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Implementation of Impedance Method in Syncope Treatment

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Current syncope treatment by cardiac pacing is limited to patients developing cardiodepressive reaction. There is strong need to apply this method to other types of reaction. Presented method shows, that impedance method can be applied for early detection of vasodepressive syncope. Thus the method can be applied for antivasovagal pacing in syncopic patients.

Key words: impedance cardiography, cardiac pacing, syncope.

Introduction

For over 20 years the measurements of intracardiac electric impedance were proposed as a method of assessing of physiological signals in pacing control. In clinical application the impedance modulus is usually calculated for one frequency from the range of 20-100 kHz, phase relation between voltage and current courses is not considered [4]. The modulus of thorax impedance and impedance changes recorded for hemodynamic cardiac activity study is called an impedance cardiography. The study on application of impedance measurements for synchronization of biventricular and atrioventricular pacing are currently performed. In applications of impedance methods for cardiac pacing one or more intracardiac pacing leads and active pacemaker housing are utilized in measurement procedure. The impedance measurement of the patient vital signals

during cardiac pacing is widely used in rate responsive algorithms. We propose to apply the impedance signal of stroke volume (SV) for early detection of changes of hemodynamic activity of the heart. The goal of the presented study was to prove the value of impedance algorithms based on SV analysis for therapeutic pacing of syncopic patients.

Impedance measurements in cardiac pacing

Respiration rate algorithm

The pacing systems with impedance methods are offered by many pacemakers companies [1, 8]. The respiration rate algorithm of rate response pacing was introduced by Italian company Biotec. The control of pacing rate is related to increasing and decreasing of respiration rate. The measurement of impedance is performed between special pole of intracardiac lead and active pacemaker housing. The algorithm is based on fact, that the higher exercise load of patient evokes rise of respiration rate. Therefore detected higher respiration rate is followed by higher pacing rate. This method may be applied to patients without respiration insufficiency.

Minute respiration volume algorithm

The minute respiration volume signal of rate response pacing was proposed by Australian company Telectronics. The increase of respiration volume per minute was manifested by rising of pacing rate. The respiration volume was measured by intracardiac lead pole and pacemaker housing. The algorithm provides better protection against misdetection of higher exercises load in patients with respiration insufficiency. The problem of patients with respiration insufficiency was solved by applying the double sensor systems. In this case the algorithm combines respiration volume module and classical accelerometer module. The final pacing rate is evaluated using two signals with preferences decided by physician for particular patients. Generally the accelerometer signal is more reliable for low exercise load but respiration volume signal for higher exercise load.

Transvalvular impedance algorithm

The recording of impedance by standard pacing leads in transvalvular configuration can provide information on cardiac mechanical activity. The transvalvular impedance signal is measured between pole of atrial lead and pole of ventricular lead. If cardiac rate regulation is impaired the parameters of mechanical activity changes could be monitored by rate response algorithm which adjusts the pacing rate to exercise load. There is an inverse relationship between right ventricle volume and transvalvular impedance. The final pacing rate for exercise workload is calculated on the base of a chronotropic index totally independent of preload effect.

Anisotropic impedance algorithm

As it follows from theoretical considerations, right and left ventricular volume changes can be seen in the right ventricular impedance measured between ventricular lead pole and pacemaker housing. The intracardiac impedance (measured by unipolar lead) is dominated by local phenomena between surface of lead and surrounding tissue. The Ventricular Inotropic Parameter (VIP), calculated from the consecutive impedance values is utilized for calculation of heart rate forced by exercise load. There is an inverse relation between VIP and calculated pacing rate.

The impedance signal in cardiac pacing of syncopic patients

The cardiac pacing is applied for treatment of patients with vasovagal syncope.

The syncope treatment by means of cardiac pacing

Generally two types of vasovagal reaction are distinguished:

- cardiodepressive reaction means a dominant role of cardiodepressive component (emphasis by heart rate (HR) decrease),
- vasodepressive reaction means a dominant role of vasodepressive component (emphased by blood pressure (BP) decrease) [3].

The vasovagal reaction must consist of vasodepressive and cardiodepressive components. In the published results [5, 6] we presented evaluation of syncope detection algorithm based on heart rate analysis and its efficacy in preventing syncope

Figure 1. The courses of HUT study with significantly later HR drop.

during head-up tilt test. The 15 patients treated by antisyncope cardiac pacing in our center were evaluated for effectiveness of this therapy. The following conclusions were worked out:

- The interventional pacing significantly increases BP in the group of patients with effective pacing.
- When the pacemaker activation, driven by HR drop, was significantly delayed and occurred during deep BP drop the pacing did not increase BP thus it did not prevent syncope.

The impedance detection algorithms in treatment of syncope patients

The patients with dominant cardiodepressive reaction can be pretty well treated with early syncope detection algorithm based on intracardiac electrocardiogram. For the dominant vasodepressive patients the other algorithm must be developed. For early syncope detection we evaluated stroke volume (SV) signals. The SV was measured by Portapres (infrared plethysmography) and by impedance rheography (impedance plethysmography) developed in Warsaw University of Technology. The signals were assessed by our diagnostic system during head up tilt test examination.

The SV courses during syncope provoked by head up tilt test.

SV courses calculated from Penaz plethysmographic signals

Our clinical study [7] showed that in group of 21 syncope patients developing vasodepressive reaction the SV (calculated from Penaz plethysmographic signal) drop was observed significantly before HR drop; mean 119.85 ± 81.45 sec. The BP drop also was observed before SV drop; mean 120.95 ± 76.22 msec., but this finding seems to be less significant for future applications.

From our study it follows, that in the study group the SV drop appeared significantly earlier to HR drop in patients with dominant vasodepressive type of vasovagal syncope as in an example of record presented below.

Comparison of SV courses calculated from Penaz plethysmographic and rheographic signals

To infer that impedance and Penaz plethysmographic methods for assessment of SV provide the same results the presented study were carried out. The group of 6 patients (2 females and 4 males) age from 15 to 79; mean 44.62 ± 28.34 years were enrolled in study group. All patients underwent standard passive head up tilt test (HUT). The standard HUT with 20 min. of elevation (60°) was followed by administration of 300 mg nitroglycerine (NTG) for patients with negative (no syncope) passive results.

- Impedance cardiography and Penaz plethysmography were performed parallelly with following schedule:
- horizontal position – one minute before tilt,
- tilted position – at 5, 10, 15, 20 minute of tilt,
- NTG provocation – every one minute (if passive test negative),
- during syncope – every one minute,
- horizontal position – one minute after return to
- horizontal position.

The courses of positive or negative HUT in provoked syncope are presented in figures 2–5 and courses of positive HUT in spontaneous syncope are presented in figures 6 and 7.

Figure 2. The courses of positive HUT in patient A with NTG provocation of syncope.

Figure 3. The courses of negative HUT in patient B with NTG provocation of syncope.

Figure 4. The courses of positive HUT in patient C with NTG provocation of syncope.

Figure 5. The courses of positive HUT in patient D with NTG provocation of syncope.

Figure 6. The courses of HUT in patient E with spontaneous syncope.

Figure 7. The courses of HUT in patient K with spontaneous syncope.

The statistical ANOVA analysis of the data obtained during the study showed no significant differences (except case presented in Figure 6) in results collected with two applied methods.

The model of measurements of SV from the intracardiac and external leads

In order to compare data obtained using intracardiac electrodes with the measurements data from the chest surface we applied simple model of electric volume conductor composed of sphere inserted in cylinder, both with uniform electric conductivity. The sphere and cylinder represented heart and chest respectively. The active electrode is placed at the heart apex and on the surface of cylinder. The resistance of medium between electrodes is given by

$$\rho = 4\pi a \frac{V(\alpha)}{I} \quad (1)$$

and voltage signal at the input of pacemaker is

$$V(\alpha) = \frac{I}{2\pi a \sigma f(\alpha)} \quad (2)$$

where:

a – is the distance between electrodes,

$V(\alpha)$ – potential at the measuring site,

σ – modulus of conductivity (depends on the site where electrode is placed),

$f(\alpha)$ – represents the influence of the geometrical parameters of volume conductor.

This simple model is useful in analysis of observed phenomena.

Discussion

Our studies showed that cardiac pacing can be successfully applied for treatment of patients with dominant cardiodepressive type of vasovagal syncope. It was found that pacing applied after significant drop of BP is ineffective for treatment of syncopic patients. The analysis of courses of HR and BP during syncope showed that algorithms

based on heart rate changes are not useful for pacing treatment of patients with the dominant vasodepressive type of syncope. In patients with dominant vasodepressive syncope the HR drop is observed shortly before BP drop and therefore the pacing, triggered by algorithm based on RR analysis, is delivered to late. The clinical examinations showed that the SV signal seems to be good enough for early detection of the syncope with dominant vasodepressive type of reaction. Additionally this signal is pretty good related to BP changes during syncope. Impedance measurements are used in control of some pacemakers parameters. The impedance measurement package may be incorporated in modern pacemakers. Clinical study showed that the plethysmography and impedance reography deliver similar results (at 95% confidence level). Although reographic results were obtained with the leads system located on the chest we presume that results are related to the results obtained from intracardiac leads system. This assumption was conformed by simulations with presented above model. The results have showed, that measured potentials and consequently calculated SV values are strongly related to $\cos\theta$ (see formula 2) and can vary from patient to patient. The theoretical results are also confirmed by experiments and clinical (during electrophysiological studies) study of SV calculated from intracardiac data [2, 9]. Applied thermodilution and electromagnetic methods gave the same results. Our study shows: a) for syncope control the trends are more important than exact values of SV, b) with both lead systems the same blood volume is measured. We think our estimation is sufficient.

Conclusions

1. The impedance SV signal measured by intracardiac leads can be applied for accurate early detection of SV drop.
2. Algorithm based on SV drop detection can be utilized for pacing treatment of syncopic patients.
3. Asses of SV impedance signal from intracardiac leads can be performed in present pacemaker technology.

References

- [1] Alt E, Barold S, Stangl K. Rate adaptive cardiac pacing. Springer Verlag Berlin 1993.
- [2] Kaye G, Edgar D, Mudawi T, Lippert M, Czygan G. Can transventricular intracardiac impedance measurement discriminate haemodynamically unstable ventricular arrhythmias in human? *Europace* 2007; 122-126.
- [3] Kenny R, Ingram A, Bayliss J et. al. Head-up tilt test: A useful test for investigating unexplained syncope. *Lancet* 1986; 1: 1351-1355.
- [4] Pałko T. Progress in methods and devices for bioimpedance studies, Monography The current research in Poland, Part III Biomeasurements, Warsaw 1994. 306-311. Wydawnictwo Exit.
- [5] Pęczalski K, Wojciechowski D, Sionek P, Kowalewski M. Diagnostics of recurrent syncope – the stand for physiological parameters evaluation, Structures-Waves – Biomedical Engineering 2000 (edited by Polish Acoustic Society in Krakow); V: 147-150.
- [6] Pęczalski K, Wojciechowski D, Sionek P, Pałko T. The impedance measurements in cardiac pacing – current applications & areas of research. Lecture notes of the ICB Seminar “Recent Achievements in Bioimpedance Research”. International Centre of Biocybernetics. Warsaw 2005, 167-172.
- [7] Pęczalski K, Wojciechowski DZ. The cardiac pacing in vasovagal syncope treatment. *Acta Bio-optica et Informatica Medica* 2000; 6(1-2): 5-14.
- [8] Schaldach M. Electrotherapy of the Heart. Springer Verlag Berlin 1992.
- [9] Zima E, Lippert M, Czygan G, Merkely B. Determination of left ventricular volume changes by intracardiac conductance using a biventricularelectrode configuration. *Europace* 2006; 8: 537-544.