Examining the Potential of Using Thorax Impedance Measured by Automated External Defibrillators for Quantification of Circulation

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Abstract

It has been suggested to acquire circulatory information from patients undergoing resuscitation from cardiac arrest by analyzing their thoracic electrical impedance using modified automated external defibrillators (AEDs). To investigate the potential of this idea, we studied the correlation between two impedance-derived parameters related to circulation, the negative peak of the impedance fluctuation (Z_{peak}) and its first time derivative (dZ_{peak}), and arterial blood pressure measurements in 26 patients undergoing resuscitation and 32 hemodynamically stable patients. The highest correlation coefficient, $\rho = 0.4338$ was found between the systolic blood pressure and the magnitude of the negative peak of the first time derivative of the impedance. The poor correlation indicates that the impedance-derived parameters are not suitable for quantification of circulation, but can be used to indicate circulation.

1. Introduction

Over 500000 people all over the world suffer from cardiac arrest every year. The probability of survival is highly dependent on correct treatment of the patient, which relies on knowledge of the current state of the patient, such as type of rhythm and circulatory information. This knowledge is difficult to obtain manually. The task of performing the carotid pulse check has for example been shown to be very inaccurate and time consuming [1]. A simple, objective and noninvasive way of monitoring circulatory parameters is therefore of great interest and may potentially increase survivability of cardiac arrest patients.

Impedance plethysmography has been studied for decades as a noninvasive technique for estimating stroke volume (SV) and cardiac output (CO) from the transthoracic impedance changes and its first derivative [2]. The contraction of the heart during systole causes a redistribution of blood in the trunk and a change in blood flow. This again leads to a fluctuation in electrical impedance of the thorax. It has been suggested to equip automated external defibrillators (AEDs) with the ability to measure the transthoracic impedance through the defibrillator pads [3]. The impedance measurement may provide the rescuer with circulatory information that will help in treatment of the cardiac arrest patient by potentially reducing the time spent on pulse check [4] and increasing the accuracy of rhythm classification [5]. Blood pressure is one of the most common circulatory parameters used in patient monitoring. In a study by Djordjevich et al [6] the correlation between arterial blood pressure levels and the magnitude of the negative peak of the first time derivative of transthoracic electrical impedance is studied. A statistically significant correlation is found between the impedance-derived parameter and mean arterial blood pressure, systolic and diastolic blood pressure, and it is found that the impedance-derived parameter is expected to decrease as the arterial blood pressure level increases. The impedance is however measured using a system of four band electrodes, which is not practical in use with an AED. We therefore wanted to investigate if the transthoracic impedance measured by an AED through standard defibrillator pads could give us information about the patient's blood pressure. This is done by correlating impedance-related parameters that has been used for SV estimation [2] with blood pressure parameters in realistic data, as done by Djordjevich et al [6].

In section 2 the data material that forms the basis for this study is presented. The impedance-derived parameters that are thought to be related with standard blood pressure parameters are then presented, along with the procedure for analysing their relationship. The results of the analysis are presented in section 3, followed by a discussion and conclusion in section 4.

2. Methods

A modified Heartstart 4000SP (Laerdal Medical, Stavanger, Norway) with the ability to record transthoracic impedance was used during resuscitation efforts of 75 in-hospital cardiac arrests at the Department of Emergency

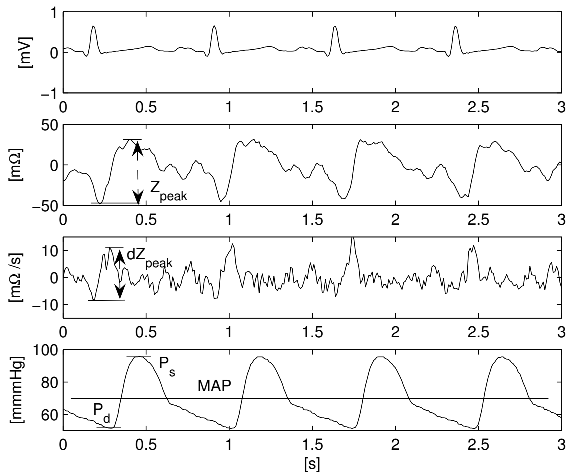

Figure 1. Example of impedance fluctuations resulting from a heartbeat as "seen" by the defibrillator. The parameters Z_{peak} and dZ_{peak} that are to be correlated against blood pressure parameters are shown.

Medicine, Medical University of Vienna from March 2003 to January 2005. The impedance measurements were recorded using commercially available self-adhesive electrode defibrillator pads (Heartstart Pads, Philips Medical Systems, Seattle, WA, USA), by passing a 32 kHz, 3 mA peak-to-peak sinusoidal current between them and measuring the resulting voltage difference between the electrodes. The blood pressure was measured via an arterial line in the arteria radialis. Measurements periods where the patient did not have a pulse were excluded from the study, and 49 episodes therefore had to be discarded. Measurements from the remaining 26 episodes are included in the study and are in the following referred to as CA data.

The same type of recordings were done on 37 hemodynamically stable patients under controlled mechanical ventilated conditions. 5 recordings were excluded due to data transfer problems between the monitors and the computer based data analysis system. Measurements from the remaining 32 recordings are included in the study and are in the following referred to as UN data.

2.1. Extracting information from the measurements

Figure 1 shows the electrocardiogram (ECG), the impedance, its first derivative and the blood pressure trace of a measurement from the UN data. The mean of the impedance signal was first removed, since we are only interested in the temporal changes of the measurement. The impedance measurement and its derivative is flipped since the negative peaks of the fluctuations historically have been the parameters used for estimation of SV [2]. For each heartbeat we calculate the magnitude of the negative peak of the impedance fluctuation (Z_{peak}) and its first time derivative (dZ_{peak}). From the blood pressure measurement we extract the systolic (P_s), diastolic (P_d), the pulse pressure (PP) and the mean arterial pressure (MAP). Some of the parameters are illustrated in Figure 1. PP is found as

$$\text{PP} = P_s - P_d \tag{1}$$

and MAP is computed as the mean pressure value over time. For each patient, we use the mean of the sample set of impedance- and blood pressure-descriptive parameters in the correlation study. The mean heart rate (HR) is also calculated for each patient.

2.2. Correlation study

For each patient we now have averages of Z_{peak} and dZ_{peak} per heart beat for which we also have parameters describing the blood pressure. We now want to see if any of the parameters are correlated over the patient group. The sample set of the different parameters are compared by computing their correlation coefficient ρ defined as [7]

$$\rho_{xy} = \frac{C_{xy}}{\sqrt{\sigma_x \sigma_y}} \tag{2}$$

where x and y are the two random processes with variance σ_x and σ_y we want to compare. C_{xy} is their covariance. By letting $\mathbf{x} = [\mathbf{x_1}, \mathbf{x_2}, ..., \mathbf{x_N}]^\mathbf{T}$ be a vector of impedance-derived parameter x of patient 1 through N, and $\mathbf{y} = [\mathbf{y_1}, \mathbf{y_2}, ..., \mathbf{y_N}]^\mathbf{T}$ be a vector of circulatory-descriptive parameter y of patient 1 through N, the covariance of the two parameters C_{xy} can be estimated as

$$C_{xy} = (\mathbf{x} - \mu_\mathbf{x})^\mathbf{T}(\mathbf{y} - \mu_\mathbf{y}), \tag{3}$$

where μ_x and μ_y are the estimated means of $\mathbf{x}$ and $\mathbf{y}$. Based on the estimated ρ_{xy}, we want to test the hypothesis $H_0 : \rho = 0$ versus $H_1 : \rho \neq 0$. This is done [8] by first computing the test statistic

$$t = \rho_{xy}\sqrt{\frac{n-2}{1-\rho_{xy}^2}} \tag{4}$$

which under H_0 follows a t distribution with $n-2$ degrees of freedom. We can thereby find the exact p-value of the test. The p-value indicates how likely it is that ρ truly is 0 and that our estimation is a result of variations in the data. We assume an underlying normal distribution for each of the random variables used to compute ρ_{xy}, and n is the number of samples from the random processes x and y. For values of p less than 0.05, the correlation is assumed to be statistically significant.

Table 1. Correlation between the impedance- and blood pressure-descriptive parameters. The significance of the correlation is shown in parenthesis. The statistically significant correlations are shown in boldface.

	$Z_{peak,CA}$	$dZ_{peak,CA}$	$Z_{peak,UN}$	$dZ_{peak,UN}$
P_s	**0.4338** **(0.0268)**	**0.4057** **(0.0398)**	0.1292 (0.4883)	0.1208 (0.5174)
P_d	0.3260 (0.1041)	0.2983 (0.1389)	0.0940 (0.6149)	0.2434 (0.1870)
MAP	0.3807 (0.0550)	0.3550 (0.0751)	0.0955 (0.6095)	0.1874 (0.3128)
PP	**0.3910** **(0.0483)**	0.3696 (0.0631)	0.0889 (0.6345)	-0.0288 (0.8778)
HR	-0.1313 (0.5228)	0.0025 (0.9903)	-0.3379 (0.0630)	-0.0012 (0.9948)

3. Results

Table 1 summarizes the results of the correlation study. The correlation is generally higher for the CA data than for the UN data. There are none of the correlations that are statistically significant for the UN data. For the CA data there is a significant correlation between Z_{peak} and P_s ($\rho = 0.4338$), between dZ_{peak} and P_s ($\rho = 0.4057$), and between Z_{peak} and PP ($\rho = 0.3910$). The distributions of the parameters are plotted in Figure 2, where each point represents one patient.

4. Discussion and conclusions

It would be valuable for a rescuer to have circulatory information about a patient undergoing resuscitation due to cardiac arrest. It has been suggested [3] to measure the thoracic impedance through the defibrillator pads, and thereby acquire information related to blood circulation [2]. We wanted to explore the information that could be drawn from such measurements, and therefore simultaneously recorded the thoracic impedance by using standard defibrillator pads and the blood pressure arterially from 79 patients undergoing resuscitation and 37 hemodynamically stable patients. By studying the correlation between descriptive parameters of the two measurements, we hope to uncover relations that can be used for future development of AEDs.

Figure 2(a) shows the parameters with the highest correlation, $\rho = 0.4338$, and illustrates that even the best relation in terms of correlation appears for the human eye to be close to random. Although the correlation is significant for some parameters, the measurements indicate that a direct use of Z_{peak} and dZ_{peak} does not provide us with much information about the circulation in terms of blood pressure. In addition a significant correlation is only found in the CA data. This may partly be explained by the difference in dynamic area of the blood pressure recordings. In the CA data P_s varies between 20 and 200 mmHg within the patient group, while P_s in the UN data varies between 80 and 170 mmHg. The difference in correlation may also indicate that the observed correlation in the CA data is not general.

In many works on plethysmography, Kubiceks formula for estimating stroke volume [9] has been used. The reason for not using this formula in this work is that it is dependent on the parameter t_e, which is extremely difficult to extract from the impedance measured through the defibrillator pads. The fluctuation resulting from heart contractions are different in shape and duration between patients, and the end of the contractile period can in most cases not be found by analyzing the impedance recording. ECG could be used for this purpose by detecting the end of the QRS complex and the end of the P wave, which are good time stamps for the start and stop of the contractile period of the ventricles. Automatic detecting of the P wave is however difficult, especially when only one ECG channel is available. The parameter t_e was therefore not examined in this study.

One weakness of the study is the limited number of data points, which leads to outliers having a significant influence on the correlation. Having more data available might have given similar results to [6], where a correlation of $\rho = 0.5236$ was found between dZ_{peak} and MAP, $rho = 0.567$ between dZ_{peak} and P_s, and $rho = 0.537$ between dZ_{peak} and P_d. The differing results may however be caused by the use of a four-band electrode system in the study by Djordjevich et al [6], while we used spot-like electrodes. Patterson has stated [10] that it has been shown over the years that spot electrodes give a very variable signal, and consistent quantitative results have therefore not been obtained. This indicates that the correlation will not be improved by more data.

Although the impedance cannot be used to quantify the circulation, it can be used to indicate circulation. It has been reported that recognition of pulselessness by rescuers is time-consuming and inaccurate [1]. An absent carotid pulse was not recognized in 10 % of the trial cases, while a pulse was not identified in 45 % of the trials despite a systolic pressure $\geq$ 80 mmHg [1]. The median diagnostic delay was 24 s, and even longer when no carotid pulse was found (30 s) [1]. This time delay and inaccuracy of manual identification of pulse can potentially be improved by using the impedance measurements as an indicator of pulse. In a recent study by Risdal et al [5] it was shown that the impedance recording contain information that can help in the discrimination between pulseless electrical activity and normal pulse rhythm.

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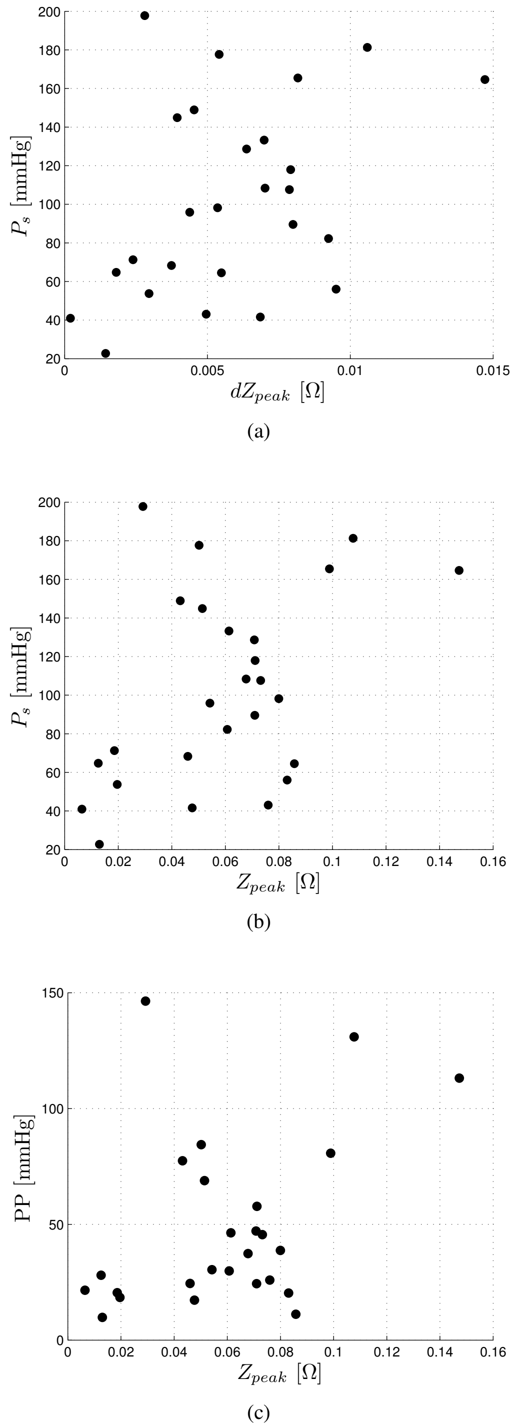

Figure 2. Scatter plots of (a) Z_{peak} versus P_s, (b) dZ_{peak} versus P_s, and (c) Z_{peak} versus PP. One point represents one patient.