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T WAVE MORPHOLOGY DURING HEART RATE TURBULENCE IN PATIENTS WITH CHRONIC HEART FAILURE

Lenis G, Dössel O

Institute of Biomedizdical Engineering, Karlsruhe Institute of Technology (KIT), Germany

Gustavo.Lenis@kit.edu

Abstract: *Heart Rate Turbulence (HRT) is the distinctive response of the sinus rhythm of the heart to an isolated ventricular ectopic beat (VEB). The quantification of this process can be used to stratify the risk of sudden cardiac death in patients with a history of acute myocardial infarction. A sensitivity of around 30% has been achieved in different studies. However, the large number of misleading results of the method suggests that new and better risk stratifiers could be developed. In this work, Holter ECG recordings were used to analyze the morphology of the T wave during the HRT in patients with chronic heart failure. The HRT was characterized by newly introduced parameters. In addition, the comparison between normal T waves before and after the VEB showed small but significant changes in morphology. The morphological changes of the T wave could be used for diagnostic purposes.*

Keywords: Electrocardiogram, T Wave, Heart Rate Turbulence, Morphology

Introduction

During a normal HRT, a sinus acceleration follows the compensatory pause after the VEB. The initial acceleration is then succeeded by a deceleration that finally stabilizes at the original RR cycle length. The acceleration and deceleration processes are quantified by the parameters Turbulence Onset (TO) and Turbulence Slope (TS) [1]. Normal values for these parameters are TO<0% and TS>2.5 $ms/beat$. The risk stratification class of a subject is 0 if both parameters are normal. The stratification classes 1 or 2 are chosen depending on the number of abnormal HRT parameters of the patient. A variety of studies has been carried out to evaluate the HRT parameters as risk stratifiers. In general, this procedure delivers a sensitivity of 30%, a specificity of 90% and positive predictive value of 32% [1]. Thus, the amount of false positives and false negatives is high and remains of great concern.

In a previous work [2], a new interpretation of the HRT was given. The HRT was characterized by a second order linear time invariant system. In analogy to the theory of vibrations, a damping coefficient d, together with a resonance angular frequency ω_0, were introduced to quantify HRT. It was stated that these two new parameters should deliver a more global description of the HRT process.

Furthermore, the morphology of the first normal T wave after the VEB was compared to the last normal T wave before it. A significant reduction in its amplitude could be observed after the VEB. Furthermore, the amplitude of the T wave did not return to the original value instantaneously, but rather following an exponential trend. This phenomenon was called Morphological Heart Rate Turbulence (MHRT). New parameters were also defined to quantify MHRT. However, the diagnostic value of MHRT still remains unknown. In this work, we studied MHRT in patients suffering from chronic heart failure. Standard risk stratification parameters gained from HRT were compared to the new parameters presented in the previous and current studies [2].

Methods

Long term ECG monitoring was obtained from a specially designed Holter device. The device records 3 channels at a sample frequency of 256 Hz.

Signal processing: A complex signal processing work flow is needed to carefully investigate ECG wave morphology. First, the R peaks are detected in the ECG signal and their corresponding QRS complexes are extracted and classified. The VEBs suitable for HRT analysis are identified. According to HRT rules, 5 normal beats before the VEB and 15 after it are needed for a reliable analysis. Second, RR intervals are measured for the QRS complexes in the vicinity of each VEB. The HRT is then constructed and the parameters TO and TS are calculated. Subsequently, the estimation of the damping coefficient d and the resonance angular frequency ω_0 is carried out.

Third, the T waves in the vicinity of each VEB are segmented. A mean T wave is built for each beat and compared to a template of the normal T waves. In this work, two morphological features (MF) are introduced to measure how the T wave changes in time and specially after the VEB. The first feature (MF_1) is related to the normalized energy of the difference signal between T wave and template:

$$MF_1(i) = \frac{2 \cdot \int\limits_{-\infty}^{\infty} T_i(t) \cdot Template(t)dt}{\int\limits_{-\infty}^{\infty} (T_i(t))^2 + (Template(t))^2 dt} \cdot 100\% \quad (1)$$

where $T_i(t)$ represents the ith T wave during the HRT and $i \in \{-5, -4, .., 15\}$. The second parameter (MF_2) is the correlation coefficient between the template and each of the T waves:

$$MF_2(i) = \frac{cov\{T_i(t), Template(t)\}}{\sqrt{var\{T_i(t)\}} \cdot \sqrt{var\{Template(t)\}}} \cdot 100\% \quad (2)$$

Patient Nr.	TO [%] ; TS $[\frac{ms}{beat}]$	d ; ω_0 $[s^{-1}]$	MTO_1 [%] ; MTS_1 $[\frac{\%}{s}]$	MTO_2 [%] ; MTS_2 $[\frac{\%}{s}]$
1	0.91 ; 0.18	1.03 ; 1.12	−0.32 ; 0.22	−0.29 ; 0.21
2	−0.01 ; 1.54	2.84 ; 0.36	−0.18 ; 0.05	−0.17 ; 0.11

Table 1: Exemplary MHRT analysis for two patients suffering from chronic heart failure

Notice that if the template and the ith T wave are exactly equal, the parameters MF_1 and MF_2 are equal to 1.

MHRT processing: MHRT is quantified in an analogous way to the HRT. Two MHRT parameters were introduced for this purpose [2]. This definition can be applied for both MF_1 and MF_2.

$$MTO_k = \frac{MF_k(1) - \frac{1}{4}\sum_{i=-5}^{-1} MF_k(i)}{\frac{1}{4}\sum_{i=-5}^{-1} MF_k(i)} \cdot 100\% \quad (3)$$

$$MTS_k = \frac{MF_k(2) - MF_k(1)}{RR(7)} \quad (4)$$

where $k \in \{1, 2\}$ and $RR(7)$ denotes the RR interval length (in seconds) of the beat number 7. MTO represents the initial perturbation in T wave morphology. MTS reflects the speed at which the morphological perturbation returns to its original value.

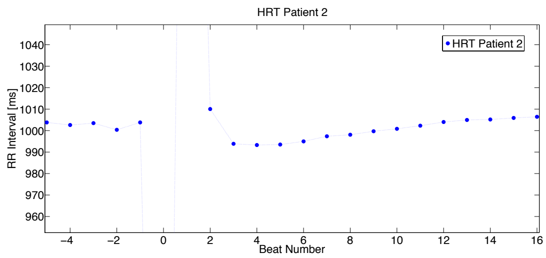
Figure 1(a) shows the HRT obtained for patient number 1. The MHRT constructed for MF_1 can be seen in figure 1(b). The T wave obtained from beat number 7 and the T wave template can be seen in figure 1(c). Even though the shape of the displayed T waves is very similar, their morphology is indeed different with a statistical significance of $p < 1\%$.

Results

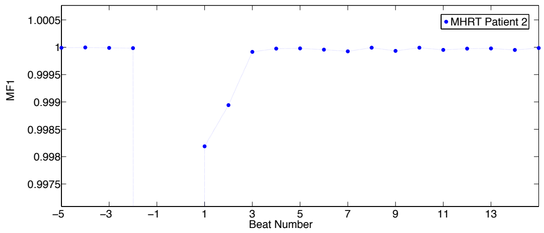
Table 1 shows the results for the MHRT analysis run in exemplary manner for 2 patients. Using only the standard HRT parameters TO and TS, patient 1 would be stratified with the highest risk class 2. However, the damping coefficient d of his HRT response is slightly greater than one. This means, the HRT is slightly over damped. The MHRT coefficients show an evident initial perturbation in T wave morphology after the VEB but a fast restitution of original shape. In contrast, patient number 2 is stratified with HRT risk class 1. However, his damping coefficient d is noticeable higher, what describes a far less responsive turbulence. Furthermore, the MHRT coefficients show a mild initial perturbation of the T wave morphology but a slower restitution of original shape.

Discussion

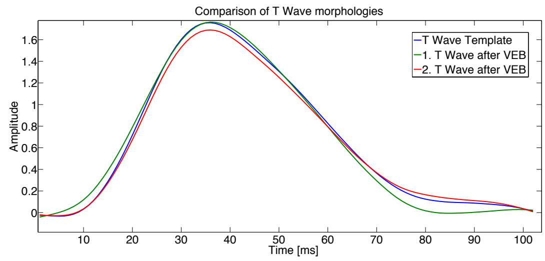
The newly introduced HRT parameters d and ω_0 present partially incompatible values with the ones delivered from the standard HRT parameters. This could lead to new information about the health status of the patient. The MHRT analysis contains also new and interesting information and has to be studied in further detail to make definite conclusions. It appears to the authors that the initial perturbation in morphology (MTO) and the speed how it goes back to its original value (MTS) a has some diagnostic value.



(a)



(b)



(c)

Figure 1: Analysis for patient 1. (a): HRT. (b): MHRT displayed for MF_1. (c): T waves after VEB and template.

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