Evaluation of the Heart Rate Variability with Laser Speckle Imaging

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Abstract - **The Autonomic Nervous System (ANS) is responsible for regulating various physiological processes in the human body. The Heart Rate Variability (HRV) represents a measurement used in evaluating the modulation of the ANS in different physiological conditions such as stress, physical activity, sleep, metabolic alterations, and, also, pathological conditions. Physical activity results in important changes in the cardiovascular system, such as an increase in blood flow and a decrease of the peripheral vascular resistance. Monitoring the peripheral microcirculation represents an important aid in evaluating the general conditions of an individual. The Laser Speckle Contrast Analysis (LASCA) is a non-invasive optical resource developed that uses nonionizing radiation in the region of the infrared and is important in the diagnosis of problems regarding the peripheral microcirculation. This work aimed to implement a method to obtain the HRV through the peripheral microcirculation utilizing the Laser Speckle Contrast Analysis (LASCA) technique. A commercial LASCA equipment was used to obtain a face-video. A custom software was implemented to process the LASCA videos and obtain the HRV. A heart rate monitor (HRM) was also utilized to measure the HRV and the values were compared against the ones obtained with LASCA. The method had consistent results in obtaining both the pulsation and the HRV, making it possible for future studies to use such a technique.**

Keywords - **Heart Rate Variability, Laser Speckle Contrast Analysis, Microcirculation, LASCA.**

I. Introduction

The autonomic nervous system (ANS) plays an important role in regulating various physiological processes in the human body, whether in normal or pathological situations [1].

The ANS participates in controlling the cardiovascular system through both sympathetic and parasympathetic nerve endings. The former acts on the myocardium while the latter acts on the sinus node, atrial myocardium, and atrioventricular node [1].

These systems are antagonistic, in such a manner that the sympathetic system promotes endings promote an increase in the cardiac frequency while the parasympathetic system produces the opposite response. For this reason, changes in the heart rate are verified as a physiological response to stimuli such as stress, physical activity, sleep, metabolic alterations, pathological conditions, and others [2].

The increase in the heart rate due to action of the sympathetic system and a reduction in the parasympathetic activity could lead to an increase in the morbidity risk due to cardiovascular problems. It highlights the need for evaluation tools that directly measures the cardiac frequency and guides intervention to maintain its properly function [3].

Thus, the development of techniques to analyze the heart rate variability (HRV) has contributed to evaluating the ANS modulation, both in physiological and pathological situations. The HRV has been applied as an indicator of cardiovascular complications, such as high blood pressure, acute myocardial infarction, coronary insufficiency, and arteriosclerosis. An elevated HRV translates into proper cardiac functions and characterizes a healthy individual, while low HRV is a strong indicator of poor heart functions [1].

The HRV is represented by the oscillations of the intervals between consecutive heartbeats. It may be estimated through measuring the difference between consecutive R-R intervals at the electrocardiogram (ECG). Monitoring the HRV through a non-invasive technique may be applied to identify phenomena associated with ANS in healthy individuals, as well as in those with some abdominal condition [4].

The electrocardiogram (ECG), obtained with the electrical cardiograph, translates the graphic representation of the cardiac impulses. The P wave on the ECG represents the impulse generated on the sinus node, which propagates to the atrium, resulting in the atrial depolarization. This impulse reaches the ventricles through the atrioventricular node, causing the depolarization of the ventricles, represented on the ECG by the Q, R, and S waves - the QRS complex. The T wave represents the ventricular repolarization [5]. Hence, the HRV is measured based on the analysis of the intervals between the R waves registered on the ECG.

Besides, the electrocardiograph, there are other instruments for the evaluation of the HRV. The heart rate monitors (HRM), are cheaper and more practical and can be utilized both during exercise and rest [6]. Though, both ECG and HRM are devices that need to be in contact with the skin to perform its measurements.

The HRV analysis has also been applied as an efficient method to evaluate the effect of physical activity on heart functions.

Based on the indicators of the HRV, it is possible to verify that individuals who are physically active show better autonomic cardiac modulation, indicating that physical exercise produces a positive cardiac response that results in a lower risk of cardiovascular diseases [7].

Therefore, studies have shown that physical activities, when in normal patterns, helped to regulate and modulate the heart frequency, which results from better adaptation of the ANS and vagal control to the body movements [8].

The stress induced by physical activity generates important alterations in the cardiovascular system and the analysis of the HRV helps to control the frequency during its execution [7].

Physical activity increases the blood flow, creating more pressure on endothelium walls. Thus, it stimulates the release of vasodilator agents and consequently lowering the peripheral vascular resistance [9].

Monitoring the peripheral microcirculation offer important data for evaluating the general conditions of an individual. Recent studies suggest an association between changes in the peripheral blood flow (microcirculation) and the development of organic complications [10, 11].

Microcirculation consists of a system of vessels with a diameter inferior to 100µm called arterioles, metarterioles, capillaries, and venules, which are responsible for transporting blood flow, carrying oxygen and nutrients to the cells and tissues of the organism [12].

Utilizing complementary techniques of the valuation of the cardiovascular functions may offer an important contribution to the clinical field.

Regarding the evaluation of peripheral microcirculation, the Laser Speckle Contrast Analysis (LASCA) technique represents an optical, non-invasive alternative. LASCA uses non-ionizing radiation, on the infrared region, to obtain images with a temporal and spatial resolution of vascularized areas with blood flow without contact. Since it is a non-invasive technique that provides no discomfort to the patient, it has been applied to aid the diagnosis of problems related to the peripheral microcirculation to measure blood perfusion in brain tissues, kidney cortex, liver, and skin [13, 14].

The LASCA technique relies on the interferometric pattern that rises form randomly distributed scatter particles. Moving particles, such as a red blood cell, with change this interferometric patter and it can be used to quantify movement. Hence, when the body surface is illuminated, imaging will show higher contrast in areas where there is an increase in blood flow [15, 16].

So, this study aimed to implement a method to obtain the HRV through the peripheral microcirculation utilizing the Laser Speckle Contrast Analysis (LASCA) technique.

II. Materials and Methods

It was approved by respective ethics committees (CEP Universidade Brasil 2.685.042) and conducted in agreement with the declaration of Helsinki for medical research involving human subjects.

A commercial equipment (moorFLPI, Moor Instruments, Devon, UK) was utilized to obtain the images with the Laser Speckle Contrast Analysis (LASCA) technique. It was obtained five-minutes video of the face posterior section by utilizing the LASCA technique.

A software was developed in a MATLAB R2019b (MathWorks, Inc., Natick, Massachusetts, United States) environment for LASCA video processing and to obtain the HRV. Figure 1 shows the flowchart of the implemented software.

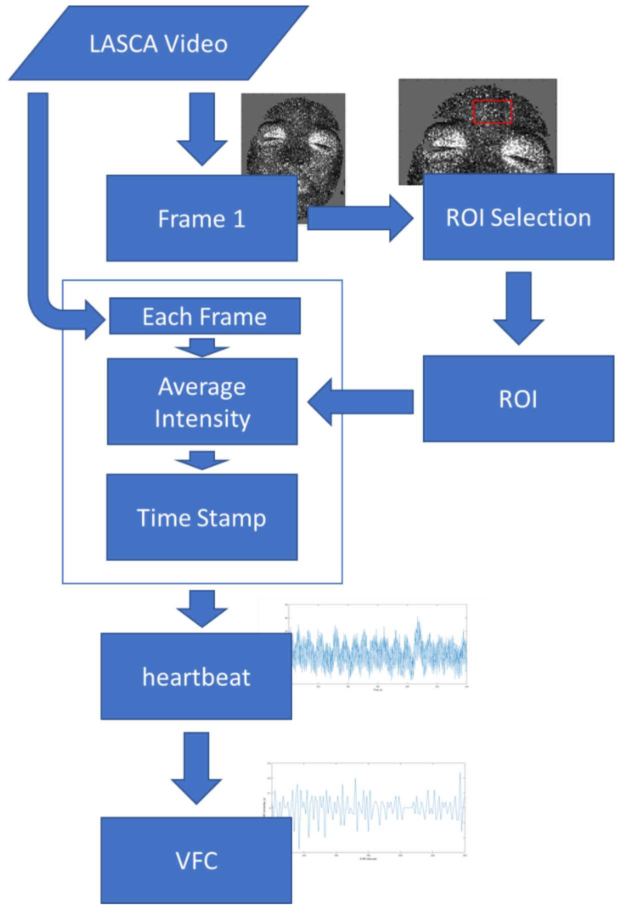

Fig. 1: Flowchart of the software algorithm to obtain the HRV from LASCA video analysis

The video was initially uploaded to the developed app. The initial frame (frame 1 in Figure 1) was presented to the operator, who selects the area of interest (the red rectangle in the ROI - Figure 1), where the analysis of the signal variance was performed. The selected ROI was utilized in all the other frames of the video.

In the ROI, the average intensity of the signal is computed on each frame of the image, thus obtaining the profile of the pulse collected through the video.

After that, the analysis of the HRV is computed, allowing us to determine the variation of the intervals between consecutive peaks, which corresponds to the RR interval.

Simultaneously to the acquisition of LASCA video, the heart rate monitor (HRM) Polar V800 collected the HRV, which has been proven reliable for measuring RR intervals according to recognized standards [17]. The result was used in comparison to the one acquired with the LASCA technique. The time series were compared using time-domain, frequency domain and non-linear methods.

III. Results and discussion

A video of the microcirculation in the area analyzed was obtained with the LASCA technique. Figure 2 shows a LASCA video frame revealing the frontal area of the face. The areas with higher microcirculation are in white. The red rectangle represents the area where the microcirculation variation was calculated (ROI).

Fig. 2 LASCA image of the microvascularization in the frontal section of the face

The video was processed to extract the HRV by the microcirculation in the skin, as previously described. Figure 3A shows the average intensity of the microcirculation signal in the selected ROI. It is possible to identify a pattern befitting to the pulsation.

This signal (figure 3A), acquired from the analysis of the microcirculation in the skin, was used to calculate the HRV with the LASCA technique.

Using the HRM it was also measured the HRV as reference for comparison. The HRV results, both the acquired with the heart rate monitor (HRM) and the LASCA technique, are presented in figure 3B.

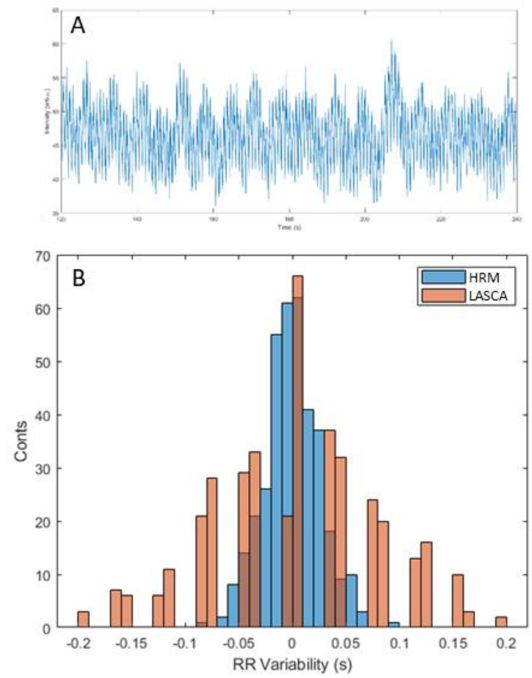

Fig. 3 (A) Average microcirculation intensity in the ROI; (B) Variability of the heart rate obtained by both the Heart Rate Monitor (HRM) and LASCA

The HRV numbers obtained with the LASCA method present a wider distribution in comparison to the ones obtained with the reference method (heart rate monitor). Moreover, the histogram presents some intervals equally spaced that do not contain any counts. That may be due to the low sampling rate of video (25 frames per second) in comparison to the rate monitor. Using a camera with a higher rate of acquisition would be a possible solution for this problem.

Table 1 presents the comparison time-domain, frequency-domain, and the nonlinear results for the time series of HRM and LASCA measurements.

Despite the low sampling rate limitation of the LASCA technique, it is possible to observe a good agreement between booth techniques. Booth the mean RR and HR do not presented statistical difference (p-value < 0.0001).

The present method shows consistent results in getting both the pulsation and the HRV, which makes it feasible for other studies to utilize this technique.

Table 1 Time-domain, frequency-domain and nonlinear results for HRM and LASCA time series

	HRM	LASCA
Time-Domain Results		
Mean RR (ms)	847.6	901.7
STD RR (SDNN) (ms)	38.6	58.6
Mean HR (ms)	70.93	66.83
STD HR (ms)	3.30	4.49
Frequency-domain Results – Peak (Hz)		
VLF (0−0.04 Hz)	0.0195	0.0039
LF (0.04−0.15 Hz)	0.1289	0.1445
HF (0.15−0.4 Hz)	0.3203	0.3711
Nonlinear Results		
Recurrence plot		
Mean line length (Lmean) (beats)	10.47	10.55
Max line length (Lmax) (beats)	355	94
Recurrence rate (REC) (%)	32.30	34.10
Determinism (DET) (%)	98.28	97.50
Shannon Entropy (ShanEn)	3.136	3.151
Other		
Approximate entropy (ApEn)	1.235	1.105
Sample entropy (SampEn)	1.702	1.317
Detrended fluctuations (DFA): $\alpha 1$	1.312	0.922
Detrended fluctuations (DFA): $\alpha 2$	0.988	0.666
Correlation dimension (D2)	2.449	4.128
Multiscale entropy (MSE)	1.202 − 2.495	1.005 − 2.089

IV. Conclusion

By analyzing the LASCA video, it was possible to get the pulsation profile and to calculate the heart rate variability.

In comparison to the results acquired with the reference method (Polar monitor - V800), the variability scores obtained with the LASCA method present a wider distribution of values.

The present method showed consistent results in obtaining both the pulsation and the HRV. More research is needed to determine the sensitivity of the technique regarding the differentiation of the states of stress.

Acknowledgment

C.M.S. Carvalho acknowledges CAPES for the financial support. This work was financially supported by CAPES and FAPESP 17/21851-0, 18/03517-8.

Conflict of interest

The authors declare that there has been no conflict of interest.

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