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Artur Karpiarz[1, 2], *Lukasz Czyzewski[3], Janusz Wyzgal[3], Monika Saran[4], Mikolaj Rusin[5], Zuzanna Popielarska[5], Brygida Krucinska[4], Urszula Szewc[3], Lukasz Szarpak[5]

Non-invasive assessment of haemodynamic parameters in pre-hospital care – a preliminary study

Nieinwazyjna ocena parametrów hemodynamicznych w opiece przedszpitalnej – badanie wstępne

[1]Independent Public Health Care Centre RM "MEDITRANS" Emergency, Medical Service Station and Sanitary Transport in Siedlce, Poland
[2]Student of Faculty of Health Sciences, Collegium Mazovia Innovative University, Siedlce, Poland
[3]Department of Nephrology Nursing, Medical University of Warsaw, Poland
[4]Student Research Circle "NEFRON", Medical University of Warsaw, Poland
[5]Lazarski University, Warsaw, Poland

Keywords

impedance cardiography, emergency medical service, monitoring

Słowa kluczowe

kardiografia impedancyjna, zespół ratownictwa medycznego, monitorowanie

S u m m a r y

Introduction. Pulse oximeters (SpO_2, HR measurement) and defibrillators (HR, NIMBP, ECG, SpO_2, $SpCO_2$ measurement) are still in use as equipment to EMS teams. This seems insufficient due to receiving an incomplete and additionally time delayed picture of the patient's condition, which does not take into account the effect of drugs or fluid therapy in such a short period of time.

Aim. The aim of the study is to assess the usefulness of impedance cardiography (ICG) in prehospital care.

Material and methods. The research was carried out in the period May-June 2018 during the activities of the "S" specialist team in the area of operation of the Emergency Medical Service substation in Sokolow Podlaski. Protocol of this study was accepted by the Institutional Review Board of the Polish Society of Disaster Medicine. In order to perform a non-invasive assessment of haemodynamic parameters, the cardiac monitor, Icon (Osypka Medical, Berlin, Germany) was used. The examinations were carried out for patients during the operation by the Emergency Medical Team in the ambulance.

Results. There were clinically significant differences between patients with suspected trauma/intoxication, cardiovascular diseases and other disease entities for: HR (81 ± 15 vs 100 ± 30 vs 88 ±12 bpm; $P = 0.084$, respectively); SVRI (2803 ± 871 vs 2730 ± 871 vs 1830 ± 661 d•s/cm^{-5}/m^2; $P = 0.092$, respectively), TFC (21.2 ± 5.7 vs 25.3 ± 6.3 vs 29.6 ± 11.8 1/kOhm; $P = 0.116$; respectively).

Conclusions. In the authors' opinion, especially for patients in trauma, in regards to haemorrhage (shock) with circulatory insufficiency (pulmonary oedema, hypertension, arrhythmias, myocardial infarction) the possibility of additional measurements, especially of the heart's performance, may be crucial in the selection and possibly assessment of the effectiveness of the undertaken actions.

Conflict of interest
Konflikt interesów

None
Brak konfliktu interesów

Address/adres:

*Lukasz Czyzewski
Department of Nephrology Nursing
Medical University of Warsaw
8 Oczki Str., 02-007 Warsaw, Poland
Phone: +48 696457655
E-mail: czyzewski_lukasz@wp.pl

S t r e s z c z e n i e

Wstęp. Dotychczas na wyposażeniu zespołów PRM do pomiaru parametrów życiowych stosuje się pulsoksymetry (pomiar SpO_2, HR) oraz defibrylatory (pomiar HR, NIMBP, EKG, SpO_2, $SpCO_2$). Wydaje się to niewystarczające, ponieważ daje niepełny i dodatkowo opóźniony w czasie obraz stanu pacjenta, który nie uwzględnia w krótkim czasie wpływu leków czy płynoterapii.

Cel pracy. Celem pracy jest ocena użyteczności zastosowania kardiografii impedancyjnej (ICG) w opiece przedszpitalnej.

Materiał i metody. Badania przeprowadzono w okresie od maja do czerwca 2018 roku w trakcie działań zespołu „S" specjalistycznego w rejonie działania podstacji Pogotowia Ratunkowego w Sokołowie Podlaskim (mazowieckie, Polska). W celu dokonania nieinwazyjnej oceny parametrów hemodynamicznych używano kardiomonitora Icon (Osypka Medical, Berlin, Germany). Badania były przeprowadzane u pacjentów podczas działań zespołu ratownictwa medycznego w karetce pogotowia ratunkowego.

Wyniki. Wykazano istotne klinicznie różnice pomiędzy pacjentami z podejrzeniem urazu/zatrucia, chorób układu krążenia i innych jednostek chorobowych dla: HR (81 ± 15 vs.

100 ± 30 vs 88 ±12; P = 0,084 u/min, odpowiednio), SVRI (2803 ± 871 vs 2730 ± 871 vs 1830 ± 661 d•s/cm^{-5}/m^{2}; P = 0,092, odpowiednio), TFC (21,2 ± 5,7 vs 25,3 ± 6,3 vs 29,6 ± 11,8; P = 0,116 1/kOhm, odpowiednio).

Wnioski. W ocenie autorów, szczególnie u pacjentów urazowych, w przypadku krwotoków (wstrząs), z niewydolnością krążenia (obrzęk płuc, nadciśnienie tętnicze, zaburzenia rytmu serca, zawał serca) możliwość dodatkowych pomiarów, szczególnie pracy serca, może być kluczowa w wyborze i ewentualnie ocenie efektywności podjętych działań.

INTRODUCTION

The research of hemodynamic parameters, which may be useful in assessing a patient's condition and monitor the effectiveness of the support provided by the medical staff of hospital emergency departments (ED), intensive care unit (ICU), cardiology and post-operative departments, has been observed for many years. The most common measurement methods are invasive, notably called cardiac or radial artery catheterization, which requires sterile conditions in which to be performed. Different methodologies such as echocardiography, are time-consuming and require the appropriate skills from doctors who perform them. The non-invasive methods of haemodynamic parameters measurement are starting to be used more frequently and they are not burdened with TEB (thoracic electrical bioimpedance) complications.

The clinical experiments indicate that the evaluation of the circulation condition is limited only to the measurement of blood pressure and heart rate is inconclusive. In regards to the group of non-invasive methods of haemodynamic parameters' measurement, such as cardiac output (CO), stroke volume (SV) and the thoracic fluid content (TFC), the monitors of cardiac output can be used, which due to the size and simple manual operation achieve the measurement in a short period of time, so they can be used to assess the haemodynamic parameters by emergency medical services (EMS). Currently, no research on using the measurements of haemodynamic parameters by emergency medical services has been performed, yet obtaining the answers about the effectiveness of the performed actions could help doctors and paramedics in undertaking appropriate treatment methods, as well as show the effectiveness of their treatment. The time of action of EMS teams until transferring the patient to the hospital staff, after deduction of travel time to the patient, varies from a few minutes to one hour, which is why the measurements of the cardiac cycle should be obtained using simple and non-time-consuming methods.

Pulse oximeters (SpO_2, HR measurement) and defibrillators (HR, NIMBP, ECG, SpO_2, $SpCO_2$ measurement) are still in use as equipment to EMS teams. This seems insufficient due to receiving an incomplete and additionally time delayed picture of the patient's condition, which does not take into account the effect of drugs or fluid therapy in such a short period of time.

AIM

The aim of the study was to assess the usefulness of impedance cardiography (ICG) in prehospital care.

MATERIAL AND METHODS

The research was carried out in the period May-June 2018 during the activities of the "S" specialist team in the area of operation of the Emergency Medical Service substation in Sokolow Podlaski (Mazovian, Poland). Protocol of this study was accepted by the Institutional Review Board of the Polish Society of Disaster Medicine. The investigation conformed to the principles outlined in the Declaration of Helsinki and was approved by the Director of the Independent Public Health Care Centre RM "MEDITRANS" Emergency Medical Service Station and Sanitary Transport in Siedlce, and all respondents gave their voluntary consent to participate in the study. The W0451 team (specialist in Sokolow Podlaski) left 1335 times in 2017 to: 1) injuries and poisoning – 293 times; 2) respiratory diseases – 135 times; 3) cardiovascular disease – 275 times; 4) resuscitation – 96 times; 5) fainting – 236 times.

The people who qualified for the study were given oral instructions about the principles, objectives and benefits of the research. The criterion for inclusion in the study was the age of the patient ≥ 18 years and disease entities due to which the ambulance team was called. The study excluded patients who could not consciously give their consent, the lack of the ability to connect the monitor during performed activities and patients who were under the age of 18.

The studied group consisted of 31 patients, including 17 men (37-100 y.o.) and 14 women (24-87 y.o.). The patients' research group was divided into 3 groups in respect to the diseased entity: 1) injuries and poisoning – 14 people, most frequently alcohol poisoning; 2) cardiovascular diseases (CVD) – 13 people; 3) other, i.e. fainting, respiratory diseases – 7 people. All patients were transported to ED/ER. The control group consisted of 9 people – employees of the ambulance station.

Assessment of haemodynamic parameters

The electrical velocimetry (EV) method is based on a modified measurement of the thoracic electrical bioimpedance (TEB). It is a relatively new methodology, characterized by the continuity of measurement, ease of implementation, practically no operating costs (four ECG electrodes are needed) and the possibility of use on a majority of patients. In order to perform a non-invasive assessment of haemodynamic parameters, the cardiac monitor, Icon (Osypka Medical, Berlin, Germany) was used. The examinations were carried out for patients during the operation by the Emergency Medical Team in the ambulance. In order to perform the measurement, two electrodes are placed on the neck and two are placed on the left-side of the chest. This allows users to perform a continuous measurement of changes in electrical conductivity within the chest cavity by supplying a current with a low amplitude and a high frequency and the resistance is measured. Distortions or artefacts in the ICG signal were detected and excluded from analysis. The ICG signal quality was always > 85% over all sets of measurements. The following parameters were recorded in each patient: CI (cardiac output/ body surface area (L/min/m^2)), SVRI (dynes-sec/cm^{-5}/m^2), TFC (1/kOhm), stroke index (SI (mL/m^2)). CI reflects the amount of blood pumped by the heart in one minute, normalized to body size; TFC is the inverse of baseline chest impedance, and any changes in TFC are directly proportional to total fluid (intravascular and extravascular) changes; SVRI represents the force the ventricle must overcome to eject blood into the aorta, which represents estimation of "afterload". The description and repeatability of the ICG method have been published elsewhere (1, 2).

Statistical analysis

The qualitative variables that are presented are as an absolute number and interest. Quantitative variables are presented as mean as well as standard deviation. The normal distribution was analysed using the Shapiro-Wilk test. The qualitative variables were compared using the chi-squared test, while the quantitative variables were analysed using one-way ANOVA. The post hoc analysis was performed using the Duncan test. In the comparative analysis of HR, SBP, DBP, as well as the clinical results, results, simple linear regression analysis (Spearman) was applied to detect and describe the strength and direction of correlations of HR, SBP, DBP to clinical, data. The statistical analysis was achieved using the Statistica 13.1 program, assuming a significance threshold of $P < 0.05$.

RESULTS

The average age of the examined group of patients is 65 ± 20 years. There were statistically significant differences between patients with suspected trauma/intoxication, cardiovascular diseases and other disease entities, for age 54 ± 22 vs 78 ± 9 vs 61 ± 21; $P = 0.005$, respectively. There were clinically significant differences between patients with suspected trauma/intoxication, cardiovascular diseases and other disease entities for: HR (81 ± 15 vs 100 ± 30 vs 88 ± 12 bpm; $P = 0.084$, respectively), SVRI (2803 ± 871 vs 2730 ± 871 vs 1830 ± 661 d•s/cm^{-5}/m^2; $P = 0.092$, respectively), TFC (21.2 ± 5.7 vs 25.3 ± 6.3 vs 29.6 ± 11.8 1/kOhm; $P = 0.116$; respectively) (tab. 1).

In simple linear regression analysis (Spearman), SVRI was negatively correlated with HR (all P for trend < 0.05) and positively correlated with SBP and DBP. TFC was negatively correlated with DBP (tab. 2).

In comparison to study group, in the control group consisting of 9 healthy volunteers, the mean age was 38 ± 11 years, male gender rate of 100%, mean HR of 90 ± 15 bpm, mean TFC of 22.2 ± 3.8 1/kOhm, mean SI of 39.9 ± 5.6, mean CI of 3.0 ± 1.1 L/min/m^2 and mean SVRI 2174 ± 326 dynes-sec/cm^{-5}/m^2.

Tab. 2. Results of simple regression analyses between heart rate, systolic blood pressure, diastolic blood pressure and clinical data in study group of patients

	HR	SBP	DBP
Age	0.006	0.038	-0.106
BMI	0.160	0.537*	0.372
HR	–	0.127	0.159
SV	-0.150	-0.013	-0.268
CO	-0.251	0.213	0.013
TFC	0.136	-0.289	-0.574*
SI	-0.141	-0.072	-0.249
SpO_2	-0.136	0.167	0.176
SYS	0.127	–	0.710*
DIA	0.159	0.710*	–
MAP	0.146	0.916*	0.912*
SVRI	-0.394*	0.377*	0.619*

*$P < 0.05$

Tab. 1. Univariate comparison of reasons for patient transport

	All	Injuries/poisoning	CVD	Other	*P*
Age [y]	66 ± 20	54 ± 22	78 ± 9	61 ± 21	0.005
BMI [kg/m^2]	26.9 ± 5.3	28.2 ± 5.6	26.5 ± 5.1	25.6 ± 5.5	0.709
HR [bpm]	91 ± 23	81 ± 15	100 ± 30	88 ± 12	0.084
SV [ml]	76.1 ± 20.3	78.0 ± 16.2	68.2 ± 12.3	87.8 ± 31.8	0.149
CI [L/min/m^2]	2.8 ± 0.8	2.9 ± 0.8	2.7 ± 0.8	2.8 ± 1.1	0.661
TFC [1/kOhm]	24.8 ± 8.1	21.2 ± 5.7	25.3 ± 6.3	29.6 ± 11.8	0.116
SI [ml/m^2]	41.8 ± 12.0	40.6 ± 7.5	37.9 ± 6,8	51.0 ± 20.1	0.128
SpO_2 [%]	94 ± 5	96 ± 2	93 ± 6	93 ± 7	0.270
SBP [mmHg]	145 ± 31	144 ± 30	149 ± 34	137 ± 31	0.931
DBP [mmHg]	87 ± 16	89 ± 15	90 ± 15	80 ± 22	0.455
MAP [mmHg]	106 ± 20	108 ± 17	109 ± 21	99 ± 23	0.667
SVRI [d•s/cm^{-5}/m^2]	2566 ± 893	2803 ± 871	2730 ± 871	1830 ± 661	0.092

DISCUSSION

Electrical velocimetry (EV) as a method of non-invasive monitoring of the cardiovascular system's haemodynamic parameters provides the possibility of a quick diagnosis for patients whose life is in direct danger. The usefulness of the aforementioned method has been described in a few clinical tests relating to Emergency Departments (ED), dialysis stations and primary health care facilities (3). In the available literature, there are no studies showing the haemodynamic profile of patients in pre-hospital care. In the conducted study, the examined group of patients did not differ significantly statistically in terms of routine measurements: SBP, DBP and SpO_2. However, in terms of haemodynamics, the examined groups were significantly different in terms of SVRI, TFC, SV. The results obtained indicate the potential need for extended haemodynamic monitoring of patients in pre-hospital care. Monitoring can enable the individualisation of patient's treatment in the ambulance. The use of fluid therapy and/or positively inotropic drugs may turn out to be less intuitive and more targeted at a specific disease entity.

Nowak et al. (4) in their research on non-invasive hemodynamic (HD) measurement examined 510 patients in a critical condition with suspected acute heart failure (AHF) (36%), sepsis (38%) and stroke (26%). The Nexfin finger cuff was used for the study. HD measurements in a Beat-to-beat mode were taken at an average for the first 15 minutes before the therapeutic intervention. The presented HD variables differed significantly between patients with suspected AHF, sepsis and stroke. These differences can potentially be helpful in distinguishing one condition from another, especially when there are overlapping elements such as dyspnoea. It is without the knowledge of HD, that patients may be poorly diagnosed with AHF volume overload and treated with diuretics when they may have an infection with cardiac dysfunction due to the high initial failure. The differentiation of diseases using HD tests may be less important for patients with suspected stroke syndromes. Most importantly, however, very diverse HD profiles were observed in each of the three groups of patients, indicating that people with suspected similar diseases have substantially different HD traits that are clinically unrecognised by doctors or paramedics. The knowledge of the individual HD results for a patient enables a better understanding of their cardiovascular functions. This can also provide potential targets for the optimal treatment. Several comparisons of disease groups were achieved and HD indicators for a 30-day mortality rate were estimated, a potential role in the early non-invasive evaluation of HD, which helps in the diagnosis of patients, individualisation of therapy based on the unique HD values of each person and predicting 30-day mortality rate. Further research and analysis is required to determine how HD assessments should be best used in the study.

Trzeciak et al. (5) conducted a study on a group of 199 patients treated for hypertension in the office of a general practitioner. The mean value of systolic and diastolic blood pressure in the given group of well-controlled hypertension was 125.1 ± 10.1 mm Hg and 77.7 ± 8.0 mm Hg, in the group with poorly controlled blood pressure – 152.7 ± 18.2 mm Hg and 89.2 ± 12/2 mm Hg. In the case of poorly controlled blood pressure group, fast heart rate, a high index of stroke volume, high vascular resistance and increased fluid content in the chest occurred significantly more frequent. The studies have shown that haemodynamic indicators differentiate significantly patients with well and poorly controlled blood pressure, which may be of potential importance in qualifying the patient for treatment in pre-hospital care.

In their research, Siebert et al. (6) indicated working methodologies which extend monitoring capabilities through non-invasive haemodynamic examination using impedance cardiography, central blood pressure analysis and monitoring of respiratory function in patients following a stroke. The authors emphasise that the given indicators describing the cardiovascular and respiratory functions allow not only performing precise therapy, but the outcome of this research can also lead to an improvement in the prognosis of patients with stroke.

An additional example of practical application of bioimpedance methods is that of a research involving 86 patients, for which blood pressure drops during haemodialysis were previously observed, while continuous ICG monitoring was performed. During this study, the following parameters were evaluated: heart rate, SV, cardiac output index, left ventricular ejection time, ejection fraction, peak expiratory flow and the cardiac contractility index. The patients were divided into two research groups: the study group and the control group. According to the results, the greatest importance in the diagnosis of approaching hypotension revealed the parameters relating to the time of cardiac muscle contraction – PEP and LVET (7).

In the study performed by Wynne et al., in which 35 dialysis patients took part, it was demonstrated that one of the most clinically relevant parameters is TFC (thoracic fluid content). The measurements ICG were registered at 15-minute intervals and included TFC, CI, BP (systolic, diastolic, and mean), SVRI and heart rate. In using the Pearson method, the percentage changes in each parameter during the HD session were correlated with the amount of fluid removed (FR), normalised to body weight. The study presented a positive correlation between this indicator and the volume of fluid removed from the body. In most cases, the changes of TFC preceded the occurrence of clinical symptoms such as intradialytic hypotension. The results had a significant impact on the correction of therapeutic treatment. The TFC parameter is easily and non-invasively measured using ICG. TFC correlates with the amount of fluid removed during HD. In comparison to other measured haemodynamic parameters, TFC was most consistently changing with fluid removal. The researchers concluded that the above-discussed compact, easy-to-use and non-intrusive ICG device with the possibility of continuous delivery of standard haemodynamic parameters, CO (cardiac output), TFC and a standard electrocardiogram with frontal electrodes can replace current monitoring systems (8).

In order to be able to compare the results of the research, it is also valuable to quote the measurements of Bayya et al. (9), who also monitored the cardiovascular system with ICG during haemodialysis. There were 48 patients with chronic haemodialysis, with frequent occurrence of intradialytic hypotension episodes, evaluated using non-invasive impedance cardiography (Physioflow) before, during and after their regular dialysis session. A sudden decrease in systolic blood pressure exceeding 20% of baseline was observed for 38% of 48 patients participating in the study. In this group, a significant decrease of CO and vascular resistance was recorded. The haemodynamic changes in the case of patients on dialysis with hypotensive episodes included a decrease in cardiac output or decrease of vascular resistance. Final lower diastolic filling proportions can be considered as a marker of reduced preload for these patients. Researchers concluded that non-invasive impedance cardiography can be used to assess risk factors for hypotension in the case of dialysis patients.

In a different group of patients, Krzesinski et al. (10) measured the effect of obesity on the haemodynamic profile in men with coronary disease in which 52 men hospitalised for rehabilitation participated in the study. In total, 97% of subjects were patients with an acute coronary syndrome. The association of obesity occurrence (BMI > 30 kg/m^2) was evaluated with haemodynamic parameters, including: left ventricular ejection fraction (LVEF) and measured by impedance cardiography: stroke index (SI), cardiac index (CI), velocity index (VI), acceleration index (ACI), heather index (HI) and systemic vascular resistance index (SVRI). Obese men (n = 18; 34.6%) with respect to non-obese were characterised by significantly lower cardioimpedance indexes of cardiac function as a pump. The conclusion from the conducted research was the fact that for men with coronary disease undergoing cardiac rehabilitation, the impedance cardiography enables identification of the presence of left ventricular systolic dysfunction associated with obesity.

The non-invasive method of haemodynamic parameters evaluation can be used in various clinical settings. The proof of this statement is the research of Krzesinski et al. (10), who determined whether impedance cardiography (ICG) could be used in the non-invasive monitoring of haemodynamic disorders at high altitude. The study was conducted in a group of 13 participants of two mountaineering expeditions in the Himalayas. The ICG examination was carried out before the expedition and then at high altitude (4300-5700 m) with simultaneous estimations of clinical symptoms of acute mountain sickness (AMS) and those that suggested an increased risk of the development of high lung pulmonary oedema (HAPO). The high altitude affected the haemodynamic profile of the subjects. Several significant changes were observed in the cases of: stroke index (baseline vs. high altitude: 51.2 ± 10.3 vs 35.5 ± 11.3 ml/m^2; $P = 0.0007$), CI (3.24 ± 0.49 vs 2.63 ± 0.66 l/min/m^2; $P = 0.013$), heather index (16.6 ± 4.3 vs 12.8 ± 4.45 Ω/s^2; $P = 0.006$), HR (64.1 ± 11.7 vs 75.4 ± 15.4 1/min; $P = 0.045$) and SVRI (2051.3 ± 438.9 vs 2668.4 ± 856.2 dyn × s × cm^{-5} × m^2; $P = 0.027$). The study has shown that ICG can be a helpful, non-invasive tool in monitoring cardiovascular dysfunctions at high altitudes, especially with breathing disorders.

There are some limitations to our study: 1) hemodynamic recordings were performed on a single occasion; 2) a randomized control follow-up trial is scheduled to evaluate the long-term effect of pre-hospital therapy on cardiac function; 3) larger groups are needed to assess the association between fluid therapy and hemodynamics parameters.

CONCLUSIONS

In the authors' opinion, especially for patients in trauma, in regards to haemorrhage (shock) with circulatory insufficiency (pulmonary oedema, hypertension, arrhythmias, myocardial infarction) the possibility of additional measurements, especially of the heart's performance, may be crucial in the selection and possibly assessment of the effectiveness of the undertaken actions.

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