Monitoring heart rate variability online using e-health oriented 3G mobile telephone services

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Monitoring heart rate variability on-line used mobile telephone 3G e-health service oriented

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Abstract. We are living an epidemic of cardiovascular and cerebrovascular diseases that have led to many researchers worldwide increase their technical studies and methods of identification, diagnosis and treatment. Moreover, risk estimate based on factors such as age, sex, blood pressure, smoking, and lipid levels is still incomplete and depend on interest of subject by going to the hospital to do lab tests. The Brazilian experience that recorded each year over 90,000 deaths caused by cardiovascular and cerebrovascular diseases, only in 2008 the Unified Health System log about 200,000 hospitalizations, which resulted in an approximate cost of $ 180 million public resource. In addition, this is responsible for approximately 40% of early retirements and leading cause of disability in the age group above 50 years. Following the premise that "The best cure is prevention", this work seeks to provide a mobile tool to prevent early cardiac arrhythmia by means of monitoring on-line and assessing heart rate variability. Preliminary results proved effective in Sao Paulo for study of heart rate variability. This new service uses mobile phone to record, evaluate and transmit information, which currently is in clinical validation.

Keywords: Tool, Prevention, Cardiac Arrhythmia, FLEEM, mobile phone.

1. Introduction

Heart rate variability (HRV) is the physiological phenomenon of variation in the time interval between heartbeats. It is measured by the variation in the beat-to-beat interval. Other terms used include: "cycle length variability", "RR variability" (where R is a point corresponding to the peak of the QRS complex of the ECG wave; and RR is the interval between successive Rs), and "heart period variability".

Methods used to detect beats include: ECG, blood pressure, ballistocardiograms, and the pulse wave signal derived from a photoplethysmograph (PPG). ECG is considered superior because it provides a clear waveform, which makes it easier to exclude heartbeats not originating in the sinoatrial node. The term "NN" is used in place of RR to emphasize the fact that the processed beats are "normal" beats.

The HRV analysis has been proven to be a powerful tool for predicting mortality after a myocardial infarction, for measuring the risk stratification of diabetic patients, for evaluating the fetal cardiovascular system maturation, or for obstructive apnea detection. The Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology propose several techniques for measuring the HRV. Two different types or methods are proposed: a)
statistics in the time domain over the RR series. Examples are the standard deviations or the calculation of the percentage of values that differ more than 50 ms from the previous one; and b) analysis in the frequency domain, or spectral analysis, which allows for decomposing the full variability in its frequency components: both low- and high frequency components.

In this study, a novel system of monitoring physiological signals takes advantage of advances in information and communication technology to acquire, process and visualize physiologic information of people in their day to day. The system measured heart rate to perform arrhythmia diagnostics. The system that allows the “Control of your health in your hands” was developed between the University of Sao Paulo, the Research Technological Center of the University of Mogi das Cruzes (SP, Brazil) and Center of Information Technology of National University of Tucumán. This product called FLEEM (Free Living Energy Expenditure Monitoring System®) can monitor HR 24h/day, 7day/week with a device that combines technology, comfort and reliability. The sensors are noninvasive, low power consumption and high sensitivity. The information is pre-processed on a mobile device and centralized on a server that does the monitoring and accompaniment for each user, allowing that data always travels with the user. Different means are used to transmit information of evaluations (Wi-Fi, Bluetooth and GSM), which ensures connectivity and extends coverage. Physiological data are processed in a telemedicine centre and accompanied by a specialized team. The monitoring of the system is non-invasive, non-intrusive, 24 x 7. As the HRV recorder will detect a “non-standard” heart rate (HR) signal, it has been necessary to compare those signals to “standard” ECG recording signals in order to evaluate the arrhythmia detection ability of the new system. Simultaneous recording of HR signals from both the mobile telephone recorder and a conventional Holter recorder was compared by two independent cardiology specialists with regard to signal quality for performing arrhythmia diagnosis. In addition, calculated R–R intervals from the two systems were correlated. A total number of 16 patients participated in the study, but in this paper is shows the monitoring the only one patient. The goal is to test the loyalty of the FLEEM System® to detect with acceptable quality the arrhythmia diagnosis.

2. Materials and Methods

This section contains four parts. First is the description of FLEEM Systems®. Second is the data acquisition. Third is the methods study protocol and HRV analysis. Finally, the whole data process is described.

2.1. FLEEM Systems® - Telemedicine

The FLEEM System® (Free Living Energy Expenditure Monitoring System®) is a system service that allows the monitoring of medical variables (heart rate, temperature, motion, etc.) and transmits them to a cell phone operating system Android via sensor Zephyr HxM BT® that measured the HR. This mobile phone has a set of others applications that, in addition to processing the measured data, can record data from the accelerometer for assessing energy expenditure or if the patient has or not a fall (fall control). The android app (Google Play Signs Physiological on-line®) also allows recording the amount of ingested food and calculate the calorie consumption. All these pre-processed data, are transmitted to an application server via (TCP/IP) via 3G or Wi-Fi synchronously (on line) or asynchronous, while it does not have connection, stores the data, and when you have it, transmits them. The phone's GPS helps to determine the geographical position of the patient. Once measurements arrive at the server, doctor who is appointed to the benefit of the patient, can display this information in different graphic formats so that they help you make decisions. These graphics are calculated based on measurements and typical data of the patient (sex, biotype, weight, height, etc.) and can be customized by the doctor. The application architecture is LAMP and is based on free tools without licensing costs, generating a runtime environment flexible, scalable, global, regime 24 × 7, safe, reliable coverage and massive capacity to care for patients at the same time.

The Figure 1 shown the outline of FLEEM System®.
2.2. Data Acquisition

Figure 2 shows the physical layout of the sensors in the body of the subject\textsuperscript{9}. Heart rate monitor sensor is installed through an adjustable elastic band directly in the chest of the subject and connected with mobile phone via Bluetooth connection. From the cellular mobile device detected and indirectly generated registered information are transmitted by the radio service (GPRS) general package of the 3G network of the cell for a large distance mobile or wireless technology for short distances or via USB connection\textsuperscript{9}.

![Diagram of sensor setup](image)

Figure 2. HR Sensors connected with mobile device and transmission of data to the central of telemedicine. (1) Heart rate monitor. (2) Connection between sensor and mobile phone. (3) Mobile phone. (4), (5) and (6) Connection 3G network between mobile phone and server of telemedicine.

2.3. Methods

The tests were conducted initially in laboratory environment and then under various free-living environments in order to record the actual data without interfering with routine activities of any subject.
2.3.1. Protocol
Ethical approval for the study was granted by the Mogi das Cruzes University Research Ethics Committee protocol FR-281644. This paper presents the monitoring the heart rate of a patient of male gender, clinically diagnosed with cardiac arrhythmia. The acquisition of the physiological signal was carried out through the sensor was connected via Bluetooth with mobile device. Monitoring and calculations was carried out through the FLEEM System® web platform over a period of 2 weeks. The protocol was that any given day within those two weeks of study the patient do not swallow medication for regulation of the arrhythmia. The patient must not inform that day was within those two weeks. This was done to test the loyalty of the system of monitoring FLEEM System® designed for detection of cardiac arrhythmias, among other analyses tools\textsuperscript{8,9,10}.

2.3.2. Data Analysis.
To analysis the HRV is used pNNx family index because it is a widely used measure of heart rate variability statistics. The software application was done in Java J2ME based in pNNx software package [xx]\textsuperscript{1}. For each RR interval series (24 hours, each 5 min), the absolute values of the differences in consecutive NN intervals were obtained. The heart rate variability is recorded during dream states (baseline), light activities (rest) and moderate activities (active), at different times of day, but during the rest are enrolled in pre-and postprandial breakfast and lunch. The data analysis separates differences distributed in the following intervals in ms: [0, 50], (50, 80], (80, 120] (120, 140] and (140, 160]\textsuperscript{6,7}, classifying total sample data. Thus, with this classification is possible a distribution histogram and calculated probability occurrence, which allows calculation of the correlation time intervals for each activity state. For analysis is necessary assess the discrimination between a variability under normal and pathological conditions for each record into different states\textsuperscript{11} (sleep, rest, activity) by using pNNx thresholds from less than 30 ms to more than 150 ms (each 20 ms interval)\textsuperscript{7,12}. In addition, we have analysis with special care to find out the changes in the autonomic tone before and after meals during normal days. The heart rate variability represents adaptive responses of autonomic nervous system to challenges for circulation as much as by breathing that which to some extent reflects the sympathovagal balance\textsuperscript{1,4,5}. Figure 3 shows record of heart rate variability from one case monitoring FLEEM System®.
The time domain methods are computationally simple, but they lack the ability to distinguish between sympathetic and parasympathetic contributions of the HRV. The power spectrum estimation techniques avoid the problem of leakage and provide better frequency resolution. In this way, spectral analysis of HRV recorded via mobile phone can be a powerful method for studying the pathophysiologic processes in certain diseases and it can also be used in the daily clinical practice. The standard frequency bands used for power calculation were the very low frequency (VLF) band, ranging from 0 to 0.04 Hz, the low frequency (LF) region, from 0.04 to 0.15, and the high frequency range, form 0.15 to 0.40 Hz.

The HF reflects the fast changes in the beat-to-beat variability due to the parasympathetic or vagal stimulation. The LF region represents a mixture of sympathetic stimulation of the heart.

The spectrogram was obtained and, after that, the power spectra were calculated for each region, as well, as the total power spectrum. The LF/HF ratio, of interest for the clinical diagnosis, was also calculated.
3. Results

In this work, we have focused on the implementation of a computerized tool that used mobile telephone 3G e-health service-oriented for analyzing the HRV recording. The FLEEM System monitored on-line, for each HR, the following measures were obtained: mean VLF power, mean LF power, mean HF power, total power, and LF/HF ratio. The Figures 4a and 4b shows the output of the HRV software package, which represents HR and HRV for one subject monitored with/out arrhythmia medication (case 1 and case 2, respectively). The period analyzed was six hour from 02:00hs to 02:30h for each protocol.

![Figure 4](image)

Figure 4. Recording of the heart rate (HR) and heart rate variability (HRV) monitoring FLEEM System® web platform (www.fleem.com.ar). (a) HR subject case 1. (b) HRV histogram subject case 1. (c) HR subject case 2. (b) HRV histogram subject case 2.

The Figure 4d shows variability greater than 100 ms intervals, being that these peaks are not registered in the situation in which the patient ingested his medication to control cardiac arrhythmia (Figure 4b). Observe that in the situation of control (Figure 4a and 4b) the cardiac frequency is much more uniform, fact that is shown in the histogram presenting peaks just for a variability in the PNN [5, 15] ms. The Table 1 shows the HR summary for each case.

<table>
<thead>
<tr>
<th>Case</th>
<th>Min</th>
<th>Max</th>
<th>Range</th>
<th>Mean</th>
<th>Median</th>
<th>Mode</th>
<th>Var</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>56.5</td>
<td>69.71</td>
<td>22.21</td>
<td>63.59</td>
<td>63.26</td>
<td>63.75</td>
<td>8.80</td>
<td>2.96</td>
</tr>
<tr>
<td>Case 2</td>
<td>56.5</td>
<td>79.93</td>
<td>43.43</td>
<td>73.32</td>
<td>73.23</td>
<td>63.36</td>
<td>126.71</td>
<td>11.25</td>
</tr>
</tbody>
</table>

Table 1. HR summary obtained during 30 min in different day with the patient with arrhythmia medication (case 1) and without arrhythmia medication (case 2).

Figure 5 shows the a plot of the Fast Fourier Transform (FFT) and the power spectrum for the HR register presented in Figure 4.
Figure 5. Spectrum of cardiac frequency signal. Case 1 and Case 2. VLF: Very Low Frequency. LF: Low Frequency. HF: High Frequency.

Table 2 shows the VLF, LF, HF power, and for LF/HF ratio calculated from the plot shows plotted in the Figure 5 for each case.

<table>
<thead>
<tr>
<th>patient</th>
<th>mean VLF Power</th>
<th>mean LF Power</th>
<th>mean HF Power</th>
<th>Total Power</th>
<th>LF/HF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>1.59x10^{-3}</td>
<td>62.01</td>
<td>8.04</td>
<td>4.86.10^{-3}</td>
<td>7.71</td>
</tr>
<tr>
<td>Case 2</td>
<td>2.12x10^{-3}</td>
<td>53.90</td>
<td>7.80</td>
<td>6.50x10^{-3}</td>
<td>6.90</td>
</tr>
</tbody>
</table>

Table 2. Summary obtained during 30 min in different day with the patient with arrhythmia medication (case 1) and without arrhythmia medication (case 2). Measures in [ms^2].

The results obtained in the analysis of heart variability in the domain of time (Figure 4 and table 1)\textsuperscript{12}, and in the domain of the frequency\textsuperscript{13} (Figure 5 and Table 2) show that there is alteration in cardiac autonomic control system. Note is that Std reported in Table 1 in Case 2 is nearly 4 times greater than in the Case 1, being that the variance is 10 times greater. This means that the patient, during the period that this supposedly relaxed (02:00h-02:30h) presents a wide variability in relation to your heart rate average (see it values means and max, Table 1).

The analysis of heart variability in the frequency domain shows absolute values of power\textsuperscript{13} altered of the Case 2 in relation to the control, Case 1. There is predominance of power average and total in case 2, this last almost 1.5 greater than in case 1\textsuperscript{12}. These results are indicative of the presence of cardiac frequency components that alter the normal heart rate\textsuperscript{12,13}. The patients used the wireless sensor while doing physical sport activities and the quality of the recorded HRV signals made it possible to perform arrhythmia diagnostics even under such conditions. In this study, the monitoring was realized daily and the analyzed was during nocturne period. Consequently, this makes possible improvements in correlating arrhythmias to physical activities. The integration of traditional risk factors with monitoring daily of heart rate variability, and the self-care, represent an effective approach for identification of stroke patients at risk for early mortality.
4. Conclusions
This tool enables the monitoring and detecting arrhythmia cardiac based on the variability of RR records analyzed. According to the table 1 and 2 and Figure 4 and 5 notes are mainly the effect of the medication for the regulation of cardiac arrhythmia, which was detected in the online of heart rate monitoring. The analysis carried out in the space of time and frequency space confirmed present in the patient cardiac arrhythmia on the day in which it not ingested medication, concluding in this way that the FLEEM system is a useful and appropriate tool for the monitoring of HR, HRV and detection of cardiac arrhythmia via online using 3G technology.

References