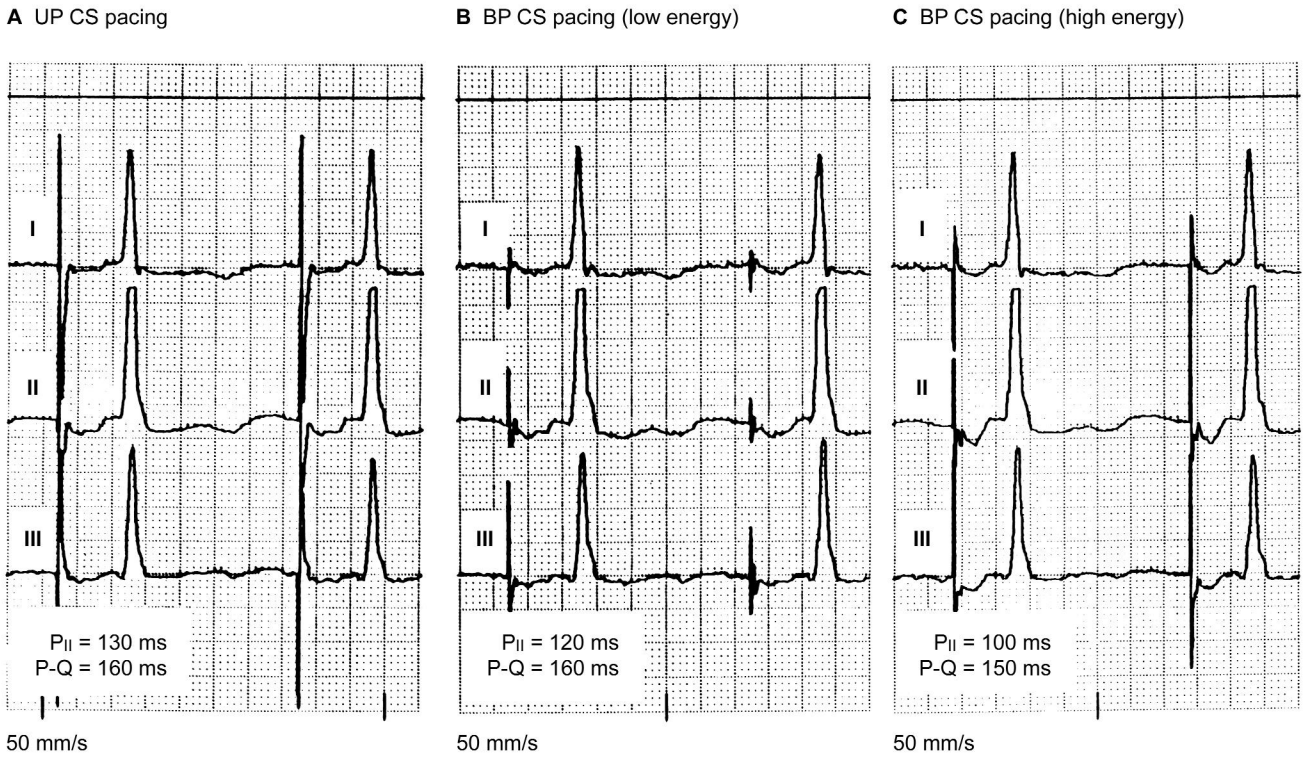

Figure 3. Classical recording of ECG leads I to III in a patient with the BP lead located in the mid CS. Different program configuration; A, B: "low-energy" pacing = pacing with energy slightly above the pacing threshold (usually 2 to 4 V/0.5 ms). C: "High-energy" pacing = pacing with energies 2 to 3 times above the pacing threshold (usually 4.8 to 7.2 V/ 0.5 to 0.75 ms). P_{II}-wave duration shortening (from 130 to 100 ms) is accompanied by a slight P-Q reduction from 160 to 150 ms (interval from atrial paced spike to Q-wave).

interval from atrial pacing spike to QRS complex to sinus rhythm. BP CS pacing does not have similar effects; P_{II}-wave duration and the atrial pacing spike-QRS complex interval remains unchanged. The morphology of paced P_{II}-waves was different, too – the amplitude of the negative phase during BP CS pacing was significantly larger (Figure 3).

The observed phenomena inspired us to perform additional examinations to rule out mere coincidence or illusion. In 163 selected patients from groups I and II, we compared the effects of BP CS pacing at different pacing outputs:

- at "threshold output" slightly above the pacing threshold, and
- at "maximal output", which was usually 7.2 V at 0.75 ms (Table 3, Figure 4).

The idea of high-energy CS pacing was born 2.5 years ago; the "energy test" was introduced as routine for patients with atrial leads in the CS, and it served only for evaluating the paced P-wave morphology. This test was performed in 164 patients and in 34 patients it was impossible due to various reasons: the necessity of reoperation and change of pacing mode to BiA (DDD), BiA or three-chamber (with split BP lead configuration in the atrial channel), due to chronic AF, missed controls, or patient death. These results corroborated conclusions drawn from Table 2 on the presence of significant differences between the electrophysiologic effects of UP and BP CS pacing, even when threshold energy was used for BP CS pacing. Additionally, we found that high-energy BP CS pacing significantly improves the synchrony of atrial excitation as the P_{II}-wave becomes shorter and the amplitude of the negative phase larger.

It may be misleading to judge the possibility of atrial resynchronization without simultaneous recording of A-waves from both atria, which can be performed only in patients with BiA pacing systems. In our 47 patients with BiA pacing systems (group III), a similar "energy test" was performed, the results of which were compared not only to respective findings during sinus rhythm, but also to that for lone RAA pacing. Due to

	Number of patients		P_{II}-wave duration (ms)	P-Q interval (ms)	P_{II}-wave amplitude of negative phase (mV)
Sinus rhythm (test 1)	163	mean	126.1	193.3	-
		± SD	27.4	34.7	-
		median	120	185	-
Unipolar CS pacing (test 2)	163	mean	140.8	204.5	1.17
		± SD	27.3	42.4	0.73
		median	140	200	1.2
Bipolar CS pacing					
Threshold amplitude (1.0 - 3.2 V) (test 3)	163	mean	131.1	193.1	1.43
		± SD	26.3	42.9	0.68
		median	140	190	1.5
Maximum amplitude (7.2 - 8.0 V) (test 4)	163	mean	112.9	177.1	1.78
		± SD	24.4	40.9	0.73
		median	110	170	1.6

		P_{II}-wave duration	P-Q interval	P_{II}-wave amplitude of negative phase
Test 1 versus test 2	No. of pairs	163	154	-
	t	7.710	5.380	-
	P <	0.00000	0.00000	-
Test 1 versus test 3	No. of pairs	163	153	-
	t	3.299	0.267	-
	P <	0.001	0.790	-
Test 1 versus test 4	No. of pairs	149	139	-
	t	5.067	6.797	-
	P <	0.00000	0.00000	-
Test 2 versus test 3	No. of pairs	164	154	121
	t	6.459	7.364	4.721
	P <	0.00000	0.00000	0.00000
Test 3 versus test 4	No. of pairs	150	140	122
	t	12.172	10.597	9.257
	P <	0.00000	0.00000	0.00000

Table 3. Data and statistical analysis in 163 patients from groups I and group II for coronary sinus (CS) pacing using different modes and pacing amplitudes. The P-Q interval is measured from P-wave to Q-wave for sinus rhythm, and from atrial paced spike to Q-wave otherwise.

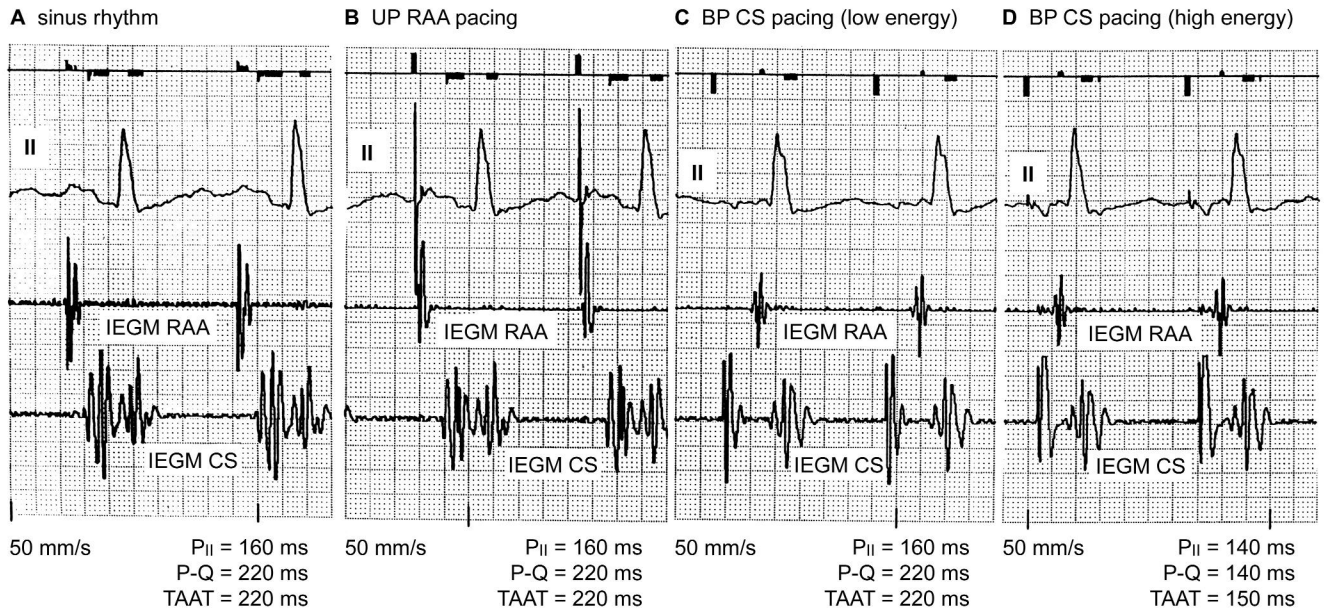

Figure 4. Patient with severe interatrial block and BiA pacing system implanted due to recurrent atrial arrhythmias. The RAA BP lead is connected to the atrial port, and the standard BP CS lead, to the ventricular port of the DDD pacemaker. This system enables simultaneous RAA and CS IEGM recording in separate channels. Observe the different P_{II}-wave morphology and duration recorded during different pacing programs. The TAAT was measured from the onset of the sinus or paced PII-wave to the end of the A-wave (IEGM) in the later activated atrium. During sinus rhythm and RAA pacing (Figures 4A and 4B), the right atrial A-wave appears first; during CS pacing, the left atrial A-wave showed first in the lower "ventricular" channel. Note the significant shortening of the P_{II}-duration (160 vs. 140 ms) and the TAAT reduction (220 vs. 150 ms) when RAA pacing was changed to high-energy CS pacing. The P-Q interval is measured from P-wave to Q-wave for sinus rhythm, and from atrial paced spike to Q-wave otherwise.

	Number of patients		P_{II}-wave duration (ms)	P-Q interval (ms)	TAAT (ms)
Sinus rhythm (test 1)	48	mean ± SD	151.1 30.9	196.2 37.4	193.7 27.9
Unipolar pacing					
RAA (test 2)	48	mean ± SD	165.6 20.1	232.9 39.6	225.8 33.0
CS (test 3)	48	mean ± SD	153.1 28.8	213.6 46.9	196.2 37.6
Bipolar pacing					
CS low energy (test 4)	48	mean ± SD	145.6 30.5	195.0 40.8	191.2 40.3
CS high energy (test 5)	48	mean ± SD	136.0 30.1	177.0 29.4	176.7 35.3

	Parameter	P_{II}-wave duration	P-Q interval	TAAT
Test 1 versus test 2	No. of pairs t P <	45 3.665 0.0007	45 9.138 0.00000	43 9.068 0.00000
Test 1 versus test 3	No. of pairs t P <	41 1.276 0.200	47 4.036 0.0002	41 0.373 0.711
Test 1 versus test 4	No. of pairs t P <	39 0.417 0.679	39 0.300 0.770	35 0.045 0.965
Test 1 versus test 5	No. of pairs t P <	25 2.070 0.049	25 2.631 0.015	18 2.143 0.047
Test 2 versus test 3	No. of pairs t P <	43 2.195 0.034	43 3.009 0.004	43 5.307 0.00000
Test 3 versus test 4	No. of pairs t P <	41 1.914 0.063	41 5.218 0.00000	35 0.999 0.325
Test 3 versus test 5	No. of pairs t P <	25 2.628 0.015	25 7.461 0.00000	18 3.289 0.004
Test 4 versus test 5	No. of pairs t P <	25 1.999 0.057	25 5.270 0.00002	18 4.173 0.0006

Table 4. Data and statistical analysis in 48 patients from group III with biatrial pacing systems. The P-Q interval is measured from P-wave to Q-wave for sinus rhythm, and from atrial paced spike to Q-wave otherwise.

technical problems (pacemaker dependence, "electrode conflict" in an older pacemaker generation, etc.), it was not possible to perform all tests in all patients. Table 4 indicates that RAA pacing significantly prolongs the pacing spike – QRS interval, P_{II}-duration, and TAAT, not only in comparison to sinus rhythm, but to UP CS pacing as well. When pacing at threshold energy, slight resynchronizing effects were observed in this group of patients, too, if the most sensitive and (in our opinion) most valuable parameter, the TAAT, was considered. Our examinations confirmed marked resynchronizing effects of high-energy BP CS pacing as compared to sinus rhythm, RAA, and threshold energy CS pacing.

According to the Daubert's concept of atrial resynchronization with BiA pacing [11], we primarily

Arrhythmias before implantation	Number of patients
sporadic (< 1/month)	57 54.8 %
frequent (> 1 week, < 1 month)	37 35.6 %
incessant (> 12/24 hours)	2 1.9 %
chronic AF reversion	8 7.7 %
total	104 100 %

Pacing conditions after 6 month	Pacing modus	Number of patients
good	active atrial pacing (> 80 bpm)	73 85.9 %
	slow atrial pacing (< 60 bpm)	8 9.4 %
high threshold	triggered ventricular pacing (VDD)	1 1.2 %
	chronic appearance of frequent arrhythmias (pacing/sensing impossible)	3 3.5 %
total		85 100 %

Table 5. Information about 104 patients from group II with brady-tachy syndrome permanently paced from the coronary sinus (CS).

	Oberservation period						
	1 week	1 month	2 month	3 month	4 month	5 month	6 month
No. of patients	101	94	88	85	84	77	70
No. of documented arrhythmias between the follow-ups	41	17	22	24	26	15	10
Total no. of patients without recurrence of arrhythmias	88 87 %	82 87 %	75 85 %	76 89 %	73 86 %	68 88 %	61 87 %
Supgroup of patients without antiarrhythmic drugs	29 29 %	14 15 %	25 25 %	41 48 %	38 45 %	29 38 %	28 40 %

Table 6. Arrhythmias and usage of antiarrhythmic drugs during a 6-month follow-up period in 101 patients from group II with brady-tachy syndrome.

inserted standard BP leads in the proximal or middle part of the CS in 104 patients with brady-tachy syndrome and recurrent atrial arrhythmias (group II). Placement of an additional right atrial electrode for BiA pacing was planned in patients with frequent recurrences of arrhythmia. This was necessary in only 13 (12.5 %) cases; the rest revealed unexpectedly good results. Important information about group II is presented in Table 5. Due to certain pacing problems, not all patients could be "continuously" paced (using relatively high basic rates and aggressive rate-adaptive sensor programming). This fact could have unfavorable influence on long-term clinical effects.

Good or very good effects observed during long-term follow-up in most of our 101 patients who were paced from the CS using mid or high energy BP stimulation support the hypothesis that BP CS pacing has an antiarrhythmic effect (Table 6).

A simultaneous analysis of Tables 5 and 6 indicates that during a 6-month follow-up period:

- 61 patients were free from arrhythmia recurrence, 28 of which were free from antiarrhythmic therapy;
- 13 patients received an additional RAA lead for institution of BiA pacing;
- in 3 patients an irreversible form of AF developed; and
- 16 patients missed the 6-month endpoint control (2 non-cardiac deaths, 12 unsatisfactory cooperation).

Discussion

The presented results confirm our earlier observations [33-35] that BP CS pacing with medium or high pacing energies exerts a slight resynchronizing effect. A significant shortening of the P-wave duration during high-energy CS pacing suggests the possibility of true bifocal pacing (of the left atrium from the tip of the lead, and of the basis of the right atrium from the ring of the BP lead located in the vicinity of the CS ostium or in the proximal part of the CS). Using high pacing energy in the CS in a BP configuration is relatively simple method, although slightly less effective than the BiA mode of atrial resynchronization.

The resynchronizing effects of high-energy, standard BP CS pacing are comparable to the results of CS pacing using OLBI system [36]. The mechanism of this slight resynchronization can only be speculated about: a bigger mass of atrial wall may be excited or it may be the result of a true bifocal pacing. The last concept is

	P_{II}-wave duration	Interatrial conduction time
Sinus rhythm		
Number of patients	38	54
mean (ms)	123	102
References	[14, 15, 19, 21]	
High RA pacing		
Number of patients	46	72
mean (ms)	137	127
References	[14, 15, 19, 20, 21]	

Table 7. Electrophysiologic effects of high right atrial (HRA) pacing on P_{II}-duration and interatrial conduction time. Metaanalysis from literature is presented.

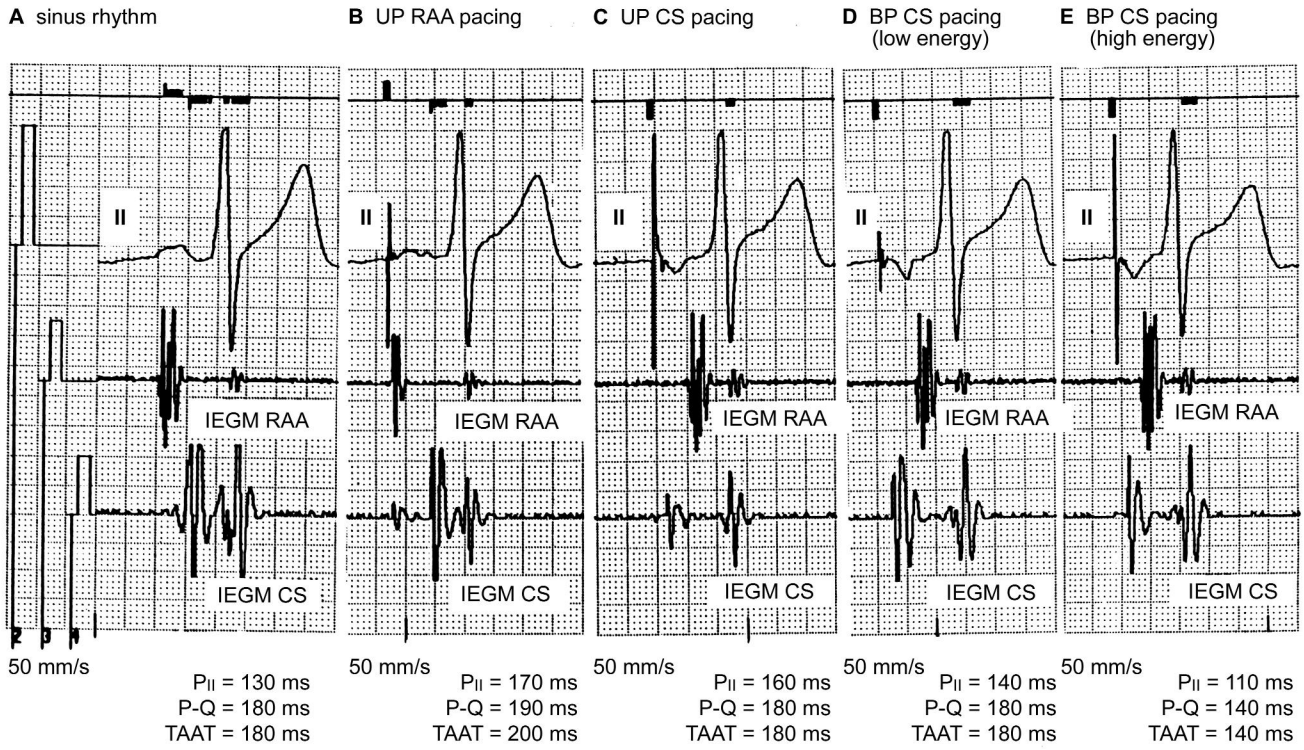

Figure 5. Patient with frequent recurrence of atrial fibrillation, moderate interatrial block (more visible in the IEGM – the TAAT is 180 ms), and BiA (DDD pacemaker) pacing system. Effects of different pacing modes are shown. A significant prolongation of the P_{II}-wave (from 130 to 170 ms) and the TAAT (from 180 to 200 ms) is seen if classical RAA pacing was switched on. High-energy CS pacing shortened P_{II} (110 ms) and TAAT (140 ms) not only in comparison to right atrial pacing (170 and 200 ms, respectively), but also to sinus rhythm (130 and 180 ms, respectively). The partial resynchronizing effect of high-energy CS pacing is seen. The P-Q interval is measured from P-wave to Qwave for sinus rhythm, and from atrial paced spike to Q-wave otherwise.

more likely. In individual patients, we never observed a linear shortening of the P-wave or/and TAAT duration during pacing with increasing energy. It always happened after crossing a certain "synchronizing threshold" energy; after which further increase in energy had no effect on the P-wave duration or TAAT. On the other hand, in a small group of patients with a very high CS pacing threshold (7.2 to 9.2 V), an additional increase in energy by pulse width prolongation never showed a synchronizing effect. We can only speculate that additional anodal ring CS pacing is one of the mechanisms underlying the observed phenomenon. Histological examinations have shown that the proximal part of the CS (first 4-7 cm) is surrounded by a muscular cuff, which originates not only from the left atrium [37], but also from the inferior portion of the right atrium and from subendocardial tributaries of the interatrial septum. Multiple connections are regularly observed between these muscle fibers and the left atrial myocardium [38].

Our findings confirmed earlier observations of Man et al. [39] that a larger P_{II} amplitude of the negative phase (0.21 mV vs. 0.16 mV) and a shorter P_{II}-wave duration (118 ms vs. 129 ms, respectively) were associated with proximal CS pacing using high energy than with distal CS pacing with low energy in the UP configuration.

It is known that conventional atrial-based pacing modes may reduce atrial arrhythmia recurrence significantly in about 80 % of patients with brady-tachy syndrome. On the other hand, RAA pacing can also increase the occurrence of arrhythmia, especially if the right atrial free wall is paced, or in patients with severe interatrial block. We examined several publications related to the electrophysiologic effects of the right atrial pacing and provided a brief metaanalysis of the published data in Table 7. The table shows unfavorable

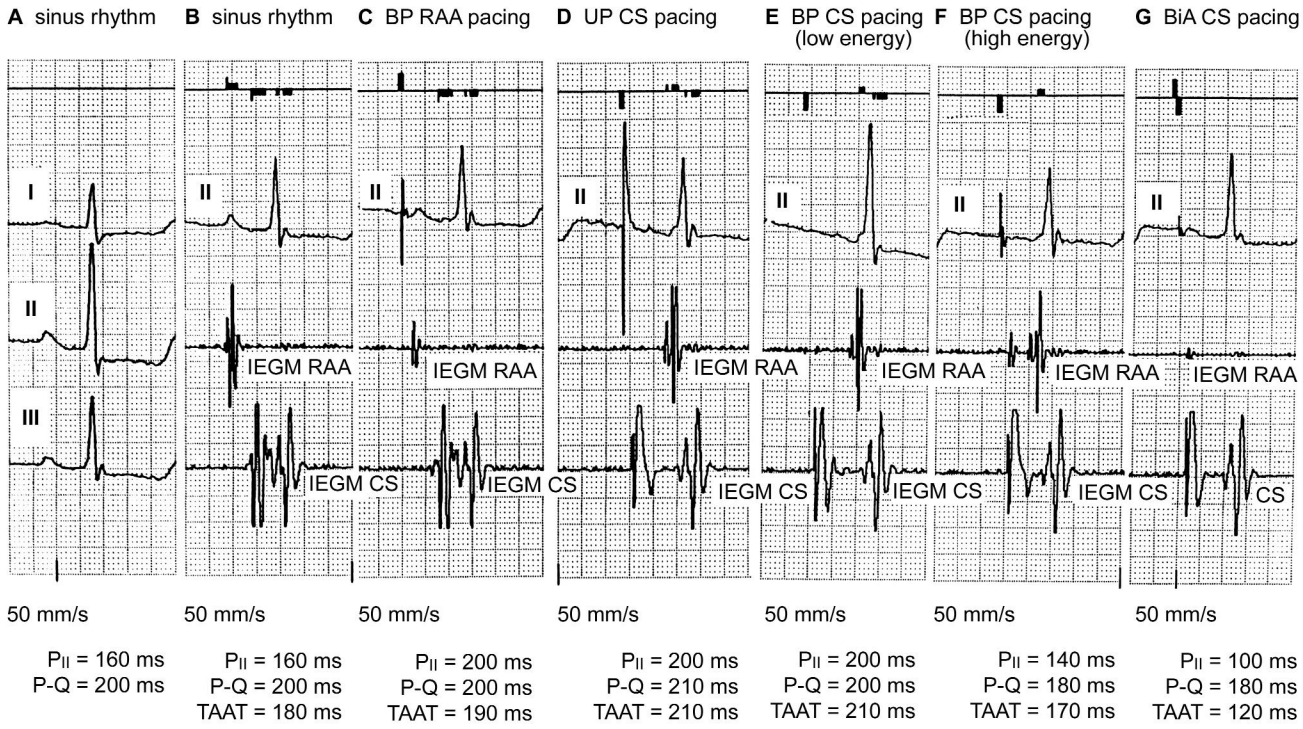

Figure 6. Patient with significant interatrial block (P_{II} = 160 ms, TAAT = 180 ms) and recurrent atrial flagellation episodes. RAA pacing increased P_{II} (200 ms) and TAAT (190 ms) duration (Figure 6C). Distal UP and low-energy BP CS pacing showed the same effect (Figure 6D and 6E). High-energy BP CS pacing (Figure 6F) provided only a very slight resynchronization (shortening of the P_{II}-duration to 140 ms and the TAAT to 170 ms). In this individual patient, only simultaneous BiA pacing (programmed minimal AV = 15 ms) is effective for P_{II} and TAAT normalization (full resynchronization). A distal (as in this individual patient) CS lead position and small distance between tip and ring of the CS lead minimizes the resynchronizing effect of high-energy CS pacing. The P-Q interval is measured from P-wave to Q-wave for sinus rhythm, and from atrial paced spike to Q-wave otherwise.

effects of high right atrial pacing compared to sinus rhythm in patients with brady-tachy syndrome with or without interatrial conduction disturbance: a longer P_{II}-duration (137 ms vs. 123 ms), a longer interatrial conduction time (136 ms vs. 98 ms), and a longer conduction time to the distal CS (127 ms vs. 102 ms). The results are similar to our results from several previous [22, 40, 41] and the present study (Figures 5-7). The suggested slight resynchronizing effect of high-energy BP CS pacing is one of the possible explanations for its antiarrhythmic effect. Improved AV synchrony on the left side of the heart and favorable secondary hemodynamic effects [17] are other possible explanations. Several other interesting electrophysiologic studies may contribute to the clarification of the mechanism of the antiarrhythmic effect of CS pacing. Giatanidou et al. showed that "high right atrium (HRA) stimulation induces a higher degree of interatrial conduction delay zone and prolongs maximal conduction delay as compared to CS or BiA stimulation, which may explain why AF is more easily initiated from HRA than CS" [42]. Hill et al. drew a conclusion from his studies that "with right atrial premature beats, a greater reduction of coupling window (of AF initiation) is observed when CS site is preexcited, which indicates that CS pacing may be more protective against AF induction" [43]. Last year, Yu et al. proved that even distal CS pacing shortens atrial conduction time, and that this pacing mode prevents induction of AF by right atrial extrasystoles [44]. Ng et al. presented similar results. They showed that lone CS pacing resulted in an increase in the coupling interval of capture premature impulses (S2) at the high right atrium without induction of AF or repetitive atrial response [45]. This year, Ishimatsu et al. demonstrated absence or narrowing of the repetitive atrial firing zone, fragmented atrial activ-

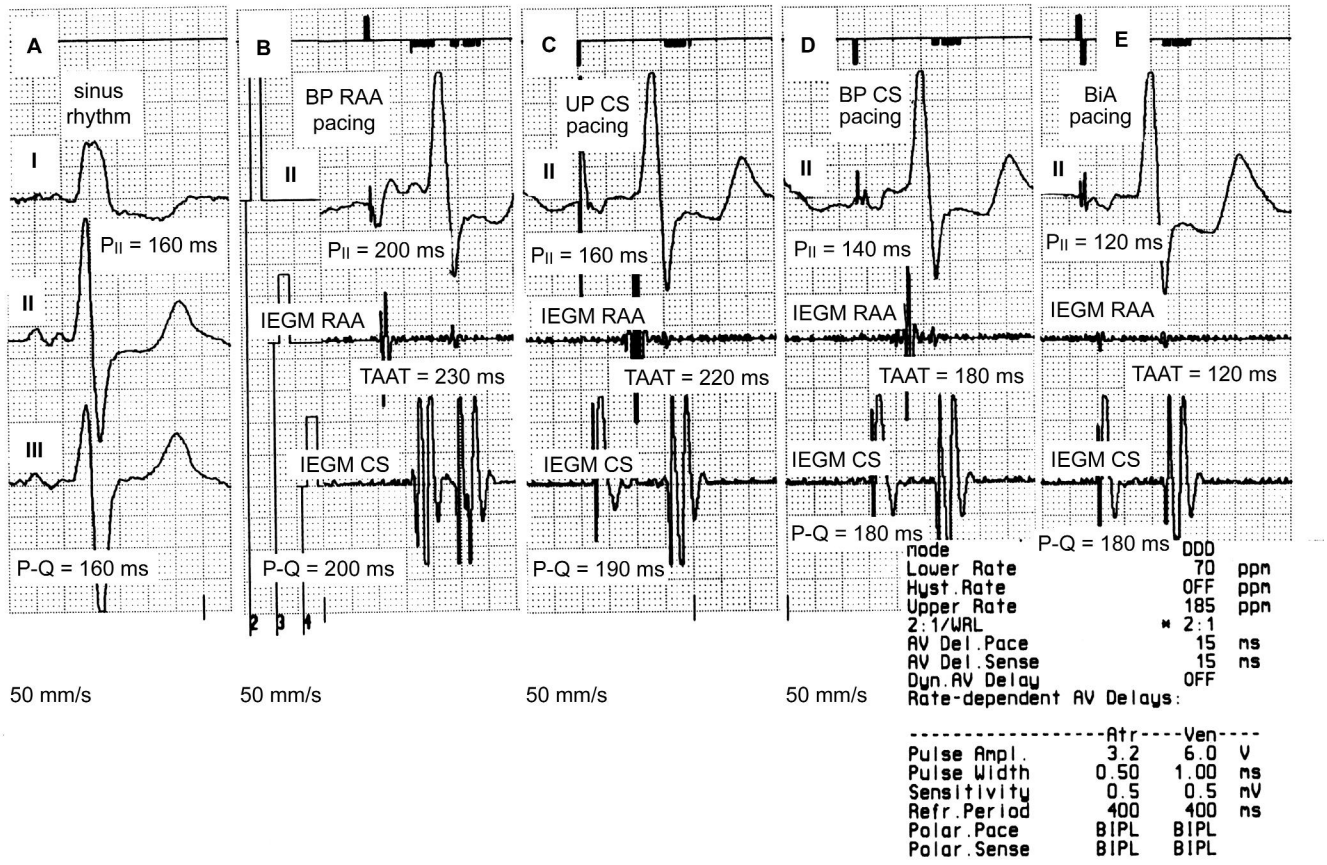

Figure 7. Patient with severe interatrial block, frequent recurrence of atrial flatter, and BiA (DDD) pacing system. Note the significant prolongation of P_{II}-duration if RAA pacing (Figure 6B) was switched on (from 160 to 200 ms), and its very significant shortening (140 ms) if CS BP high-energy CS pacing was programmed (Figure 7D). Full resynchronization was obtained only during BiA pacing (DDD program with AV delay 15 ms). It is important to remember that the simultaneous recording of both intraatrial signals (TAAT) is more valuable than the P_{II}-duration only for evaluating the degree of atrial resynchronization (see similar P_{II} morphology and different RAA A-wave timing in Figures 7D and 7E). The P-Q interval is measured from P-wave to Q-wave for sinus rhythm, and from atrial paced spike to Q-wave otherwise.

ity zone, and conduction delay zone, and normalized values of the effective refractory period during CS pacing in patients with AF. He concluded that CS pacing significantly decreases vulnerability to AF and indirectly suggested the possibility of using CS pacing for the prevention of AF [46].

All these results show that CS remains an interesting, valuable site for permanent atrial pacing/sensing in patients with atrial arrhythmias. If the observed P_{II}-wave shortening (also expressed as the TAAT in IEGMs) is not an illusion, if it really shows partial atrial resynchronization, and if the observed unexpected antiarrhythmic effect of BP CS pacing with moderate or high energy turns out to be constant, we believe that this mode of permanent atrial pacing will be a promising pacing mode in selected patients with brady-tachy syndrome. Furthermore, our findings seem to indicate direction that future development of permanent BiA pacing systems should take: there are indications for BP pacing from the left atrial channel. This solution introduces the possibility of trifocal atrial pacing.

Conclusions

- BP CS pacing leads to a more synchronous atrial activation in comparison to sinus rhythm, RAA pacing, and UP CS pacing, especially when higher pacing energies are used;
- BP pacing of the mid part of the CS with relatively high energy may have some resynchronizing and antiarrhythmic effects;
- In some patients with recurrent atrial arrhythmias and

different degrees of interatrial conduction disturbances, only partial resynchronization may be sufficient to achieve satisfactory antiarrhythmic effect.

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