What is the Optimal Configuration for Permanent Biatrial Pacing?

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Summary

Biatrial pacing has become an accepted non-pharmacological treatment for the prevention of reentrant atrial arrhythmias in patients with interatrial conduction disturbances. However, the optimal lead configuration and connection remain an open question. Simultaneous pacing of both atria using a cathodal current (split with a Y connector), which avoids anodal pacing, will probably replace the split bipolar configuration that is currently the most popular. A common anode location and its influence on the effectiveness of biatrial pacing were previously not evaluated. Twelve patients were implanted with a biatrial pacing system based on commonly accepted criteria. A standard J-shaped bipolar right atrial lead and a bipolar coronary sinus designed lead were used. We examined the threshold, pulse amplitude, impedance, and energy consumption parameters during split bipolar and dual cathodal pacing of both atria, using different locations of the common anode and different coronary sinus lead connections. Standard pacemakers and programmers were used for a more exact evaluation of the pacing conditions. The results show that there are big differences in the effectiveness of biatrial pacing in individual patients depending on the pacing mode (split bipolar or dual cathodal bipolar), and whether the proximal or the distal ring of the coronary sinus lead are used as a cathode or an anode. A detailed analysis led us to several general and specific conclusions: The coronary sinus offers sensing conditions comparable to those in the right atrial appendage, but coronary sinus pacing consumes several times as much energy in permanent pacing. The bipolar configuration offers more favorable pacing/sensing conditions than unipolar coronary sinus pacing. The dual cathodal bipolar pacing configuration is generally not worse than a split bipolar configuration for permanent biatrial pacing. Locating the common anode in the proximal ring of the coronary sinus lead allows a significant improvement of the effectiveness of biatrial pacing in the dual cathodal bipolar configuration in most patients (without significant influences on the sensing conditions). The marked differences in coronary sinus pacing conditions in some patients (when comparing proximal and distal coronary sinus ring electrodes) indicate the necessity for an exact evaluation of biatrial pacing conditions (threshold pulse amplitude, impedance) using different lead connections. Selecting the most favorable pacing configuration for each patient individually is also necessary. There is no universal optimal configuration for permanent biatrial pacing. Available hardware has to permit for optimal lead connections and leads for permanent biatrial pacing in each patient.

Key Words

Biatrial pacing effectiveness, biatrial pacing configurations, coronary sinus pacing

Introduction

The role of intra-/interatrial conduction disturbances (IACD) as an important and relatively common substrate of recurrent atrial reentrant arrhythmias (including atrial flutter and fibrillation) was shown many years ago [1,2]. Only multisite (resynchronizing) atrial pacing modes created new therapeutic options for these patients. In 1994, Daubert (in Rennes, France) proposed a biatrial (BiA) pacing configuration, and Saksena and Prakash (in New York, USA) introduced a dual-site right atrial pacing configuration [3,4].

Early and long-term results of both research groups were very promising: 50 to 60 % of the patients remained free of arrhythmia and did not need drug treatment [5-8]. In 20 to 30 %, the frequency of arrhythmia recurrences decreased significantly; and only in 20 to 30 % of the patients, either atrial resynchronization did not change the frequency of arrhythmia recurrence or the patients showed permanent atrial fibrillation.

Special pacemakers for BiA pacing are currently not available on our market and therefore we had to use standard devices. The most popular lead connection for BiA pacing remains the split bipolar (SBP) configuration [3-8]. In this unique configuration, a Y connector enables the connection of the cathode to the tip of a standard right atrial unipolar (UP) lead and of the anode to another atrial lead with its tip located in the coronary sinus (CS) ostium region [4,6,8] or the mid (less frequently proximal or distal) CS [3,5,7]. This pacing/sensing configuration allows for excellent sensing of both atria and effective resynchronization by pacing (if the AAT mode is used), even during sinus rhythm and premature ectopic excitations from the right or left atrium [3-8]. One disadvantage of this configuration (with the electrodes connected in series) is a high global impedance and relatively high pacing threshold values [9-16]. Another disadvantage consists in the necessity of anodal pacing, because it has been known since the early 1970s that anodal pacing is generally worse compared to cathodal pacing [17,18]. Recently, Stokes and Kay presented current knowledge about the differences of cathodal and anodal pacing conditions and their electrophysiologic effects [19]. There are three main differences between cathodal and anodal pacing conditions and effects:

- a higher pacing threshold during anodal pacing,
- special arrhythmogenic anodal current properties (shorter atrial effective refractory period for anodal pacing), and
- an increased tip corrosion rate caused by the anodal potential, especially when the tip has a small surface area. The last point is no longer very important.

Also, rings of standard bipolar (BP) leads are usually large enough (with a surface area of over 50 mm^2) to prevent dangerous (tachyarrhythmia generating) accidental anodal pacing. All knowledge about the electrophysiologic effects of anodal pacing was obtained during ventricular pacing, and it has not been proven (nor excluded) that these results can be extrapolated to atrial pacing.

These doubts inspired Cazeau to propose a different lead connection for multisite cardiac pacing - the dual cathodal unipolar (DUP) configuration. Leads are connected in parallel and together to the cathode of the pacemaker's atrial port, using a UP-UP Y connector (Figure 1), and the pacemaker case plays the role of common anode [20]. This BiA pacing configuration offers worse atrial sensing conditions due to real UP sensing of both atria; pectoral myopotentials can be sensed if the sensitivity is programmed too high. Global resistance and pacing threshold values are relatively low, but the energy consumption is significantly higher than for the SBP configuration [11-13,15,16]. In cases of high left atrial pacing thresholds, the capacity of a standard pacemaker may not be sufficient to guarantee the programmed high voltage output [21]. The main advantage of the dual cathodal UP configuration remains avoidance of anodal pacing and its proarrhythmic properties.

We began BiA pacing four years ago [22], and we have shown the usefulness of our modification of Daubert's SBP BiA pacing configuration. Inversion of lead polarity and cathodal CS pacing improves the left atrial pacing effectiveness by decreasing the pacing threshold values and energy consumption and minimizing the risk of left atrial capture loss during BiA pacing [10,14]. Other multiple examinations that we conducted

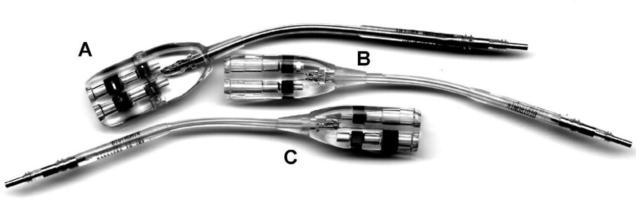


Figure 1. Different Y connectors (all Biotronik, Germany) for pacing of both atria using the atrial channel of a standard DDD pacemaker (or SSI pacemaker). A: real Y BP: BP + BP connector for dual cathodal BP pacing/sensing. Cathodes in "distal" and anodes in "proximal" position (standard); if right atrial lead is UP, the proximal ring of the CS lead plays the role of common anode. B: Y connector for split BP pacing (BP: cathode UP + anode UP); only "distal" positions (tip of leads, distal ring) can be used. We must select which atrial lead connects to the cathode and which one to the anode. C: Y connector for SBP pacing (BP: cathode UP + anode UP); anode can be connected to "distal" position (tip of right atrial lead) and cathode to "proximal" position (proximal ring of the CS lead).

Figure 2. The new CS-designed lead Corox and, for comparison, a standard J-shaped BP lead, the Synox (all Biotronik, Germany). A 6 cm long, electrically inactive strand (with longer and stronger tines than standard ones) permits anchoring the tip of the lead in the narrow cardiac vein and prevents its dislodgement. Two narrow, fractal coated rings serve for pacing/sensing of the left atrium from the mid part of the CS.

Recently, we showed the feasibility of a new CS-designed lead for permanent BiA pacing [24,25]. The lead contains two ring electrodes and different connections offer the possibility of pacing two different places of the CS (Figures 2, 3 and Table 1). Additionally, one of the two ring electrodes of the CS lead can serve as a common anode.

There are several open questions that are important from a practical point of view:

- Are there any significant differences in pacing effectiveness between SBP and dual cathodal configuration if the ring of the right atrial lead replaces the pacemaker case as the anode?
- Does the proximal or the distal ring of the CS-designed lead offer better pacing/sensing conditions, and which one is more useful for the SBP and the dual cathodal BiA pacing configuration?
- Can the use of one of the two rings of the CS lead as a common anode improve left atrial pacing effectiveness and reduce the energy consumption in the dual cathodal BP BiA pacing?
- What is the optimal location of the common anode in the dual cathodal BiA pacing configuration?

The main aim of the study was to answer a still open general question: What is the optimal configuration for permanent BiA pacing?

confirmed Moss' and Greenberg's old idea that the CS can be effectively paced from the ring electrode [9,10,14]. Cathodal ring pacing of the proximal part of the CS eliminates the risk of accidentally pacing the ventricle with an anodal current (there is a slight possibility of this if the distal part of the CS is paced). Recently Bennet confirmed the potentially proarrhythmic property of anodal current if enough energy is applied [23]. It can be suspected that even right atrial appendage (RAA) anodal pacing can trigger atrial arrhythmias during unsensed atrial beats due to the possibility of pacing during the effective atrial refractory period. These concerns renewed an interest in a dual cathodal configuration for permanent BiA pacing. Most likely, this theoretically safer but more energy-consuming system will be used more frequently. The long, large area of the ring electrode of the RAA lead can serve as the common anode (Figure 2, Table 1).

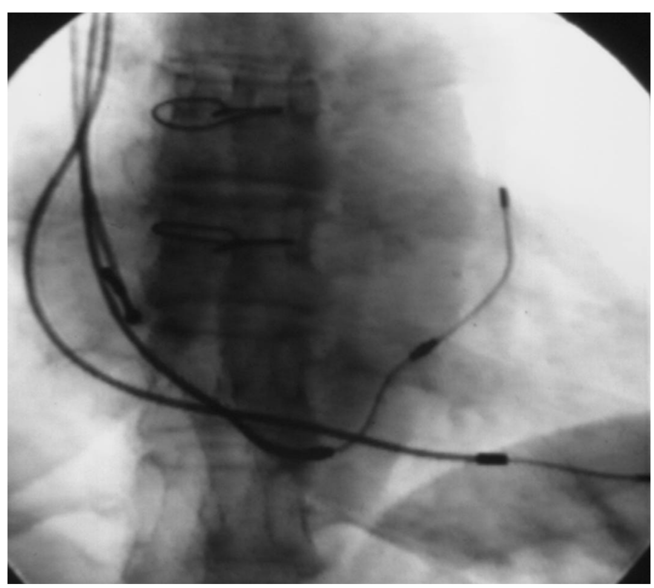


Figure 3. The new CS-designed lead by Biotronik in a BiA pacing system.

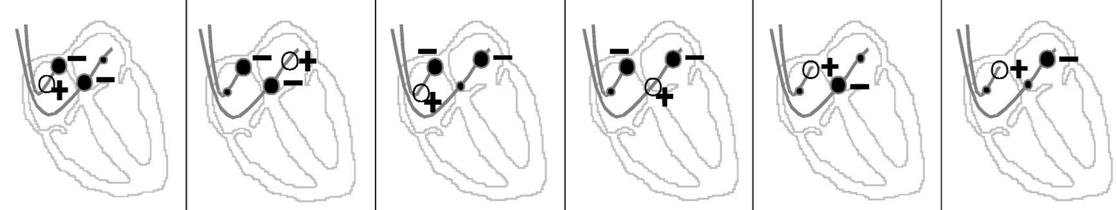
BiA pacing mode	Dual cathodal BP configuration (both atrial cathodal electrodes connected in parallel anode - ring of atrial lead)				Split bipoles configuration (electrodes in series)	
Cathode	RA tip and CS proximal ring		RA tip and CS distal ring		CS proximal ring	CS distal ring
Anode	RA ring	CS distal ring	RA ring	CS proximal ring	RA tip	RA tip
						

Table 1. Cathodal and anodal electrode connections and configurations during simultaneous pacing of both atria using different BiA pacing systems.

PART ONE

Right and left atrial pacing/sensing conditions

Methods

In 12 patients (6 male, 6 female, age 52 to 76 years, mean age 66.4 years) with IACD (P_{II} over 125 ms) and recurrent atrial arrhythmias, we examined the pacing/sensing conditions from the tip of the RAA lead, and the proximal and distal ring of the CS lead in UP configuration (Table 2) during implantation of a BiA pacing system (10 patients) or during re-operation (2 patients). Finally, we examined the same parameters of CS pacing/sensing conditions in the BP configuration. We used the external threshold analyzer ERA 300 B (Biotronik, Germany). In all patients, we recorded the IEGM on paper (for manual measurement of the A- and V-wave amplitudes and to calculate the AV ratio).

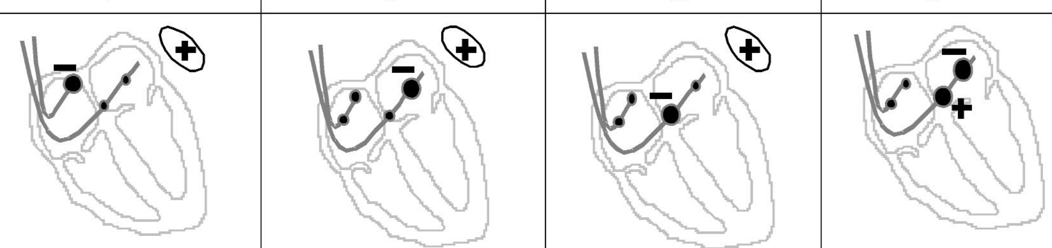
Atrial pacing / sensing mode	RA UP pacing / sensing	CS pacing / sensing		
Cathode location	tip of RA lead	distal ring of CS lead	proximal ring of CS lead	distal ring of CS lead
Anode location	pacemaker pocket			proximal ring of CS lead
Polarity	UP			BP
No. of BiA pacing configuration	I	II	III	IV
Hardware: ERA 300 automatic measurement and IEGM paper records				

Table 2. Electrode connections during evaluation of unifocal right and left atrial pacing/sensing conditions.

Pacing/sensing configuration					
Cathode		RA tip	CS ring distal	CS ring proximal	distal CS ring
Anode		pacemaker pocket			proximal CS ring
No. of BiA pacing configuration		I	II	III	IV
A wave amplitude (mv)	mean	2.57	2.88	3.27	2.43
	sd	1.97	2.52	3.27	2.43
Pacing threshold	mean	0.60	2.44	2.57	2.27
	sd	0.37	1.59	2.51	1.65
Threshold current (mA)	mean	0.77	5,10	5.41	4.33
	sd	0.68	3.91	2.52	2.46
Impedance (Ω)	mean	695.10	438.90	368.50	588.30
	sd	235.10	95.70	58.20	123.00
A wave amplitude (printout IEGM) (mV)	mean	2.80	3.22	2.33	3.80
	sd	1.48	1.67	1.72	1.45
V wave amplitude (printout IEGM) (mV)	mean	1.73	3.00	3.34	2.29
	sd	0.57	0.91	1.00	0.95
A/V ratio	mean	1.80	1.19	1.21	2.11
	Sd	1.03	0.82	1.03	1.84

Table 3. Comparison of unifocal right and left atrial pacing/sensing conditions.

Results and Interpretation

The results are presented in Table 3.

The table indicates that the RAA offers the most favorable values of acute pacing/sensing conditions. The CS sensing conditions were generally better in the BP sensing configuration if the AV ratio was used as the criterion. Acute CS pacing threshold and energy consumption parameters were 4 to 5 times higher than during RAA pacing (the pacing threshold was about 2.5 V, and the threshold current, about 5 mA).

Comments

In most patients, we used high impedance (5 patients) or standard impedance (3 patients) leads (SX or PX 53 BP, Biotronik, Germany) for RAA pacing. This fact explains the relatively high impedance and low energy demand of RAA pacing. For CS pacing, we used the new CS-designed lead by Biotronik (Figure 2) in most patients. The smaller area of its distal ring (and its shape) can explain its slightly better pacing conditions and higher impedance in comparison to the larger proximal ring. Our findings are in accordance with the general consensus that the BP atrial sensing configuration offers detection of more local potentials and a much more favorable AV ratio (Figures 4 and 5).

It is important that lead stability and pacing threshold values were regarded as the main criteria for the final CS lead location; sensing conditions played only a minor role.

PART TWO

What is the optimal configuration for permanent BiA pacing?

The general aim of this part of the study was to evaluate and compare the pacing conditions during different modes of BiA pacing. Detailed goals of this study included answering questions that are important from a practical point of view:

- Is the proximal or the distal ring of the CS lead more useful for permanent BiA pacing in the split BP and the dual cathodal BP configuration?
- Does the common anode location (ring of the right atrial lead or proximal or distal ring of the CS lead) have an influence on BiA pacing effectiveness (pacing threshold values and energy consumption)?
- Which system is most useful and effective for permanent BiA pacing?

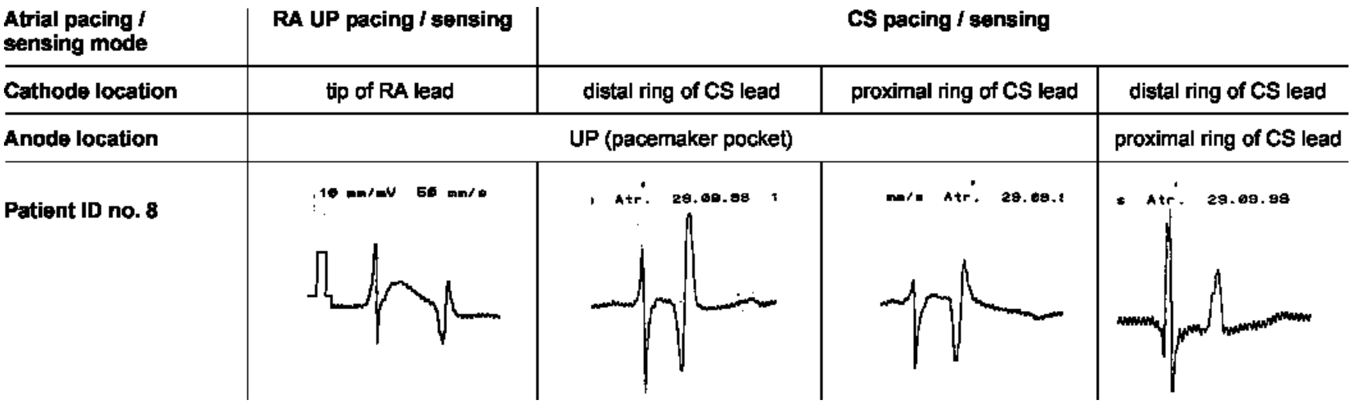


Figure 4. Examples of IEGMs recorded after final right atrial and CS lead placement. All records were made using the external threshold analyzer (ERA 300 B); standard recording conditions were a gain of 1 mV = 10 mm and a paper speed of 50 mm/s. The CS offered sensing conditions comparable to those of right atrial sensing, but a more favorable AV ratio was found in the RAA IEGM recordings.

Methods

The second part of the study was performed with the same patients during the same operations. Effectiveness of the different modes and configurations of BiA pacing were examined and compared. All examined pacing configurations are presented in Table 1.

The sensing conditions could not be evaluated exactly using those configurations - only the A wave of the right atrium, which was sensed first, could be measured automatically. In some patients, we recorded the IEGM with the programmer (ERA 300 B). Examples are presented in Figure 5.

For a more exact evaluation of the pacing conditions (energy consumption) in all configurations, we used standard DDD pacemakers and the programmer PMS 1000 (all Biotronik, Germany) instead of the external threshold analyzer. The threshold pulse amplitude for simultaneous pacing of both atria was evaluated by looking at the paced P-wave morphology and duration, and the S-QRS (pacemaker spike-QRS) interval as well Figure 6.

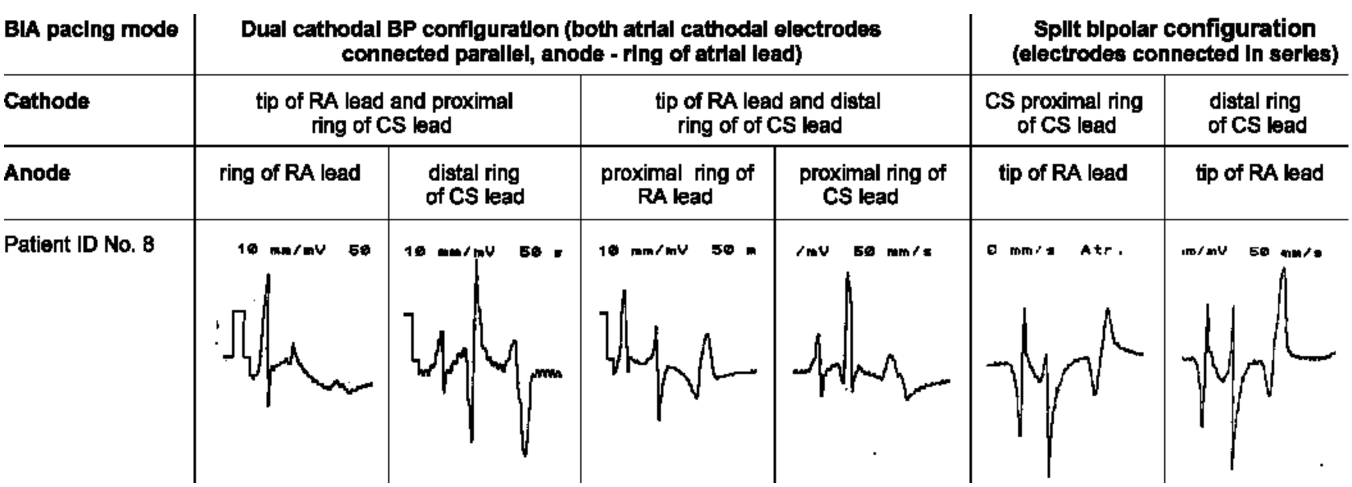


Figure 5. Examples of BiA IEGMs (the same patient as in Figure 4). The records were obtained during simultaneous sensing of both atria using 6 BiA pacing sensing configurations that were examined and compared in this study. The split BP configuration offered optimal sensing of both atria. In the dual cathodal sensing/pacing configuration, locating the common anode in the ring of the right atrial lead improves right atrial A-wave sensing; transferring the anode to the ring of the CS lead slightly improves left atrial A-wave sensing, but worsens sensing of the right atrial potential.

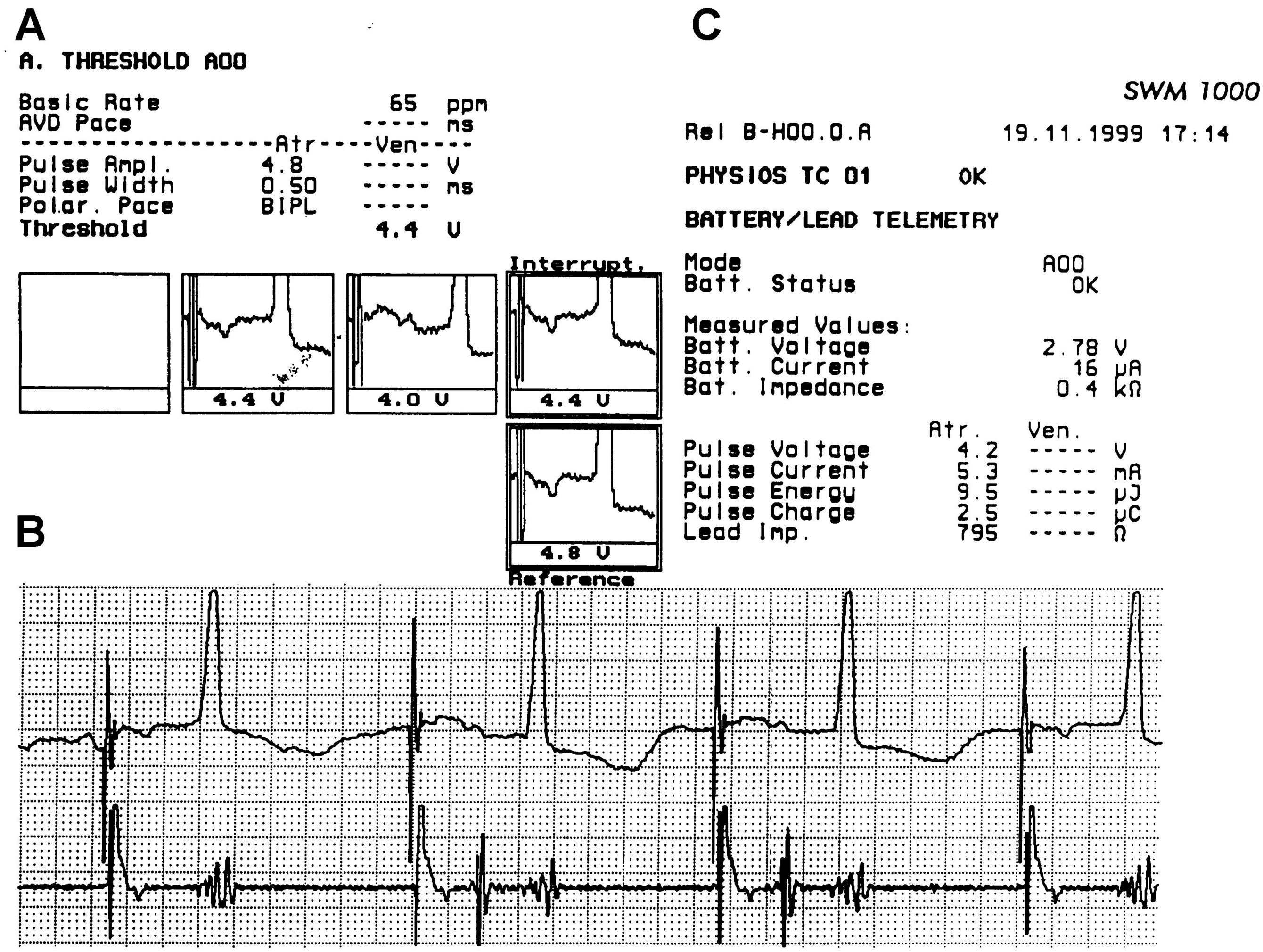


Figure 6. Use of the threshold test of a standard pacemaker for the rapid evaluation of BiA (resynchronizing) pacing threshold values (A). A programming pulse amplitude slightly below the BiA pacing energy points to situations when only a single atrium is paced or both atria are paced alternately (B). The battery lead telemetry test enables exact measurement of the threshold pacemaker output (C).

The IEGM allowed an exact verification of the threshold pulse amplitude for effective pacing of both atria (Figure 6).

After temporary programming of the threshold pulse amplitude, lead telemetry was performed, and the global impedance of the entire external circuit, as well as different parameters of energy consumption, were measured automatically (Figure 6).

Results

The parameters of the pacing conditions obtained during threshold amplitude pacing were examined for different BiA pacing modes and configurations. The results are presented in Table 4.

The average values for the examined parameters of the pacing conditions obtained from the same patients during different BiA pacing modes and lead connections were compared; the significance of the mean differences was evaluated using the Student's pair test. The table indicates that the type of lead connection has a significant influence on BiA pacing threshold values and energy consumption parameters. Connecting the distal ring of the CS lead to the cathode (in the split BP and the dual cathodal BP pacing mode) offers the best BiA pacing effectiveness (lowest pacing threshold values and output demand). The effectiveness of the dual

BiA pacing configuration			Dual cathodal BP				Split bipoles	
Cathode			tip of RA lead and proximal ring of CS lead		tip of RA lead and distal ring of CS lead		proximal ring of CS lead	distal ring of CS lead
Anode			ring of RA lead	distal ring of CS lead	ring of RA lead	proximal ring of CS lead	tip of RA lead	
No. of BIA pacing configuration			I	II	IV	V	III	VI
Pacing threshold (V)		mean	4.01	3.25	3,19	2.65	5.29	3.80
		SD	2.16	1.94	2,34	1.14	2.27	2.28
Battery lead telemetry (pacing with threshold pulse amplitude)	Energy (µJ)	mean	18.45	9.18	13,46	5.54	18.92	7.37
		SD	19.76	10.06	21,52	4.80	19.34	12.84
	Current (mA)	mean	11.12	5.70	7,54	4.77	5.84	3.55
		SD	7.37	3.38	4,72	1.83	3.85	1.73
	Battery current drain (µA)	mean	28.67	19.25	24,5	13.17	33.83	18.92
		SD	25.73	16.16	25,67	3.86	23.12	15.79
	Impedance (Ω)	mean	353.20	551.80	384,2	519.40	970.70	1020.10
		SD	67.40	109.40	76,7	78.70	366.50	351.70

Table 4. Biatrial pacing/sensing conditions using different lead configurations and connections of electrodes.

cathodal BP configuration was comparable to that of the split BP configuration. Most important and interesting seems to be the finding that, during dual cathodal BP pacing, moving the common anode from the ring of the right atrial lead to the proximal ring of the CS lead results in a decrease in the BiA pacing threshold and energy consumption by about 50 %.

Comments

The results presented in the second part of this study are in accordance with those obtained in the first part of our examinations: BP CS pacing threshold values and threshold energies were lower than in the standard UP configuration. We question whether this is due to the effect of additional anodal current in the same atrium. The number of patients was not very high, and as a consequence of the relatively large dispersion of the obtained results (high SD values), the marked differences between the mean parameters evaluated were frequently not statistically significant. We looked for the causes of the (sometimes extremely) different BiA pacing effectiveness when different lead connections and leads were used. We focused on the following:

- Do unifocal (local) pacing conditions (at right atrial and CS electrodes) influence BiA pacing effectiveness?
- Which pacing conditions play the most important role in BiA pacing effectiveness?
- Can we predict global BiA pacing effectiveness during the implantation of atrial leads?
- Which pacing parameter is most valuable for the prediction of BiA pacing conditions?

In general, data were difficult to interpret, due to the high standard deviation values.

- We can conclude that the threshold current (mA) seems to be similarly or slightly better suited to predict BiA pacing effectiveness than the threshold pulse amplitude (V). It must be remembered that two points of the heart have to be paced during BiA pacing from one (atrial) channel in an optional configuration, and excellent pacing conditions in one location can be overridden by poor conditions at the second location.
- The final conclusion drawn from this table is that BiA pacing conditions (the energy necessary for simultaneous pacing of both atria) have to be evaluated during the implantation of the BiA pacing system, before the final selection of leads and lead connections (Figure 6).

A detailed analysis in each patient was performed with the following results:

- The split BP configuration proved to be more effective (less energy consuming) than the dual cathodal BP configuration. In 10 of 12 patients, BiA threshold pulse currents (mA) were lower during the split BP than during the dual cathodal BP configuration;

the highest values of threshold pulse current were noted in all 12 patients during dual cathodal BP configuration.

- In all 12 patients, the highest global impedance was noted during split BP pacing.

In comparing the effectiveness of BiA pacing between only different modifications of the dual cathodal BP configuration, it was noted that in 11 patients, the lowest BiA pacing threshold pulse currents (mA) were observed when the common anode consisted of the ring of the CS lead.

- Only 1 patient showed a lower pulse current when the common anode was localized in the ring of the right atrial lead. The highest values for BiA pacing threshold pulse amplitudes (V) and threshold pulse currents (mA) were recorded when the common anode was connected to the ring of the right atrial lead in 9 and 11 patients, respectively.
- In all 12 patients, the lowest values for global impedance (Ω) were observed when the common cathode was connected to the tip of the right atrial lead and to the proximal ring of the CS lead, and the common anode to the ring of the right atrial lead.

We can conclude that the SBP configuration shown is a less energy-consuming system. But if we want to avoid atrial pacing with an anodal current, the dual cathodal BP configuration offers a comparable effectiveness for BiA pacing if the lead connections are properly selected. In most patients, locating the common anode in one of the two rings of the CS lead makes this configuration's effectiveness in BiA pacing (and its energy demand) comparable to that of the split BP configuration.

We found that very exact intraoperative measurements of single- and dual-site atrial pacing conditions allow the optimal pacing configuration to be found for each individual patient. Reasonable general rules do not apply to some individual patients, and the selection of a pacing configuration optimal for each particular patient makes BiA pacing most effective and helps to limit energy consumption (differences in energy consumption for different lead connections can even exceed 100 %).

In some patients, we recorded a BiA IEGM on paper (ERA 300 B) using different sensing configurations (Table 1; Figures 4 and 5). We found that the split BP configuration offers the best sensing conditions for both atria (it confirmed our previous observations [14-16]). In the dual cathodal BiA pacing/sensing configuration, the location of the common anode has an influence: right atrial ring anode connections improve right atrial sensing conditions. Transferring the anode to one of the two rings of the CS lead clearly improves sensing of the left atrial A wave, but worsens sensing of the right atrial potential. We can only suspect that connecting both "anodal" rings of both atrial leads together could improve sensing of both atria. But, on the other hand, such an arrangement would surely lead to a higher energy consumption, due to the very low impedance in dual-site common anode systems (the same effect as with common anode location in the pacemaker case).

Discussion

Different types of atrial lead connections for BiA pacing offer significantly different sensing/pacing conditions, and each one of them presents very specific advantages and disadvantages. The question of how to connect the atrial leads for BiA pacing remains under discussion and does not seem to have one universal answer. In the "classical" split bipolar configuration proposed by Daubert, usually the cathode paces the right atrium and the anode paces the left atrium. Pacing between two electrodes joined by a Y connector in series and connected to the atrial BP port of the pacemaker was named "split BP pacing configuration" by Barold [20]. Disadvantages of this configuration (with the electrodes connected in series) remain a high global impedance and, secondary to that, relatively high pacing thresholds [9-16]. The CS is paced with an anodal current, the arrhythmogenic properties of which have recently been pointed out again [23]. The frequent problems with proper left atrial pacing that we observed in patients with the classical Daubert pacing system inspired us to study the question: Can a change in the polarity of the right atrial and the CS lead and cathodal CS pacing improve the conditions of CS pacing [10,14]? Our acute examinations and long-term experience with split BP BiA pacing with inverted lead polarity indicated that this pacing system showed a better functionality [9,10,14]. The results were so impressive that we later never tried to pace the CS using anodal current in a split BP configuration. Both split BP BiA pacing systems described (the classical and the inverted one) can be characterized as having good sensing conditions and being well protected against myopotential interference. Due to the summation of impedance (split electrodes), they offer lower energy consumption. But, if the global resistance is too high (approaching 1600 Ω), a loss of left atrial capture becomes more evident, and the energy consumption has a rising tendency due to the high current output and increased current drain for the pacemaker voltage doubler. These systems prefer low/moderate impedance leads, and high impedance related pacing problems can be predicted if a high impedance lead was previously implanted in the right atrium. We proved that connecting the cathode to the CS lead and the anode to the right atrial lead not only improves the effectiveness of BiA pacing but also helps to save energy. Since we have already shown this phenomenon in different groups of patients, there was no reason to repeat this examination in this study (unnecessary prolongation of the operation was to be avoided).

Several years ago, Barold et al. proposed a different lead connection for multisite cardiac pacing - the dual UP (DUP) configuration [20]. Leads are connected in parallel and together to the cathode of the pacemaker's atrial port using a UP-UP Y connector. The main advantage of the DUP configuration is the avoidance of anodal pacing and the risk of proarrhythmic effects. We recently confirmed that DUP cathodal pacing (with the cathode connected to the right atrial and the CS lead, and the pacemaker case serving as common anode) results in weak sensing conditions, and (due to real UP sensing of both atria) low BiA pacing effectiveness (high or very high energy consumption, considerable risk of loss of left atrial capture due to very low global impedance) [15,16]. Connecting the common anode to a ring of the atrial lead eliminates all of these inconveniences of the UP system and improves sensing conditions and pacing effectiveness.

Our present examination showed that transferring the common anode from the ring of the right atrial lead to the proximal ring of the CS lead significantly improves BiA pacing effectiveness in most (but not all) patients. This may be because the smaller geometric area of the CS ring electrode compared with the standard area of the ring of the right atrial lead increases global impedance significantly (but still within safe limits) (Figure 2). In spite of the unfavorable electrophysiologic effects of anodal pacing recently confirmed by Bennet [23] (shorter refractory periods for anodal current), we do not want to overrate this phenomenon for proximal CS pacing; this effect is only possible if extremely high energy (exceeding the anodal pacing threshold values by many times) is applied. Such energy values are not used during BiA pacing (the left atrium is paced with values slightly above the cathodal pacing threshold, the right atrium is paced with values much higher than the safe margin energy due to pacing threshold differences). In the past, we have shown that left ventricle pacing is possible only in a low percentage of patients, only during distal CS pacing, and only if relatively high pacing energies were applied [9,14,26]. The proximal CS electrode location eliminates the possibility of ventricular pacing. We think that the proposed configuration (dual cathodal BP configuration with the common anode at the proximal ring of the CS lead) remains generally optimal for permanent BiA pacing in most patients. This configuration seems to be an especially useful solution for patients with older UP right atrial leads and a planned change of pacing mode to BiA pacing (CS leads are usually BP).

Conclusions

The CS offers sensing conditions comparable to those in the RAA but CS pacing remains several times more energy consuming for permanent pacing. The BP configuration offers pacing/sensing conditions that are more favorable than those of the UP CS configuration. The dual cathodal BP configuration is generally not worse than the split BP configuration for permanent BiA pacing.

Location of the common anode in the proximal ring of the CS lead significantly improves the effectiveness of BiA pacing in the dual cathodal BP configuration in most patients (without significant influences on the sensing conditions).

In some patients, marked differences in CS pacing conditions (between the proximal and the distal CS ring electrode) indicate the necessity for an exact evaluation of the BiA pacing conditions (threshold pulse amplitude, impedance) using different lead connections. In addition, each patient must be evaluated for a final selection of the most favorable pacing configuration.

No universal optimal configuration for permanent BiA pacing exists. Available hardware has to permit optimal (for each patient) lead connection and leads for permanent BiA pacing.

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