PREDICTION OF TRANSTHORACIC IMPEDANCE TO DEFIBRILLATING CURRENT IN EXTERNAL DEFIBRILLATION

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Abstract
Transthoracic electrical defibrillation is administered by high voltages and currents applied through large size electrodes. Therefore, the defibrillator load impedance becomes an essential factor for the efficacy of the procedure.
Attempts at "prediction" of transthoracic impedance by pre-shock measurement with low amplitude high frequency current yielded apparently promising results.
We undertook a reassessment of the transthoracic impedance measured in a wide frequency range (bioimpedance spectroscopy). Two and four- electrode configurations were used. An estimation of the possibilities for pre-shock "prediction" of the impedance was attempted, which would allow adequate selection of defibrillation energy or current with the intention of increasing the possibility for positive results with the first shock.
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1. Introduction

Transthoracic electrical defibrillation is achieved by applying a high voltage pulse on the patient chest by two electrodes. The resulting current must depolarize most myocardial cells in order to achieve defibrillation. For this reason, large surface electrodes are used with low-resistive conductive substance interface, placed on optimum locations on the thorax (*Geddes 1994*).

The defibrillator load impedance, which includes the electrode-skin and the patient transthoracic impedance, is an essential defibrillation parameter. The importance of load impedance in determining the defibrillating current amplitude and energy, therefore the defibrillation threshold, was shown by many authors (*Savino et al 1983 Dalzell et al 1989, Kerber et al 1996*).

Kerber et al (1984) stressed the importance of transthoracic impedance in low-energy defibrillation. Shocks of 100 J or even lower energy in patients with low transthoracic impedance were reported as effective. A close relationship between transthoracic impedance and defibrillation success rate was observed (*Machin W 1978, Kerber et al 1984, Dalzell et al 1989*). Prediction equations were developed based on the statistical comparison of impedance measured by high frequency (from 20 to 35kHz) low amplitude current before defibrillation, and impedance measured during the shock (*Geddes et al 1976*). The latter was obtained by dividing the maximum voltage applied to the maximum current passed, called apparent impedance (*Geddes 1994*).

Based on the concept of advance prediction of transthoracic impedance, current-based rather than energy-based defibrillators were developed (*Dalzell et al 1989, Kerber et al 1996*). It was reported that success rate in current-based defibrillation is comparable to conventional energy-based defibrillation with significantly less delivered energy and current per shock (*Dalzell et al 1989*). *Kerber et al (1985)* and *Kerber et al (1988)* reported a method for automatic control of the defibrillator output energy in dependence of the preshock measured transthoracic impedance. However, a recent multicenter study showed no significant increase in success of current-based compared to energy-based shocks *(Kerber et al., 1996)*.

These considerations raised our interest in reassessment the transthoracic impedance characteristics measured by low amplitude high frequency current. Two and four- electrode configurations were used in wide frequency range measurements. (bioimpedance spectroscopy). Modeling by equivalent circuits was used for assessment of the impedance components involved. Transchest impedance during cardioversion shocks was recorded and an estimation of the possibilities for pre-shock "prediction" of the impedance was undertaken.

2. Method

We used an in-house developed instrument for bioimpedance spectroscopy in the frequency range of 500 Hz to 300 kHz (*Nenchev et al., 1998*). Its block-circuit is shown in Fig. 1. In this application the impedance range was reduced to 120Ω. The stabilised current was $2mA_{p-p}$ (about $0,7mA_{eff}$) and the maximum voltage limited to $20V_{p-p}$. A balanced differential current source was developed, resulting in high output impedance and common mode rejection. The impedance module and phase angle were measured at 8 frequencies: 1, 2, 5, 10, 20, 50, 100 and 300 kHz.

The voltage drop across the impedance is acquired by the instrumentation amplifier A1. Another amplifier of the same type (A2) takes a reference signal from a small resistor R inserted in the patient circuit. The injected current reference signal is compared to the signal from A1, thus obtaining a phase angle measurement channel. The current and voltage patient leads cable capacitances were compensated by driving the screens with 0.99 gain buffers (*Al Hatib, 1988*). The current source output impedance exceeds 1 MΩ and the voltage measurement instrumentation amplifier input impedance is over 4 MΩ, with a common mode rejection ratio > 60dB for the entire frequency range. The overall measurement accuracy is about 0,1%. The demodulated filtered and 12-bit AD converted signals were transferred by optically isolated link to a personal computer.

Two- and four electrode configurations were obtained by operating the switches S1 and S2 (Fig. 1).

Damped sinusoid cardioversion shocks were applied from a commercial defibrillator (Defigard 1002, Bruker Medical, France). The voltage and current waveforms applied during defibrillation episodes were acquired by a 1000:1 voltage divider across the electrodes and a 0,1 Ω resistor in series (Fig. 2). The voltage (S_U) and current (S_I) signals were buffered and subjected to analogue-to-digital conversion (ADC) with a sampling rate of 16,5 kHz per channel and 16 bit resolution, in a highly isolated floating module, satisfying the electrical safety standards. The digitized signals were then transferred by an optically isolated link to a personal computer (PC). The apparent impedance Z_{AP} according to *Geddes (1994)* was obtained as $Z_{APMAX}=Su_{PEAK}/SI_{PEAK}$. The transchest impedance $Z_{AP}= S_U/S_I$ was recorded for the duration of the shock.

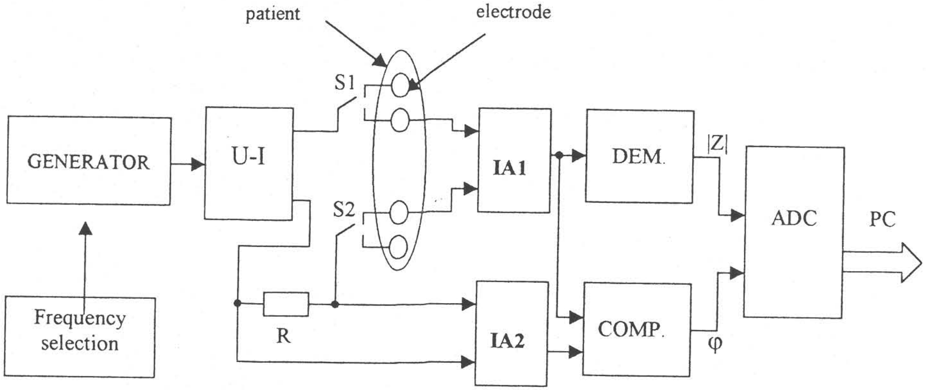

Fig. 1
Block-circuit of bioimpedance spectroscopy instrument

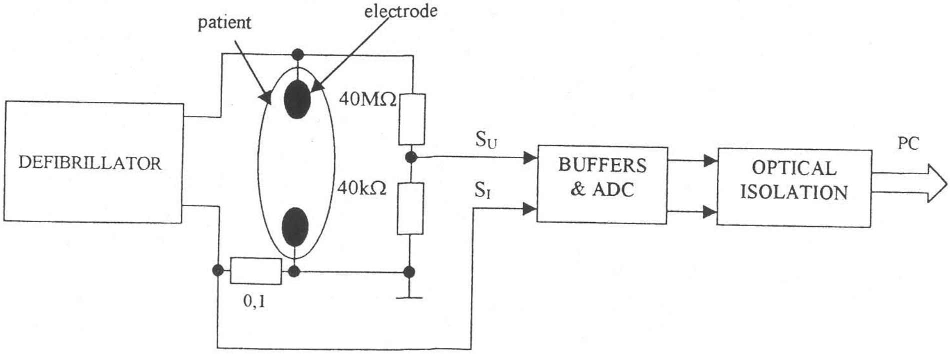

Fig. 2
Block diagram of the instrumentation for monitoring the voltage applied across the thorax and the current flowing, during the defibrillation impulse.

Thoracic impedance spectroscopy measurements were performed on 10 patients immediately before planned application of transchest atrial cardioversion for treatment of sustained atrial fibrillation or flutter in the Cardiology Intensive Care Department of the National Centre of Cardiovascular Diseases and Rehabilitation and on 10 volunteers.

Two and four- electrode measurements were taken, by changing the configuration by the switches S1 and S2 (Fig. 1). The defibrillator paddles (65 cm^2, interfaced to the skin with standard saline soaked pads) were used as voltage take-off electrodes, placed in the anterior position. The current injecting electrodes (conventional stick-on ECG type) were located on the right shoulder and left flank, approximately in a straight line with the paddles. The distance between injecting and voltage electrodes was kept above 10 cm.

The voltage and current waveforms were recorded during cardioversion of 10 of the above patients.

Results

The impedance spectroscopy measurement results with two-electrode configuration are shown in the plots of Fig. 3 to Fig.5, for the module Z (Fig. 3) and phase angle ϕ (Fig. 4) respectively, for all 20 patients. The corresponding plots from the four-electrode configuration are shown in Fig. 5.

An example of the recordings of voltage and current waveforms in cardioversion of a patient is shown in Fig. 6 (first and second trace respectively). The apparent impedance (Z_{AP} - 3rd trace) was computed and plotted using the ratio of S_U/S_I for each sample. Fig. 7 shows that a phase difference between voltage and current waveforms is not observable.

The results of the linear regression analysis between low amplitude high frequency current pre-shock measured impedance in wide frequency range (Z) and the transthoracic impedance measured during the shock are shown in table 1. Correlation coefficients and the standard error of estimate (SEE), as well as the regression equations are given.

Discussion and conclusion

Two- and four electrode thoracic impedance spectroscopy measurements (Fig.3-5) show that skin-electrode impedances are the principal components of the transthoracic impedance measured prior to defibrillation with high frequency and low current density. The equivalent circuit corresponding to this impedance consists of resistances and capacitances connected in series representing the skin-electrode impedances and resistances and capacitances connected in parallel representing the tissue impedance (Fig.8).

The transthoracic impedance measured during the defibrillating shock is virtually a pure resistance, as shown in Fig. 7 and as recently reported by Geddes *(1994)*. There was no measurable phase shift between voltage and current waveforms. This was confirmed without exception in all 10 measurements with damped sinusoid shocks. Thus the opinion that the high voltage porates the tissue membranes could be

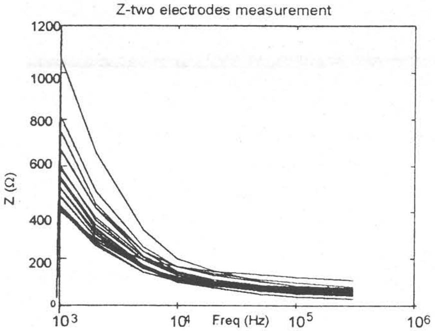

Fig. 3

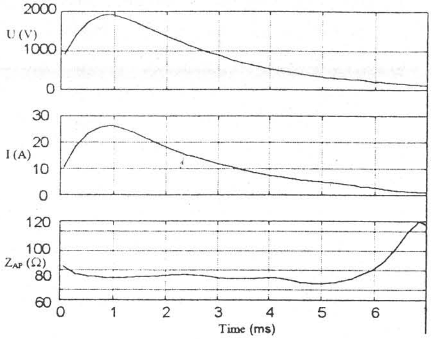

Fig. 6

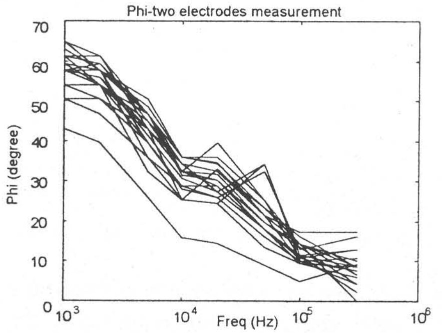

Fig. 4

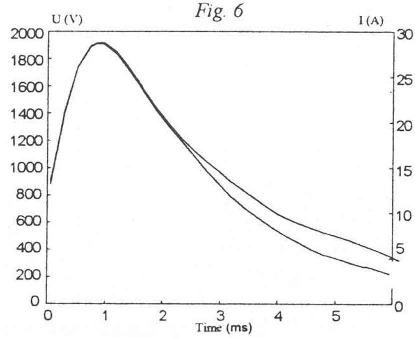

Fig. 7

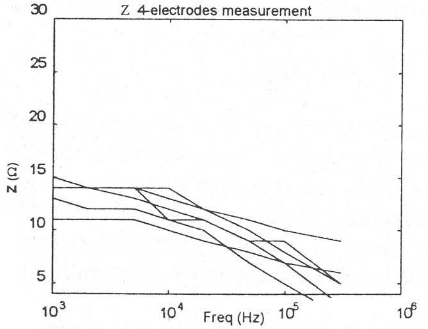

Fig. 5

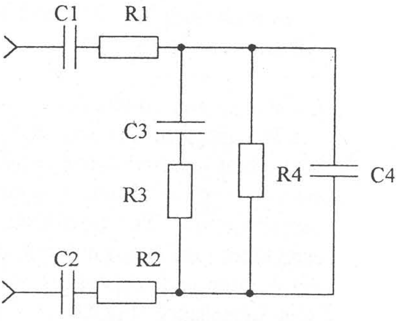

Fig. 8

supported. On the other hand, the fluctuations of Z_{AP}, observable in lower voltage levels (Fig. 7), suggest that probably the current pathways change during the shock.

A nonlienarity of Z_{AP} can also be observed, as it becomes higher with lower voltages. The attempts for predictive measurement of the defibrillator load impedance, aimed at adequate setting of stored energy, thus defining the current, are based on comparison of Z_{AP} with low current high frequency impedance measurements. The apparent impedance as discussed above can be represented with a simple resistor while the low current high frequency impedance is represented with complex equivalent circuit. Very high correlation coefficients (table 1) were obtained, but the standard error of estimate (SEE) was quite high demonstrate in a clear way that transthoracic electrical impedance is a strongly individual parameter. Care must be taken when using regression equations for predictive measurement of the transthoracic impedance prior to defibrillation.

Table. 1

F	r	**SEE**	Regression equation
10kHz	0.56	8.19 Ω	$Z_{AP} = 0.45Z+33$
20kHz	0.79	6.80 Ω	$Z_{AP} = 0.76Z+7.6$
50kHz	0.86	7.68 Ω	$Z_{AP} = 0.70Z+22$
100kHz	0.95	6.01 Ω	$Z_{AP} = 0.9Z+12$
300kHz	0.83	7.42 Ω	$Z_{AP} = 0.72Z+34$

References

1. Al-Hatib F **1998** Patient-instrument connection errors in bioelectrical impedance measurement *Physiol Meas* **19** 285-296
2. Dalzell GWN Cunningham SR Anderson Jadgey AAJ **1989** Initial experience with microprocessor controlled current based defibrillator *Br Heart J* **61** 502-505
3. Geddes LA **1994** Electrodes for transchest and ICD defibrillation and multifunctional electrodes in Defibrillation of the heart ICDs, AEDs, and manual Mosby-Year Book 82-118
4. Geddes LA Tacker W A Schoenlein B S Minton M Grubbs S Wilcox P **1976** The prediction of the impedance of the thorax to defibrillating current *Med Instrum* **10** 159-162
5. Kerber RE Kieso RA Kienzle MG Olshansky B Waldo AL Carlson MD Wilber DJ Aschoff AM Birger S Charbonnier F **1996** Current-Based Transthoracic Defibrillation *Am J Card* **78** 1113-8
6. Kerber RE Martins JB Kienzle MG Constantin L, Olshansky B Hopsond R Charbonnier F **1988** Energy, current, and success in defibrillation and cardioversion: clinical studies using an automated impedance-based method of energy adjustment *Circulation* **77** 1038-1046.
7. Kerber RE McPherson D Charbonnier F Kieso R Hite P **1985** Automated impedance based energy adjustment for defibrillation: experimental studies *Circulation* **71** 136-140
8. Kerber RE Kouba C Martins J Kelly K Low R Hoyt R Ferguson D Bailey L Bennett P Charbonnier F **1984** Advance prediction of transthoracic impedance in human defibrillation and cardioversion: importance of impedance in determining the success of low-energy shocks *Circulation* **70** 303-308
9. Machin W **1978** Thoracic impedance of human subjects *Med Biol Eng Comp* **16** 169-178
10. Nenchev N Hatib F Daskalov I **1998** Monitoring relative fluid balance alterations in haemodialysis of diabetic patients by electrical impedance *Physiol Meas* **19** 35-52
11. Savino GV Ruiz EV Valentinizzi ME 1983 Transventricular impedance during defibrillation EEEE Trans Biomed Eng 30 364-367