OLBI Stimulation in Biatrial Pacing? A Comparison of Acute Pacing and Sensing Conditions for Split Bipolar and Dual Cathodal Unipolar Configurations

A. KUTARSKI, M. SCHALDACH*, M. WÓJCIK, K. OLESZCZAK, A. GLOWNIAK
Department of Cardiology, University Medical Academy, Lublin, Poland
*Department of Biomedical Engineering, University of Erlangen-Nuremberg, Germany

Summary

Split bipolar (SBP) configuration is widely used in biatrial pacing. Although SBP pacing concept gives rise to a relatively high pacing threshold and elevated pacing impedance due to the small cathode and anode electrode surface areas, it is associated with only moderate battery energy consumption. Furthermore, the SBP configuration makes anodal coronary sinus (CS) pacing feasible, an opportunity that may be of certain advantage. Conversely, dual cathodal unipolar (DUP) pacing yields a lower pacing impedance and pacing threshold. But the need for two stimulation pulses in DUP pacing, one in each atrium, results in a significant increase of battery energy consumption compared to SBP systems. Overlapping biphasic (OLBI) pacing that consists of two electrical pulses of opposite polarity was recently introduced to increase efficacy of atrial wall stimulation from the rings of floating atrial electrodes. We postulated that incorporation of OLBI in biatrial pacing systems may improve stimulation efficacy and reduce energy consumption. During implantation of a biatrial pacing system in 12 patients with brady-tachy syndrome, we evaluated sensing and pacing conditions for different lead configurations. J-shaped unipolar or bipolar leads were implanted in the right atrium and conventional straight bipolar leads in the CS. Mean A-wave amplitudes in the SBP and OLBI configurations (bipolar sensing) of 2.7 and 2.4 mV, respectively, were better than in the DUP configuration (1.9 mV). The lowest pacing thresholds were obtained for OLBI pacing (mean 1.8 V at 0.5 ms), as compared to 3.9 V and 2.3 V in the SBP and DUP configurations. The lowest pacing impedance was recorded in the DUP configuration (215 Ohms), versus 622 and 589 Ohms for SBP and OLBI configurations. The highest energy consumption was obtained in the DUP configuration (10.5 mJ), whereas SBP and OLBI required only 5.9 and 6.0 mJ. We evaluated energy consumption and sensing conditions in additional six patients, with the aid of pacemaker telemetry and pacemaker programmer. This additional study was conducted during the final stages of biatrial system implantation. Findings of the additional study corroborated results of the main study. In conclusion: (1) sensing performance was better in the bipolar (SBP and OLBI) than in the unipolar (DUP) configuration; (2) the DUP biatrial pacing was associated with the highest energy consumption despite relatively low pacing threshold values - this can be explained by very low global pacing impedance; (3) the most important advantage of the OLBI system seems to be an independence from global resistance. The OLBI mode thus could be a solution for patients with impedance-related problems during biatrial pacing. The advantages of OLBI system may pave the way to a real, efficient three-chamber pacemaker construction.

Key Words

Split bipolar pacing, dual unipolar pacing, OLBI configuration, biatrial pacing, energy consumption

Introduction

Atrial arrhythmias are one of the remaining challenges in cardiology at the beginning of the new millennium. Interatrial conduction disturbances (IACD) have been identified as an important substrate leading to reentrant atrial arrhythmias due to spacial asynchrony of atrial depolarisation and repolarisation processes and increased dispersion of atrial repolarisation. Resynchronisation of the electrical and mechanical activity within the atria is achievable through simultaneous stimulation of the right and left atria (biatrial pacing), with CS pacing playing a key role [1-3]. Indications for the resynchronising atrial pacing have not been fully established, but biatrial pacing is usually used in patients with frequent recurrence of atrial arrhythmias (on a daily or weekly basis) presented with IACD ($P_{II,III}$ > 120 ms and total atrial activation time > 150 ms [from the onset of P_{II} to the end AOE or CS]), in case previous antiarrhythmic therapy was unsuccessful [1-4].

The major problems encountered in biatrial pacing have been 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 energy consumption. The most widely used configuration in biatrial pacing has been the SBP one, where the right and left atrial leads are attached to the pulse generator via an "Y-connector". The lead in the right atrium is ordinarily connected to the cathode outlet of the pacemaker connector and the lead in the left atrium (i.e. CS lead) to the anode outlet of the same connector port. The term SBP was proposed by Barold et al. [5], based on the considerations and clinical findings of Daubert et al. [2,3] in biatrial pacing and of Cazeau and Ritter et al. in biventricular [1] pacing. Presence of two elements with a high electrical resistance (the two electrode tips) within the SBP pacing circuit nearly doubles pacing impedance and increases pacing threshold [6-8]. Mean acute pacing threshold in SBP pacing is up to 10 times higher (about 3 - 4 V at 0.5 ms pulse width) than in the conventional (separate) right atrial pacing (0.3 - 0.4 V).

Several years ago, Cazeau and co-workers proposed DUP lead connection concept for multisite cardiac pacing. According to the DUP principle, the right atrial and left atrial leads should be connected in parallel and to the cathode outlet of the atrial (or ventricular) port of a pacemaker, with the aid of a unipolar Y-connector [5-8]. This system results in significantly lower global resistance and, thereby, in increased energy consumption. Consequently, there are no guarantees for a standard pacemaker (in view of its output capacity) to maintain programmed voltage in case of high pacing threshold.

OLBI system was incepted for pacing of the right atrial wall from floating ring electrodes [9]. In the OLBI concept, two separate capacitor systems are used to generate two impulses of opposite electrical polarity, improving stimulation efficacy and penetration depth of the impulses. Actually, OLBI system employs two independent pacing circuits, which allows a usage of two unipolar leads for simultaneous pacing of two regions of the heart in the unipolar configuration.

Aim of the Study

The purpose of the study was to evaluate the utility and compare acute performance of the three aforementioned systems for biatrial pacing/sensing (SBP, DUP, and OLBI). The focus was placed on sensing properties and energy consumption-related parameters.

Patients and Methods

Twelve patients (8 female), 48 - 76 years old (mean 64.4 years), suffering from the brady-tachy syndrome, received a biatrial pacing system. While none of the 12 patients had a CS lead implanted before, five patients have been already equipped with a right atrial lead as a part of their earlier AAI or DDD pacing systems. Seven standard unipolar or bipolar J-shaped leads (TIR 53 JBP, Biotronik) and five other leads were used for pacing and sensing in the right atrium, and conventional straight bipolar leads (TIR 60 BP, n = 6; PX 60 BP, n = 4; SX 60 BP, n = 2; all Biotronik) were inserted into the CS. Tines of the CS leads were left unremoved to facilitate lead fixation and enhance pacing success from the ring of the CS leads. The tip of the lead in the right atrial appendage and the tip and the ring of the CS lead were involved in the evaluation of pacing and sensing conditions in different biatrial configurations. During the evaluation, the leads were temporarily connected to a threshold analyser ERA 300 B (Biotronik, Germany). Following the acute investigations, the ring of the CS lead was in nearly all cases connected to the cathodal pacemaker outlet and the tip of the right atrial lead to the anodal outlet, and SBP configuration was applied permanently.

We carried out a more precise evaluation of energy consumption-related parameters in additional six patients (4 female) during the final stages of a biatrial system implantation. In this supplemental investigation, standard Biotronik pacemakers and the programmer (PMS 1000) were used instead of the ERA 300 B threshold analyser, which allowed a variety of output

	RA (unipolar) tip-case	CS (unipolar) ring-case	CS (unipolar) tip-case	CS (bipolar) tip-ring
A-wave amplitude (mV)	2.3	2.3	2.1	2.9
Pacing threshold (V at 0.5 ms)	1.0	1.7	5.5	2.9
Impedance (Ohm)	477	263	532	563
Energy consumption (µJ)	1.4	6.5	9.1	5.6

Table 1. Mean pacing and sensing values in the right atrium (RA) and coronary sinus (CS).

parameters to be programmed with a fine resolution. Energy consumption-related values were measured using pacemaker telemetry during biatrial pacing at the threshold pulse amplitude in the SBP and DUP configurations.

Results

Table 1 displays acute pacing and sensing values measured after final lead positioning and fixation, in the unipolar and bipolar lead configurations in 12 patients. A-wave amplitudes measured from the right atrium and CS were satisfactory in most of the patients and at all of the examined places. Pacing threshold and energy consumption values were 2 - 3 times higher during CS than during right atrial pacing. Remarkably higher pacing threshold (5.5 V) was measured at the tip of the CS lead, which was probably caused by the fact that unremoved tines kept the lead tip far from the CS wall. Pacing from the tip of the CS lead was not our goal - tines played only an anchoring role. Impedance values were at their lowest when the ring of the CS lead was used for pacing.

Table 2 depicts acute biatrial pacing and sensing values in SBP, DUP, and OLBI configurations. In any case, the ring of the CS leads was used for pacing and sensing in the left atrium and the tip of the right atrial lead for pacing and sensing in the RA. Mean A-wave amplitudes were significantly larger in the SBP and OLBI configurations (bipolar sensing): 2.7 mV and 2.4 mV, respectively, than in the DUP configuration (1.9 mV). Pacing thresholds were significantly lowest for OLBI configuration (mean 1.8 V), while in the SBP and DUP configurations mean values were 3.9 V and 2.3 V, respectively. Mean impedance values were significantly lowest during pacing in DUP configuration (215 Ohms), while in the SBP and OLBI configurations mean impedance values were 622 and 589 Ohms. Energy consumption values showed different tendency than pacing thresholds. The highest energy consumption was recorded in the DUP configuration (10.5 mJ), while in the SBP and OLBI configurations energy consumption was 5.9 mJ and 6.0 mJ, respectively.

Table 3 presents acute biatrial pacing and sensing values in SBP, DUP, and OLBI configurations using the tip of the CS lead for pacing and sensing in the left atrium and the tip of the right atrial lead for pacing and sensing in the right atrium. Mean A-wave amplitudes in the SBP and OLBI configurations (bipolar sensing) were significantly larger: 2.0 mV and 2.8 mV, respectively, than mean amplitudes in the DUP configuration (1.5 mV). Mean pacing thresholds were significantly lower in the OLBI configuration (3.3 V) than in the SBP and DUP configurations (5.5 V and 6.0 V, respec-

	SBP	DUP	OLBI	SBP vs. DUP	SBP vs. OLBI	DUP vs. OLBI
A-wave amplitude (mV)	2.7	1.9	2.4	NS	NS	< 0.05
Pacing threshold (V at 0.5 ms)	3.9	2.3	1.8	< 0.002	< 0.003	< 0.05
Impedance (Ohm)	622	215	589	< 0.001	NS	< 0.001
Energy consumption (µJ)	5.9	10.5	6.0	< 0.001	NS	< 0.001

Table 2. Comparison of mean pacing and sensing values for different biatrial configurations using the ring of CS leads for pacing and sensing in the left atrium.

	SBP	DUP	OLBI	SBP vs. DUP	SBP vs. OLBI	DUP vs. OLBI
A-wave amplitude (mV)	2.0	1.5	2.8	< 0.001	NS	< 0.01
Pacing threshold (V at 0.5 ms)	5.5	6.0	3.3	NS	< 0.01	< 0.002
Impedance (Ohm)	787	345	797	< 0.001	NS	< 0.001
Energy consumption (µJ)	7.3	15.7	8.0	< 0.001	NS	< 0.004

Table 3. Comparison of mean pacing and sensing values for different biatrial configurations using the tip of CS leads for pacing and sensing in the left atrium.

tively). Mean impedance values were significantly lower during pacing in the DUP configuration (340 W) than in the SBP and OLBI configuration (787 and 797 W, respectively). Similarly to the results with the ring of the CS lead, the highest energy consumption was associated with the DUP configuration (15.7 mJ), compared to the 7.3 mJ and 8.0 mJ in the SBP and OLBI configurations, respectively. Table 4 illustrates precisely measured energy consumption parameters in the SBP and DUP configurations (mean values for six pts).

The SBP configuration offered significantly better sensing conditions than DUP configuration (2.8 mV vs. 1.1 mV A-wave amplitude). In spite of the significantly higher pacing threshold (4.6 V vs. 3.5 V), the SBP configuration resulted in a lower battery current drain and energy consumption due to remarkably higher pacing impedance (600 vs. 240 W).

Discussion

Multisite cardiac pacing has been increasingly used for certain hemodynamic and antiarrhythmic indications. The two most common multisite pacing concepts: DUP and SBP have their own advantages and disadvantages. The SBP pacing concept features favourable sensing performance and provides a good protection from the skeletal muscle interference. Thanks to the summing-up of high resistance components (two electrode tips), pacing impedance in SBP configuration is high and energy consumption satisfactorily low. However, the total pacing impedance in SBP configuration may be very high (striking 2,000 W), potentially leading to loss of capture in the left atrium. This will, in return, require a higher pacing output and increased battery current drain, in part due to the increased consumption within the voltage amplification circuitry. The SBP concept performs optimally in conjunction with low- or moderate-impedance pacing leads. High-resistance-related pacing problems are expected mainly in cases when high impedance leads are implanted in the RA. Not sufficiently examined potential disadvantage of the SBP concept is the need to pace one of the two atria with the anodal current, which may have pro-arrhythmic effects. Namely, in case of incidental pacing during the relative cardiac refractory period, anodal current imposes a greater danger of triggering arrhythmia than the cathodal current, as previously demonstrated for ventricular pacing [10-12].

	SBP	DUP	T	p
A-wave amplitude (mV)	2.8	1.1	4.137	< 0.006
Pacing threshold (V at 0.5 ms)	4.6	3.5	5.009	< 0.0001
Impedance (Ohm)	600	240	22.092	< 0.0001
Battery current (µA)	23.7	27.1	3.925	< 0.05
Pulse voltage (V)	4.38	3.12	6.231	< 0.0004
Pulse current (mA)	7.33	13.52	4.11	< 0.004
Pulse energy (µJ)	14.68	19.33	0.26	< 0.802
Pulse charge (µC)	3.47	5.30	3.891	< 0.005

Table 4. Energy consumption parameters in SBP and DUP configuration.

The DUP configuration during biatrial pacing results in impaired sensing performance since both atria are actually sensed in the unipolar configuration. Sensed A-wave amplitude in the DUP configuration is lower than in the SBP concept and pectoral myopotentials may be interfering pacemaker function, particularly if high sensitivity gains are programmed. Pacing impedance and pacing threshold values are lower in the DUP than in the SBP concept, resulting in a significantly higher energy consumption. In case of a particularly high pacing threshold in the left atrium, output capacity of a standard pacemaker may not be sufficient to guarantee the programmed high voltage output. A potential advantage of the DUP configuration seems to be an avoidance of anodal pacing.

The OLBI pacing concept has been devised to allow a deeper impulse penetration [9]. The clinical value of OLBI pacing has been demonstrated for floating right atrial wall pacing and, recently, for CS pacing using standard straight bipolar leads [13,14]. Since they have two separate output capacitor systems, devices featuring OLBI pacing enable a delivery of two separate impulses from the two connector outlets of either atrial or ventricular channel. This results in two independent atrial circuits, where pacing impedance do not sum-up and do not divide. Therefore, the OLBI systems may be beneficial in pts with high-impedance leads implanted in the right atrium as well as in other patients with high-resistance-related problems. An additional convenience of the OLBI concept could be increased protection from different sources of sensing interference. According to our experience, the advantages of OLBI concept may lead to the construction of an effective, real three-chamber pacemaker system.

Conclusions

1. Sensing conditions are better in the bipolar (SBP and OLBI) than in the unipolar (DUP) configuration.
2. Pacing from the ring of a standard bipolar CS lead, instead from the tip, significantly reduces pacing threshold and energy consumption.
3. The DUP biatrial pacing configuration yields high battery current drain and energy consumption despite relatively low pacing thresholds, due to the very low total pacing impedance as a consequence of the parallel connection of the two stimulating electrodes.
4. An independence from the global impedance appears to be the greatest advantage of the OLBI pacing concept. Thus, OLBI pacing may represent solution in patients with high-resistance-related problems during biatrial pacing. The advantages of OLBI concept may allow a real, efficient three-chamber pacemaker construction.

References

[1] Daubert JC, Leclercq C, Pavin D, et al. Pacing therapy in congestive heart failure: present status and new perspectives. In S Barold, J Mugica (eds.): Recent Advances in Cardiac Pacing. Goals for the 21st Century. Armonk NY, Futura Publishing Company, Inc. 1998: 51-80.

[2] Gras D, Mabo P, Daubert C, et al. Left atrial pacing: Technical and clinical considerations. In S Barold, J Mugica (eds.): Recent Advances in Cardiac Pacing. Goals for the 21st Century. Armonk NY, Futura Publishing Company, Inc. 1998: 181-202.

[3] Cazeau S, Ritter P, Bakdach S, et al. Four chamber pacing in dilated cardiomyopathy. PACE. 1994; 17: 1974-1979.

[4] Kutarski A, Pleszak K, Oleszczak K, et al. Biatrial and coronary sinus pacing - long term experience with 264 patients. Prog Biomed Res. 1998; 3: 114-120.

[5] Barold SS, Cazeau S, Mugica J, et al. Permanent multisite cardiac pacing. PACE. 1997; 20: 2725-2729.

[6] Limousin M. Current limitations of multisite pacing technmology. Arch Mal Coeur Vaiss. 1998; 91 (3): 246 (abstract).

[7] Mc Venes R, Christie M. ECG characteristics of simultaneous biventricular stimulation in canines. Arch Mal Coeur Vaiss. 1998; 91 (3): 64 (abstract).

[8] Mc Venes R, Stokes K, Christie M, et al. Technical aspects of simultaneous biventricular stimulation thresholds. Arch Mal Coeur Vaiss. 1998; 91 (3): 152 (abstract).

[9] Lazarus A, Taskiran M, Ritter P, et al. Reduction in energy pacing thresholds by overlapping biphasic stimulation versus conventional bipolar pacing. PACE. 1998; 21: 2166-2170.

[10] Furman S. Basic concepts. In S Furman, DL Hayes, DR Holmes (eds.): A Practice of Cardiac Pacing. Armonk NY, Futura Publishing Company, Inc. 1993: 29-88.

[11] Kay GN. Basic aspects of cardiac pacing. In K Ellenbogen (ed.): Cardiac Pacing. Blackwell Scientific Publications, Boston. 1992: 32-119.

[12] Stokes KB, Kay GN. Artificial electric cardiac stimulation. In KA Ellenbogen, GN Kay, BL Wilkoff (eds.): Clinical Cardiac Pacing. Philadelphia, W.B Saunders Company, 1995: 3-37.

[13] Kutarski A, Oleszczak K, Schaldach M, et al. Left atrial and multisite atrial pacing using OLBI stimulation. In: E Adornato (ed.): Rhythm Control from Cardiac Evaluation to Treatment. Proceedings of the VI Southern Symposium on Cardiac Pacing Giardini Naxos - Taormina. Edizioni Luigi Pozzi, Roma, 1998: 343-353.

[14] Kutarski A, Poleszak K, Oleszczak K, et al. Does the OLBI™ configuration solve the problem of exit block during permanent CS pacing? Progress in Biomedical Research 1998; 3: 22-28.