Pulse Width Programming in Patients with Biatrial Pacing Systems

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Summary

Increased battery energy consumption due to high pacing thresholds at the left side of the heart hampers clinical application of permanent biatrial (BiA) and biventricular pacing systems. We postulated that using pulse widths longer than the conventional 0.5 ms leads to energy savings in the "split bipolar" BiA pacing configuration (most frequently used in the clinical application of BiA pacing). This is because the strength-duration curve is shifted upward and to the right in high-threshold systems, resulting in longer chronaxie values than in standard-threshold systems. We evaluated our hypothesis in 22 patients implanted with split bipolar BiA pacing systems. Voltage thresholds were assessed for pulse widths ranging from 0.25 to 1.5 ms during routine follow-ups, and the associated pacing current, pulse energy, pulse charge, and total battery current drain were determined by telemetry and compared. The same measurement procedure was repeated in the same patient population during left atrial pacing via the coronary sinus lead in the unipolar configuration. The study results indicated that chronaxie values in high-threshold systems (split bipolar BiA pacing) could be in the range of 1.0 to 1.5 ms, as minimum pulse energy consumption and minimum battery current drain were achieved using pulse widths of such lengths. In contrast, battery energy consumption during unipolar left atrial pacing via the coronary sinus lead could not be reduced if pulse widths exceeding the conventional 0.5 ms were used.

Key Words

Pulse width, biatrial pacing, pacing threshold, energy consumption

Introduction

The major problems associated with transvenous multisite (biatrial [1-6] and biventricular [7-13]) cardiac pacing have been: a relatively high dislocation rate of the leads implanted at the left side of the heart (5%-13%), risk of left heart exit block, and increased battery energy consumption due to high pacing thresholds at the left heart side. Most frequently, the right and left atrial (or ventricular) leads are connected to a pulse generator via a "Y connector," using the split bipolar configuration. The term split bipolar configuration was proposed by Barold et al. [14], and is based on the considerations and clinical findings of Daubert et al. [6,8,14-16] in biatrial (BiA) pacing and of Cazeau and Ritter et al. [8,9,11,14,16-19] in biventricular pacing. In the split bipolar BiA pacing, the right-heart-sided lead is usually connected to the cathode outlet of the pacemaker connector, and the left-sided lead to the anode outlet of the same connector port. Chronic voltage thresholds in this multisite pacing configuration are mostly between 3 and 5 V with a 0.5 ms pulse width, which is more than thrice the chronic threshold values in the conventional right atrial appendage leads (0.3-1 V) [1-16]. Although the main reason for the higher pacing thresholds is an inability to establish a direct contact between the transvenous electrode and the myocardium at the left side of the heart, pacing thresholds in the split bipolar configuration are additionally increased by the presence of two elements with a high electrical resistance (the two electrode tips) within the pacing circuit [6-13,16,20]. One advantage of the split bipolar configuration is that it uses only one pacing pulse to stimulate both atria, whereas alternative BiA pacing systems need two separate, synchronized pulses.

It is well known that the lowest energy threshold for pacing can be achieved with pulse width values near the chronaxie value on the strength-duration curve [21-25]. For conventional pacing, chronaxie is usually about 0.5 ms. In BiA pacing systems, considerably higher pacing thresholds and elevated pacing impedance may result in higher chronaxie values due to the shift of the strength-duration curve upward and to the right [21-24]. Therefore, minimum energy consumption during split bipolar BiA pacing might be achieved by applying pulse widths exceeding standard (0.5 ms) values. This study evaluated the influence of programmed pulse widths on energy consumption during BiA pacing at the threshold level.

Material and Methods

Twenty-two consecutive patients received a split bipolar BiA pacing system that was slightly modified by the author: The atrial cathode outlet of the pacemaker connector was connected to the ring of a standard bipolar coronary sinus lead, and the anode outlet was connected to the tip of the lead placed in the right atrial appendage [20]. In this patient population, voltage threshold was determined at different pulse widths: 0.25 ms, 0.5 ms, 0.75 ms, 1.0 ms, and 1.5 ms. Pacing current (in mA), pulse energy (μJ), pulse charge (μC), and the total battery current drain (μA) were measured by telemetry for each threshold (output) setting.

Pacemakers (BIOTRONIK, Germany) featuring different pulse widths were used in the study. Pulse width values of 0.25, 0.5, 0.75, and 1.0 ms were available for 10 patients implanted with either a Pikos, a Dromos, or a Physios pacemaker; values of 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, and 1.5 ms were programmable in 11 patients implanted with an Actros or a Kairos pacemaker; and values of 0.05-…(0.05)…-2.0 ms were available in the remaining patient with an Inos pacemaker. Considering that not all the pulse generators offered the pulse widths of interest for our study, and that we wanted to make paired comparisons of the telemetry values using the Student's t-tests for 0.5 ms pulse width versus 0.25 ms, 0.75 ms, 1.0 ms, and 1.5 ms pulse widths, our study results were processed as illustrated by Tables 1 and 2. The measurements were conducted for split bipolar BiA pacing (Table 1) and for left atrial pacing via the coronary sinus lead in the unipolar configuration (Table 2) in the same patient population. Differences were considered signicant if $p < 0.05$.

Results

The mean pacing impedance during split bipolar BiA stimulation was 780 Ω, which is lower than it would be had the tip of the coronary sinus lead been used for left atrial stimulation instead of the lead ring. Thus, the examined BiA pacing configuration represented a moderate resistance, high-threshold system, with the mean voltage threshold at 0.5 ms exceeding 5.2 V.

Table 1 shows a significant decrease of voltage threshold and pacing current with the increase of pulse width, a finding which is completely in accordance with the strength-duration principle [21-24]. The values for pulse energy and total battery current drain were slightly lower at pulse widths between 0.75 and 1.5 ms than those at 0.5 ms.

When the left atrium was paced via the coronary sinus lead in the unipolar configuration (Table 2), the mean pacing impedance was 282 Ω, and the mean voltage threshold at 0.5 ms was about 2.3 V. This pacing configuration, thus, exhibited low pacing impedance and moderate-to-high pacing thresholds. Again, a significant decrease of voltage threshold and pacing current occurred with the extension of pulse width, while pulse energy and total battery current drain were virtually uninfluenced by the selection of pulse width.

Discussion

The shape and the location of the strength-duration curve for cardiac pacing have been mostly determined during invasive electrophysiologic studies and pacemaker implantation procedures. It is known that the strength-duration curve [21-24] may be shifted upward and to the right in pacing systems featuring high pacing thresholds, which will result in a longer chronaxie value than in conventional systems with low-to-moderate thresholds and about 0.5 ms chronaxie values. Thus, split bipolar BiA (high-threshold) pacing showed a considerable difference between the voltage thresholds at 1.0 ms and 1.5 ms (Table 1), but this was not the case for unipolar coronary sinus (lower-threshold) pacing (Table 2). Furthermore, the rheobase value in conjunction with the data in Table 1 cannot be reliably estimated using a maximum pulse width of 1.5 ms, in contrast to the situation for the data in Table 2. In other words, in split bipolar BiA pacing "the knee" of the strength-duration curve and the chronaxie value could be located somewhere in the 1.0-1.5 ms pulse

Pulse width (ms)		Voltage threshold (V)		Pacing current (mA)		Pulse energy (μJ)		Pulse charge (μC)		Total battery current drain (μA)	
Compared values	No. of pairs of results	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p
0.25	10	7.8	3.1	12	3.5	18.9	2.3	2.68	1.1	32.2	6.3
		(1.4)	(0.9)	(3.6)	(2.0)	(7.1)	(5.4)	(0.8)	(1.0)	(8.4)	(15.5)
0.5		4.7	9.608	8.5	5.45	16.6	1.34	3.7	3.37	25.9	1.28
		(1.2)	0.00001	(4.5)	0.004	(10.3)	0.212	(1.7)	0.008	(10.5)	0.23
0.75	9	5.2	0.9	9.2	2	23.4	2.5	5.4	0.8	36.5	0.62
		(1.6)	(0.5)	(3.0)	(2.0)	(11.8)	(3.7)	(1.4)	(0.8)	(18.3)	(6.9)
0.5		6.1	5.1	11.3	2.86	25.8	1.91	4.7	2.81	37.1	0.25
		(1.9)	0.001	(4.5)	0.24	(13.7)	0.96	(1.6)	0.022	(16.0)	0.805
1	13	4.1	1.5	6.5	2.7	16	5	4.9	0.9	30.1	2.7
		(1.2)	(0.7)	(2.8)	(2.3)	(8.3)	(6.4)	(1.8)	(0.6)	(16.3)	(10.5)
0.5		5.7	7.57	9.2	4.25	21	2.8	4	4.98	32.7	0.33
		(1.8)	0.00007	(4.6)	0.001	(13.1)	0.015	(1.7)	0.0003	(16.0)	0.618
1.5	5	3.3	2.3	4.2	2.3	12.5	4.5	4.5	1.3	23.4	8.4
		(1.2)	(1.3)	(1.7)	(1.1)	(8.3)	(5.30)	(2.0)	(0.5)	(7.3)	(15.8)
0.5		5.7	4.13	6.5	4.8	16.9	1.87	3.1	4.71	31.8	1.18
		(2.4)	0.007	(2.7)	0.008	(13.1)	0.133	(1.5)	0.018	(21.4)	0.302

Table 1. Pacemaker output values determined by telemetry for different pulse widths during split bipolar BiA pacing. No. = number, diff. = difference, sd = standard deviation, t and p = statistical values (see Material and Methods).

width range. In the unipolar coronary sinus pacing mode, the chronaxie values appear to be shorter, most likely in the range of 0.5 to 0.75 ms, i.e., slightly longer than for conventional pacing.

A lower pulse energy and decreased battery current drain measured for longer pulse widths during the BiA pacing seem to confirm this hypothesis. An opposite and statistically significant trend in pulse charge changes with changing pulse widths is demonstrated in Table 1: The pulse charge increases with increasing pulse widths. This is easily explained by the fact that the pulse charge is the product of pacing current and pulse width, and it does not take into account the pulse amplitude.

In addition to longer chronaxie values, two more factors may explain the reduced energy consumption for 1.0-1.5 ms pulse widths in high-threshold systems (Table 1). First, longer pulse widths in high-threshold systems will reduce the need for generating high output voltages, thereby decreasing energy consumption within the voltage amplifier (the lower the voltage amplification, the lower the battery energy expenditure by the amplifier) [26]. Second, it is well known that pacing impedance increases with the prolongation of pulse width due to the lead polarization effect [22]. This may reduce the mean pacing current during the pulse and the total battery current drain for longer pulse widths.

When comparing the results in Tables 1 and 2, one should keep in mind that total battery current drain is a primary indicator of anticipated battery longevity. It takes into account all components of battery current drain, including current used for pacing and the internal "overhead" current that runs the electronic circuitry inside the pacemaker housing [24, 27-29].

Conclusion

While programming pulse duration in pacing systems featuring high thresholds, such as split bipolar BiA stimulation, it may be useful to evaluate battery energy consumption for 0.5 ms, 1.0 ms, and 1.5 ms pulse widths via telemetry and chose the pulse width yielding the lowest battery energy consumption. In many

Pulse width (ms)		Voltage threshold (V)		Pacing current (mA)		Pulse energy (µJ)		Pulse charge (µC)		Total battery current drain (µA)	
Compared values	No. of pairs of results	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p	mean (Sd)	diff. (Sd) t p
0.25	14	4.3	1.8	15.5	6.12	12.9	3.9	3.1	0.8	21.3	0.85
		(1.2)	(0.7)	(6.4)	(2.7)	(7.9)	(3.1)	(1.4)	(0.5)	(10.6)	(0.85)
0.5		2.5	8.96	9.3	8.3	9	4.25	4	6.5	20.5	0.556
		(0.6)	0.00001	(4.4)	0.000001	(5.4)	0.0009	(1.7)	0.00002	(8.3)	0.588
0.75	8	2.3	0.47	9.4	2	9.6	1.6	5.2	0.5	24.1	0.12
		(0.4)	(0.6)	(3.2)	(2.2)	(4.3)	(5.5)	(1.5)	(1.2)	(8.0)	(4.2)
0.5		2.7	2.25	11.4	2.6	11.2	0.88	4.7	1.23	24	0.08
		(0.7)	0.058	(3.8)	0.03	(5.4)	0.402	(1.3)	0.253	(8.6)	0.953
1	13	1.8	0.66	6.4	2.5	6.6	2.1	4.5	1	20.8	1.08
		(0.2)	(0.6)	(2.7)	(2.1)	(3.9)	(5.06)	(1.7)	(0.8)	(7.2)	(3.2)
0.5		2.5	4.35	8.8	4.09	8.6	1.41	3.5	4.3	19.7	1.18
		(0.7)	0.0009	(4.2)	0.001	(5.4)	0.183	(1.4)	0.001	(8.3)	0.262
1.5	7	1.6	0.5	4.9	1.61	7.33	1.5	5.2	2.2	15.6	1.2
		(0.4)	(0.18)	(2.3)	(0.76)	(7.2)	(5.0)	(2.7)	(1.8)	(2.1)	(2.9)
0.5		2.1	7.24	6.5	5.17	5.8	0.72	3	2.87	14.4	0.908
		(0.5)	0.0003	(2.8)	0.003	(3.1)	0.504	(1.2)	0.034	(4.9)	0.414

Table 2. Pacemaker output values determined by telemetry for different pulse widths during unipolar coronary sinus pacing. No. = number, diff. = difference, sd = standard deviation, t and p = statistical values (see Material and Methods).

cases, the 1.0-1.5 ms pulse widths will result in a lower battery current drain than the conventional 0.5 ms pulse width. A broader clinical study is necessary to elucidate the clinical significance of the findings indicated in this article.

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