T Wave Width Alterations during Valsalva Maneuver in Diabetic Patients

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Abstract

In this work we analyzed the T wave width evolution on an ECG database containing 27 records coming from diabetic patients performing the Valsalva Maneuver (VM). The objective is to assess whether the maneuver is accompanied with early signs of ischemia and if those are measurable by T wave shortening. The hypothesis for this T wave shortening is that endocardial action potentials reduce their duration at the very beginning of global ischemia generated by the VM while epicardial action potentials duration remains unchanged so reducing the overall T width. The absence of significant ST changes evidence no severe ischemia. We found a mean T wave shortening in 27ms with standard deviation of 2.5ms ($p < 10^{-5}$) during VM as compared to the control situation (before VM). Delineation of T wave is done automatically. Since the T onset delineation had not been validated in manually annotated databases, several thresholds have been swept, looking for the best display of T wave width shortening.

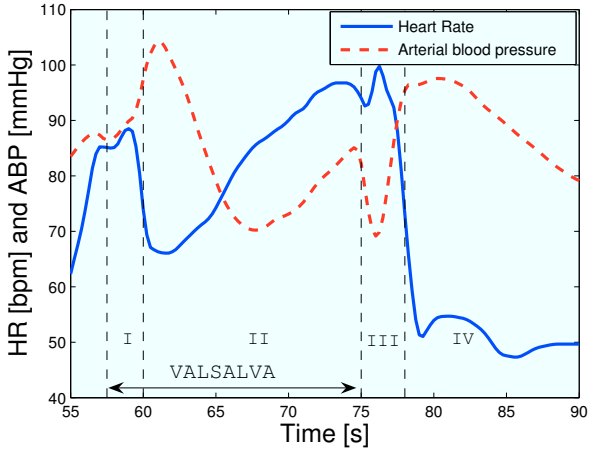

Figure 1. Response of the arterial pressure and the heart rate during the Valsalva maneuver describing the four phases.

1. Introduction

The Valsalva maneuver (VM) is used as a test to evaluate the performance of the autonomic nervous system (ANS), which provides automatic, involuntary regulation of several body functions including the cardiac muscle activation. This regulation is controlled by the activation of the sympathetic and the parasympathetic autonomous branches.

The maneuver is performed by having the subject conduct a maximal, forced expiration against a pressure of $40mmHg$ and holding this for about 15 seconds. Before, during and after this maneuver, the expiratory pressure and the electrocardiogram (ECG) are monitored and registered. The Valsalva maneuver leads to hemodynamic changes in heart rate (HR), blood pressure and cerebral blood flow and may be divided into four phases. See figure 1.

When the VM starts, contraction of the thoracic cage compresses the lungs and causes a large rise in intrathoracic pressure (the pressure measured in the space between the lungs and thoracic wall). This rise in intrathoracic pressure compresses the vessels within the chest. Aortic compression results in a transient rise in aortic pressure (Phase I), which causes a reflex bradycardia due to baroreceptor activation. Because the thoracic vena cava also becomes compressed, venous return to the heart is compromised, resulting in a large fall in cardiac output. This leads to a secondary fall in aortic pressure (Phase II), and as aortic pressure falls, the baroreceptor reflex increases HR. After several seconds, arterial pressure (both mean and pulse pressure) is reduced, and HR is elevated. When the subject starts breathing again, the sudden loss of compression on the aorta can cause a small, transient dip in arterial pressure and further reflex increase in HR (Phase III). When compression of the vena cava is removed, venous return suddenly increases causing a rapid rise in cardiac output several seconds later which leads to a transient increase in

arterial pressure (Phase IV). Arterial pressure overshoots during Phase IV because the systemic vascular resistance is increased due to sympathetic activation that occurred during Phase II. HR reflexively decreases during Phase IV in response to the transient elevation in arterial pressure [1].

This maneuver generates a diminution in the blood flow leading to an initiation of myocardial ischemia. In the first phase, the ischemia is subendocardial since subendocardium is the first affected region by the reduction in myocardial blood flow. The transmembrane action potential duration of ischemic cells gets shorter in the first minutes of a coronary occlusion at the endocardium, then reducing the dispersion in duration between endo and epicardium, and so generating a narrowing of the T wave [2].

Ischemia modifies action potentials in amplitude and duration what may alter ventricular repolarization dispersion (VRD). VRD is related to the variance among recovery times throughout ventricular myocardium as a result of differences in both activation times and action potential duration. An increased VRD implies a modification of the T wave morphology. New experimental studies seem to point out T wave duration as a good quantifier of VRD [3].

In this work we study the evolution of the T wave duration during the different phases of Valsalva maneuver,in order to evaluate the extent of flow reduction and their manifestation on the T wave width as a marker of early ischemia at the endocardium cells. The T wave duration is measured by an automatic delineator of the T onset and T end and their values at different time instants of the maneuver are compared.

Diabetes may alter the autonomic nervous system and it has been demonstrated that autonomic conditions directly affect the ventricular myocardium causing differences in QT interval that are independent of the HR [4].

2. Methods

2.1. Database

The database consists of single-lead ECG and expiratory pressure records before, during and after the VM in 27 diabetic patients: 12 women (2 with diabetes type I and 10 with diabetes type II) and 15 are men (4 with diabetes type I and 11 with type II). The age of the patients range from 28 to 76 with a mean of 48 years and the duration of the diabetes range from 1 to 45 years with a mean of 13 years [5].

2.2. T wave delineator

An ECG delineation system based on the wavelet transform (WT) has been used for QRS detection and T wave location and delineation. This delineator has been previously described and evaluated in standard databases [6].

The WT provides a description of the signal in the time-scale domain, allowing the representation of the temporal features of a signal at different resolutions; therefore it is a very suitable tool to analyze the different patterns which have different frequency content (QRS complex, P and T wave) occurring in the ECG. The multiscale approach permits to attenuate noise at rough scales, and then to refine the precision of the positions with the help of finer scales.

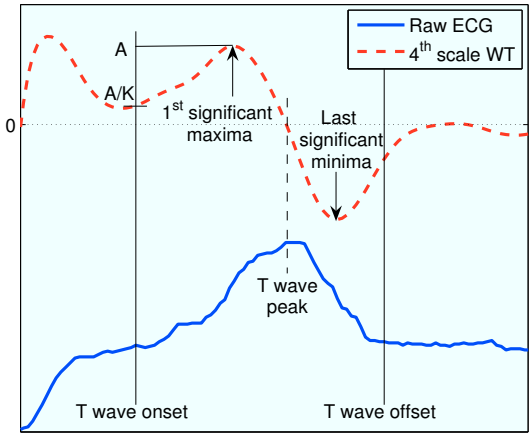

Figure 2. Example of T wave onset, peak and end delineation.

The process for multiscale T wave detection and delineation consists of first defining a T wave search region window for each beat, relative to the QRS position and function of the recursively computed RR interval. Within this window, at least two local maxima in the 4^{th} scale, exceeding a threshold, need to be found in order to asses the presence of a T wave. The zero crossing between them are considered as T wave peaks. Depending on the number and the polarity of the found maxima there are six different possible T waves: positive (+), negative (-), biphasic (+/- or -/+), only upwards and only downwards . If the T wave is not found in the 4^{th} scale the process is repeated over the 5^{th} scale. The onset (offset) of the T wave is identified by finding the crossing point of the WT signal with a threshold defined by a fraction K_{on} (K_{off}) of the first (last) significant maximum (A) of the WT modulus (see figure 2). If a local minimum is found before the threshold is crossed, the local minimum is considered as the onset (offset).

3. Results

We calculate the root mean square series (RMS) of the the ST level with the same technique we used in [7]. Then, we perform a median filtering with a window size of 5 sec-

onds on the T width series and distinguish five different stages: 5 seconds before the start of the VM (bef), during the 5 seconds immediately after the beginning of the VM (VM_1), from 5 s to 10 s within the VM (VM_2), between the 10^{th} second and the end of the VM (VM_3) and finally during 5 seconds immediately after the end of the VM (aft). We compare the middle position of the median filtered T width series before the VM interval with the ones during and after the VM.

We have used the paired Student's t test in order to assess whether the means of T width in each two periods are statistically different from each other. We redo the calculations with the HR, the interval from T apex to T end, the RMS od the ST segment and the QT interval. The results in terms of p-value and 95% confidence interval (C.I.) are shown in Table 1

Table 1. Differences in heart rate (HR), T wave width (TW), interval from T apex to T end (TE), QT interval (QT), and RMS value of ST segment (ST) between the different segments during and after the VM ($VM1$, $VM2$, $VM3$, aft) with respect to the 5 second segment previous to the maneuver (bef).

	p-value	**C.I.**
$HR_{VM_1} - HR_{bef}$ *[bpm]*	0.08	[-7.3, 0.5]
$HR_{VM_2} - HR_{bef}$	0.002	[2.4, 9.6]
$HR_{VM_3} - HR_{bef}$	$4 \cdot 10^{-8}$	[10.6, 18.3]
$HR_{aft} - HR_{bef}$	$2 \cdot 10^{-12}$	[15.0, 21.0]
$TW_{VM_1} - TW_{bef}$ *[ms]*	$2 \cdot 10^{-5}$	[-26.6, -11.7]
$TW_{VM_2} - TW_{bef}$	$9 \cdot 10^{-6}$	[-36.6, -16.7]
$TW_{VM_3} - TW_{bef}$	$5 \cdot 10^{-6}$	[-35.7, -16.8]
$TW_{aft} - TW_{bef}$	0.12	[-14.7, 1.8]
$TE_{VM_1} - TE_{bef}$ *[ms]*	0.47	[-2.5, 5.3]
$TE_{VM_2} - TE_{bef}$	0.78	[-6.0, 4.6]
$TE_{VM_3} - TE_{bef}$	0.05	[-7.8, -0.1]
$TE_{aft} - TE_{bef}$	0.17	[-9.3, 1.7]
$ST_{VM_1} - ST_{bef}$ *[μV]*	0.76	[-1.0, 1.4]
$ST_{VM_2} - ST_{bef}$	0.94	[-1.9, 1.8]
$ST_{VM_3} - ST_{bef}$	0.61	[-2.1, 3.5]
$ST_{aft} - ST_{bef}$	0.9	[-2.0, 2.2]
$QT_{VM_1} - QT_{bef}$ *[ms]*	0.005	[2.1, 11.2]
$QT_{VM_2} - QT_{bef}$	0.04	[0.1, 7.7]
$QT_{VM_3} - QT_{bef}$	0.07	[-0.4, 10.4]
$QT_{aft} - QT_{bef}$	0.38	[-7.0, 2.8]

Delineation of the T wave onset using the WT method, in contrast with the rest of significant points, had not been validated before, due to the absence of databases with manual T wave onset annotations. Therefore we studied the behavior of the delineator by varying the threshold K_{on} trying to find the K_{on} value at which the shortening of the T wave is better observed.

We tested evenly distributed K_{on} values from 1.5 to 7, performed the delineation process and calculated the differences in T width between before VM (bef) and during either $VM1$, $VM2$ or $VM3$. The p-values obtained from the Student's t test are shown in figure 3. A minimum in the p-value is not reached because determination of T wave onset is bounded by the local minimum protection rule, which does not move further the onset even if the K_{on} is extremely reduced. Figure 3 seems to point out 4 to 4.5 as optimal values for the K_{on} fraction. In our results we have used $K_{on} = 4$, as proposed in [6].

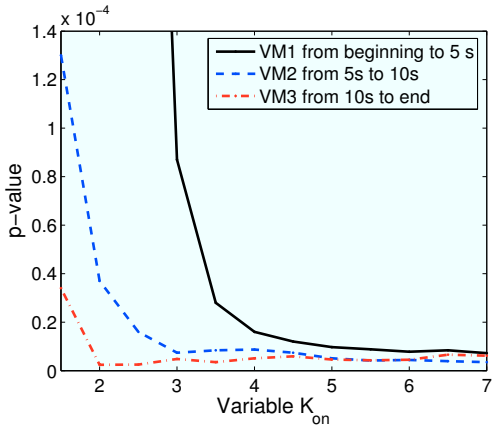

Figure 3. Significance (p-value) of the Student's t test for the differences between T wave width before VM and in the the 5s segments (initial, medium and final) of the VM, as a function of the K_{on} values used in the T wave onset delineation process.

4. Discussion and conclusions

Table 1 shows a statistically significant shortening in T wave width during VM performance ($p = 2 \cdot 10^{-5}$), which enlarges again after the release attaining a width similar to the one before the maneuver ($p = 0.12$). The increased HR does not seem to be the responsible since after the VM, the HR is even higher than during VM whilst T wave has recovered its original width (see figure 4). This observation might evidence the viability of the T width to mark very early signs of ischemia and its potential use for ischemia monitoring like in coronary care unit, etc.

T width shortening seems to result from a width reduction from the onset to the T peak rather than from the peak to the T wave end. This may be related to the spatial distribution of action potential modifications which will require some deeper clinical investigations.

The differences in HR between before the VM and during the first 5 seconds of it are not yet statistically different ($p = 0.08$). However the HR after the first 5 seconds of

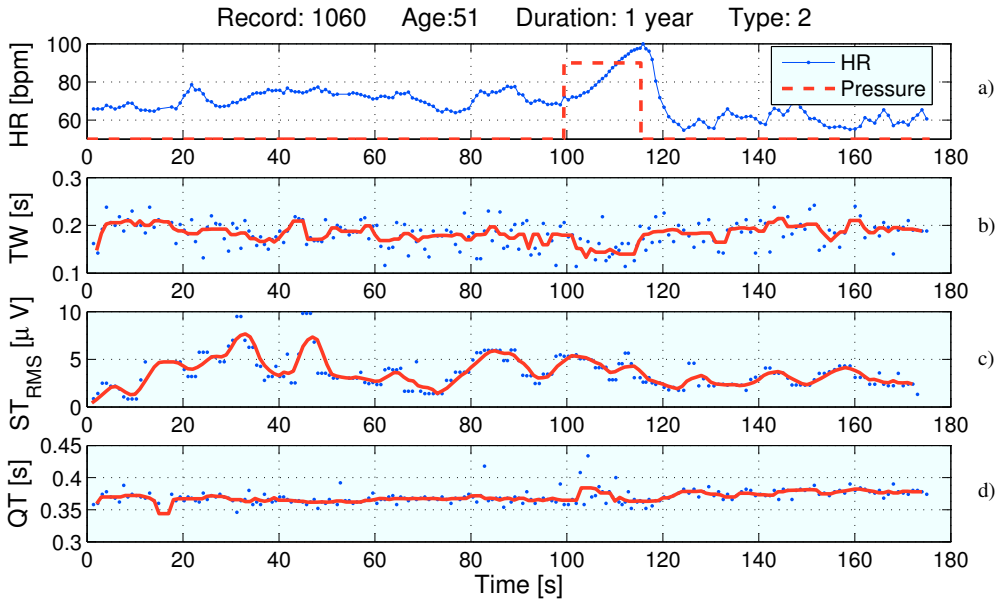

Figure 4. The figure shows in a) the expiration pressure in arbitrary units (dashed line) and the HR (dotted-solid line). In b) the T width of every beat is represented together with a median filtering with window size of 5 s (solid line) showing a shortening of the T width just during the expiration pressure. c) shows the RMS of the ST segment of each beat together with a moving averaging series with window size of 5 s (solid line) and d) the QT interval of every beat represented together with a median filtering with window size of 5 s (solid line).

the maneuver is increasing during and even after VM and the divergences are statistically significant.

ST segment changes are not statistically significant between before and during and after VM. This supports the fact that compression of the arteries and flow reduction due to the effort during VM does not cause a severe ischemia, rather just the initial blood flow reduction which is perceived by the T width shortening as a result of a shortening in duration of the action potential at the endocardium, the first affected part when flow reduction occurs.

QT shows an adaptation to the increment of HR in the beginning of the VM but after the minute 10, QT interval is not following the shortening which occurs with RR interval. As diabetes may alter the autonomic nervous system and autonomic conditions directly affect the ventricular myocardium, the QT adaptation to RR may be impaired and this may be the explanation of the observed behaviour.

Acknowledgements

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References

[1] Porth C, Bamrah V, Tristani F, Smith J. The valsalva maneuver: mechanisms and clinical implications. Heart Lung 1984;13(5):507–518.

[2] Bayés de Luna A. Clinical Electrocardiography: A Textbook. Armonk, N.Y.: Futura Publishing Company, 1998.

[3] Arini P, Valverde E, Beltran G, Laguna P. Geometrical and temporal ecg features for quantification of increased ventricular repolarization dispersion in an experimental heart rabbit model. In XXXII Ann. Conf. Computers in Cardiology. IEEE Press, 2005; 89–92.

[4] Magnano AR, Holleran S, Ramakrishnan R, Reiffel JA, Bloomfield DM. Autonomic nervous system influences on qt interval in normal subjects. Journal of American College of Cardiology 2002;39(11):1820–1826.

[5] Risk M, Bril V, Broadbridge C, Cohen A. Heart rate variability measurement in diabetic neuropathy: review of methods. Diabetes Technol Ther 2001;3(1):63–76.

[6] Martínez JP, Almeida R, Olmos S, Rocha AP, Laguna P. A wavelet-based ecg delineator: Evaluation on standard databases. IEEE Transactions on Biomedical Engineering 2004;51(4).

[7] Mincholé A, Skarp B, Jager F, Laguna P. Evaluation of a root mean square based ischemia detector on the ltst database. In XXXII Ann. Conf. Computers in Cardiology. Lyon: IEEE Press, 2005; 853–856.

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