character of atropine-induced activity is quite noticeable. We can notice a certain degree of resemblance with spike and wave episodes induced by low doses of pentyleneetetrazol or gamma-hydroxybutyrate (3,13). The natural endogenous GABA metabolite, gamma-hydroxybutyrate is known to induce rhythmic spike and wave activity of a shape very similar to atropine-induced activity, as demonstrated in Fig. 3. However, there is a marked difference in the occurrence of both these types of spike and wave activity in the EEG patterns. While atropine-induced activity is quite regular in this sense and its frequency is as low as 0.33 Hz, gamma-hydroxybutyrate-induced spikes show a cluster arrangement within EEG pattern and a higher rate of frequency.

Additional evidence is necessary to solve the problem of classification of atropine-induced activity in relation to the other experimental models of epilepsy.

Acknowledgement:
Author wish to thank Mrs. J. Bajgarová for skilfull technical assistance.

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Submitted June 1998. Accepted July 1998.

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A NEW METHOD OF ESTIMATION OF THE OPTIMAL AV DELAY BY USING PULSE OXIMETRY IN DDD PACED PATIENTS

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1st Department of Internal Medicine, Charles University, Faculty of Medicine and Teaching Hospital, Hradec Králové; (Head: prof. MUDr. J. Kvasnička, CSc.)

Summary: The paper gives a detailed description of a new method for estimating the optimal AV delay in dual chamber paced patients, which is non-invasive, not dependent on the examiner, not time consuming and inexpensive. In principle, the pulse oximetry signal obtained by common finger probe was used to measure the change in its time course after changes in pacemaker stimulation. The Eagle 4000 monitor, manufactured by Marquette USA, was used for measurements and digitizing the data and then this data was analyzed using a portable personal computer with original programs developed in Fannulus v. 3.5. Our results were compared to the standard method for optimizing AV delay which uses the direct measurement of blood pressure in the ascending aorta. Twenty-four patients with Physios pacemakers were enrolled in the pilot study. Measurements showed a positive correlation (r = 0.982, N = 432) between the changes in the pulse oximetry amplitude and changes in the pressure pulse amplitude measured in the ascending aorta by a catheter-tip manometer. These results indicated that this new method could be a possible alternative to the currently used techniques for AV interval optimization.

Key words: DDD pacing, Optimal AV interval, Pulse oximetry, Atrial contribution

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Summary: The paper gives a detailed description of a new method for estimating the optimal AV delay in dual chamber paced patients, which is non-invasive, not dependent on the examiner, not time consuming and inexpensive. In principle, the pulse oximetry signal obtained by common finger probe was used to measure the change in its time course after changes in pacemaker stimulation. The Eagle 4000 monitor, manufactured by Marquette USA, was used for measurements and digitizing the data and then this data was analyzed using a portable personal computer with original programs developed in Fannulus v. 3.5. Our results were compared to the standard method for optimizing AV delay which uses the direct measurement of blood pressure in the ascending aorta. Twenty-four patients with Physios pacemakers were enrolled in the pilot study. Measurements showed a positive correlation (r = 0.982, N = 432) between the changes in the pulse oximetry amplitude and changes in the pressure pulse amplitude measured in the ascending aorta by a catheter-tip manometer. These results indicated that this new method could be a possible alternative to the currently used techniques for AV interval optimization.

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Introduction
About 50% of patients indicated for pacemaker treatment have dual chamber pacemaker implanted. In this test the term DDD mode (DDDM) pacing is used only when the right atrium and the right ventricle are both sensed and stimulated. It is generally accepted that optimizing the AV interval becomes necessary when determining in all patients (1). Of particular importance is the optimizing of the AVI in patients with hypertrophic obstructive cardiomyopathy, dilated cardiomyopathy with severe prolongation of the AVI and in patients with left ventricular dysfunction associated with a presystolic mitral regurgitation. There is still the problem how to estimate this optimal AVI (11). The optimal AVI for the atrial synchronous pacing (DDDM) may be defined as the time interval between the atrial and the ventricular stimuli, at which the stroke volume is highest. Most currently used techniques for determining this optimal setting are either expensive or time-consuming (2,5.4), and therefore are not routinely used. The aim of our study was to investigate a new, alternative method, which is easily reproducible and does not have these known disadvantages.

Theoretical basis of the research
The basis for our idea came from the experiments of Mitchell et al. in 1965 (3). Their experiments were performed in sequentially paced dogs with surgically induced AV block. They demonstrated a decrement in stroke volume in ascending aorta by a Doppler flow probe mounted on the aorta when they changed stimulation by switching off the atrial stimulus. In this way they were able to quantify the atrial contribution. In our study, we replaced the complicated direct measurement of aortic flow by an invasive direct measurement of aortic blood pressure (aBP). Keeping in mind that under these conditions, the heart rate and the mean pressure do not change and therefore there is tight correlation between the pressure pulse and the stroke volume (8,9). The main idea of this paper has been to replace an invasively measured parameter by the photoplethysmographic technique, which was already tested (4,10). Other studies showed that every person has only one AV delay, when the atrial contribution (AC) is maximal.

Technical equipment
The equipment used for the chosen technique had to be common in cardiac pacing laboratories and it could not contain non-standard parts, i.e. special finger oximetric probe or special software in the monitor of vital signs.

The way of the pacemaker programming
We enrolled patients with Physios dual chamber pacemakers produced by Biotronik, Germany. The programmer EPR 1000 Color (Biotronik) was used.
Procedure of measurement

During the procedure, a constant ventricular rate was maintained to exclude the impact of the force-frequency phenomena on the force of ventricular contractions. All patients were paced at the ventricular rate of 70/min or at a rate 10 beats above the resting sinus rate.

In the first part of the examination, the AVI was increased and then decreased in steps of 50 ms. During each step the data was recorded on the hard disc of the PC.

In the second part of the examination, the pacemaker was changed from dual chamber stimulation (DDIM) to single chamber ventricular stimulation (VVIM) for 2-3 beats and then back to the DDIM stimulation. In this way, we were able to switch off the atrial stimulus.

We were interested only in the first beat after the stimulation change because of the fact that the OS amplitude quickly reverted back to its original magnitude. This quick change back can be explained in two ways. First, there can be prompt changes in a finger’s microcirculation and secondly the oximetric curve is expression of the time course of relative numerical values. The oximetric devices constantly change the calibration of oximetric graph on the screen to maximize the graph on the screen. This maximization occurs within 5-10 beats.

Computer analysis

Before starting the measurement, a patient’s name and heart rate was saved into a text file.

Data acquisition

Data were transferred from the monitor to the PC by the ethernet connection online. A special program in MS-DOS was used for data acquisition. We did not use absolute values of ECG, aBP and OS, but rather assessed the stability of the magnitude of OS pulse amplitude. The measurement was accepted when the pulse amplitude of the first pattern beat was within 96% and 104% of the amplitude of the second pattern beat. The second criterion assessed stability of the level of the minimal saturation measured. The examination was accepted if the minimal level of the first pattern beat was within ±5% and ±4% of the amplitude of the second pattern beat above the minimal level of the second pattern beat.

Measurement procedures

Dual chamber pacing with an AV interval change

We changed the AV interval in steps of 50 ms, from 50 ms to 100 ms, 100-150, 150-200, and from 200 ms to 250 ms and then from 250 ms to 200 ms, 200-150, 150-100, and from 100 ms to 50 ms. We calculated an index of atrial intervals (IAI) for each obtained data. The IAI is the difference between the amplitude of the tested beat and the amplitude of the second pattern beat expressed in % of the amplitude of the second pattern beat. Accepted data together with the patient’s name, the heart rate, and the time coordinates of the desired parts of the aBP and the OS curves were saved on hard disc into the test file. The file was automatically assigned its name with the number and the specification of the measurement procedure.
Technique for the monitoring of vital signs

The monitor of vital signs Eagle 4000, Marquette USA, was used to record and digitize the ECG, aBP and oximetr
cic signal (OS). The sampling frequency for EKG, aBP and OS was 240, 120 and 60 Hz respectively. The monitor has
three regimes for filtering and displaying curves of vital sigh
ts. The operating room regime was chosen for our resear

ECG acquisition

The ECG curve was recorded from the II limb lead in
patients who had pacemakers in right subclavian area. For
patients with the pacemaker in the left subclavian area, limb lead III was used. The aim was to obtain a minimum
amplitude of 1 mV for the magnitude of the pacemaker im-
pulse. The voltage of pacemaker impulses could be increa
sed for the quality ECG record within the time of measure
ment.

Blood pressure measurement

The Millar manometer-tip catheter was used for the di
direc, invasive aBP recording. The monitor automatically ca
ribmates the blood pressure curve on the screen.

Pulse oximetry measurement

Recording the pulse oximetry signal was the feature of
our method. We used a common finger probe manufactu
red by Marquette. The monitor displayed two times the or
iginal magnitude of pulse oximetric curve.

Patient's preparation

Patients were examined in the supine position with an
elevated left upper extremity to get the finger probe higher
than the chest wall thus eliminating any impact of upper ex
ternal factors influenced the time course of OS. Many external factors influenced the time course of OS. We changed the AV interval in steps of 50 ms, from 50

Procedure of measurement

During the procedure, a constant ventricular rate was
maintained to exclude the impact of the "force-frequency
phenomena" on the force of ventricular contractions. All
patients were paced at the ventricular rate of 70/min or at
a rate 10 beats above the resting sinus rate.

In the first part of the examination, the AVI was incre
ased and then decreased in steps of 50 ms. During each
step the data was recorded on the hard disc of the PC.

In the second part of the examination, the pacemaker
was changed from dual chamber stimulation (DDIM) to
single chamber ventricular stimulation (VVIM) for 2-3 be
ats and then back to the DDIM stimulation. In this way, we
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teen to maximize the graph on the screen. This maximization occurs within 5-10 beats.

Computer analysis

Before starting the measurement, a patient's name and
heart rate was saved into a text file.

Data acquisition

Data were transferred from the monitor to the PC by
the ethernet connection online. A special program in MS
DOS using the Marquette format was developed. We did
not use absolute values of ECG, aBP and OS, but rather
synchronously arranged relative numerical values which
correctly copied the time course of variables. The recording
was started and stopped manually using a visual control on
the screen of PC. The program saved data into text files af
fer finishing each measurement. A batch program started
another program for data analysis.

The main part of data analysis was performed by the
Famulus 3.5 program (7). This is program for simulation and
programming of mathematical and physical models. It can read and write data in text format to the hard disc and start
or finish programs written in the Famulus through the use
of the user’s menu. A set of original programs was pro
grammed for this measurement analysis. The programs were
started by icons from the desktop section of Windows.

Assessment of measurement quality

The main program was started after saving the data on
a hard disc. Impulses of pacemaker were detected on the
ECG record. The second derivation of ECG time course
was counted and the values were corrected. The values hig
hier or equal to 1000 were replaced by 0. Values where we
were able to find time coordinates of impulses of pacemaker
were obtained. The first stimulus and the first complete
beat were located, in which the coordinates of atrial and
ventricular stimulus were known, with programmed cycles
with constants. The constants’ values were counted from
known sampling frequency of ECG known heart rate and
values from five possible values of the tested AV intervals. All
ECG records were tested until the moment when the time
between atrial and ventricular impulses was different from
that time in the first complete beat. We had to find two
"pattern" beats with the same AVI as in the first complete
beat before the "tested" beat. When we could not fin
them, we had to reject the data and repeat the measure
ment.

We identified two beat patterns immediately before the
tested beat, the tested beat, and the beat immediately after
the tested beat. We knew all coordinates of the important
ventricle impulses from this point and we could find amplit
tudes of aBP and OS in both pattern beats and the tested beat (see Fig. 1).

Many external factors influenced the time course of OS.
We have estimated two quality criteria which served for re
jection of those examinations, during which the pulse oxy
gen saturation signal was not stable enough. We used them
during both ways of the measurement. The first criterion as
sembled the magnitude of OS pulse amplitude and
constant of relative numerical values. The oximetric devices con
stantly change the calibration of oximetric graph on the sc
teen to maximize the graph on the screen. This maximization occurs within 5-10 beats.

Measurement procedures

Dual chamber pacing with an AV interval change

We changed the AV interval in steps of 50 ms, from 50

Fig. 1: Estimation of pulse amplitudes after the first and se
cond pattern beats and the tested beat when switching the
stimulation mode from DDIM to VVIM.

Fig. 2: Computer printout of one of the examinations.

Values calculated from the oximetric signal (upper graph) and the aortic blood pressure signal (lower graph) using
two different methods: The curves in the upper parts of
graphs are constructed from the increments or decrements of the analyzed pulses, induced by changes in the AV inter
val length (the maximal amplitude was taken as 100%). The
points below are calculated from the changes induced by
switching-off the atrial stimulus (switched from DDIM to
VVIM of pacing). The maximal atrial contribution is found
at the AV interval of 200 ms.
Discussion

Contemporary methods for optimizing the AV intervals are not routinely used. They are generally time consuming, invasive, and/or expensive. The most frequently used method for estimating an optimal AV interval is to evaluate the systolic volumes in different AV delays using echo Doppler measurement of the blood flow in the ascending aorta. One of the disadvantages of this method is that it is too time-consuming, which affects the experience level of echocardiographers (2). The other, more accurate methods are invasive or use technical devices, which would not be common equipment in pacing laboratories (3.4.5).

The pulse oximetry technique is usually not used for measuring hemodynamic variables because it is only a relative value with big interindividual variability. The measurement of pulse oximetry is based on the photoelectrometric principle using red and infrared light. The main aim of the developers of this technology was to get a digital form of the oxygen saturation value. The curve of the time course of the oxygen saturation changes is only a side product, complementing information about vital signs already available on the screen of the monitor. Our experience showed that the Marquette USA system is suitable for our new method. It shows the full amplitude and variations of the OS without losing the minima by replacing them with an OS value.

As documented in the literature, each of our patients had only one AV interval in which the atrial contribution was maximal (4). The time course of blood pressure values during the changes in stimulation was intrindividually repeatedly constant. The most important result was the evidence of the tight correlation between the changes in pressure pulse amplitude and changes in the pulse amplitude of oximetric signal during changes in the stimulation. The correlation coefficient 0.982 from our pilot study is similar to that from the Fargel and Lindvall study (r = 0.53-0.97). The value of atrial contribution estimated by our method is lower than the value estimated by Fargel (35-94%).

The fact is important, since the same optimal AV interval in each patient was obtained by both procedures of measurement. This suggests that one could use only one procedure for estimating the AV interval in the future. It seems, that the procedure in which the atrial impulse is switched off will be better, because the values obtained from the original measurement are similar. Our new method has limitations as well. In addition to the construction of the pulse oximetry device, there is an important role of patient’s compliance. The correct way to breathe must be practiced with patients before measurements are recorded. The most frequent mistake of the patients was deeper inspiration before expected apnea or forced expiration immediately before apnea. Another mistake was Valsalva within apnea. Not all patients were able to avoid these mistakes. Movement of hands or fingers with the pulse oximeter was another source of the measurement inaccuracies. These factors that affect the measurement were if the patient was nervous or there was an impact of a brain atherosclerosis and a parkinsonism.

Conclusion

If no other limitations will be found in the future, the present method would be a new, easy way for the optimization of AV interval in dual chamber paced patients.

Acknowledgement

Supported by grant No. 3677/3/96 of the Internal Grant Agency of the Ministry of Health of the Czech Republic.

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Submitted May 1998. Accepted July 1998.

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Measurement with switching off the atrial impulse

We switched the stimulation mode from DDIM to VVIM for 2-3 beats during the second procedure to estima-
tive the optimal AVI. After switching off the atrial impulse the stimulation continued in DDIM. We performed the me-
surement at AVIs of 50, 100, 150, 200, and 250 ms. This sequence was measured two times. We attempted to locate a beat without an atrial impulse. Every variable was measured and data was saved the same way as in the first method of the measurement.

Final analysis and the estimation of the optimal AV interval

The data from the first procedure using DDIM pacing were multiplied by 1 in measurement with the ascending changes of AVI. The final IAC for a given AVI was counted as the mean of indexes of atrial contribution from the ac-
cending and the descending change of that AVI. The final IAC for a given AVI in the second measurement procedure was calculated as the mean of indexes of atrial contri-
bution measured for that specific AVI.

The graphic presentation was made after the determina-
tion of the optimal AV delay for aBP and OS as well. The beat with the maximal value of the final IAC was the beat in which the AC was maximal. The graphic presentation of the first procedure was displayed in the upper curve of the graph with the maximal AC being the 100% value. The de-
crements of AC for the other AV intervals were presented in % of the value of the preceding AC. The graphic presentati-
on of the second measurement was placed in the lower part of graph. These points represented values of both indexes of AC and the final IAC in each AV interval (see Fig. 2).

Results of the pilot study

Twenty-four patients with Physios dual chamber pace-
makers were enrolled into our pilot study. The pacemaker was implanted for sick sinus syndrome in 12 patients and for complete AV block in 12 patients. Both procedures of measurement were performed on each patient. Correlation between the values obtained for the aBP changes and oxy-
gen saturation changes showed a tight association, the cor-
relation coefficient being 0.982 for 432 measurements. From the aBP measurement, the optimal AVI was found to be 150 ms in 10 patients, 200 ms in 8 patients and 250 ms in 6 patients. The saturation pulse analysis identified the same interval in 19 patients. In the remaining 5 patients the maximal AC identified by the pulse saturation differed from the maximum identified by the pulse pressure analysis by no more than 50 ms. In all of these 5 patients, the dif-
ference in magnitude of the IAC of the beats in question was less than 2% of the amplitude of the second pattern beat, i.e. the atrial contribution indexes of the two beats were ne-
earily identical in amplitude. The mean AC that was deter-
dined by pulse oximetry in our study was 33.7% (8.1-57.9%).

Discussion

Contemporary methods for optimizing the AV intervals are usually not routinely used. They are generally time consuming, invasive, and/or expensive. The most frequently used meth-
 hod for estimating an optimal AV interval is to evaluate the systolic volumes in different AV delays using echo Doppler measurement of the blood flow in the ascending aorta. One of disadvantages of this method is the high dependency on the experience level of echocardiographist (2). The other, more exact methods are invasive or use technical devices, which would not be common equipment in pacing labora-
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Our new method has limitations as well. In addition to the construction of the pulse oximetry device, there is an important role of patient’s compliance. The correct way to breath must be practiced with patients before measurements are recorded. The most frequent mistake of the pati-
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Conclusion

If no other limitations will be found in the future, the present method would be a new, easy way for the optimiza-
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Submitted May 1998. Accepted July 1998.

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