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ORIGINAL ARTICLE

Impedance cardiography as a tool for haemodynamic monitoring at high altitude: a preliminary study

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Abstract

Background: Altitude illness is a relevant threat to the life and health of participants in mountaineering expeditions.

Aim: To determine if impedance cardiography (ICG) can be used in noninvasive monitoring of haemodynamic disturbances at high altitude.

Methods: The study was performed in a group of 13 participants of two mountaineering expeditions in the Himalayas. The ICG examination was performed before the expedition and again at high altitude (4,300–5,700 m) with concurrent estimates of clinical symptoms of acute mountain sickness (AMS) and those suggesting an increased risk of high altitude pulmonary oedema (HAPO).

Results: High altitude influenced the haemodynamic profile of the subjects. Significant changes were observed for: stroke index (baseline vs. high altitude: 51.2 ± 10.3 vs. 35.5 ± 11.3 mL/m^2; p = 0.0007), cardiac index (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 Ohm/s^2; p = 0.006), heart rate (64.1 ± 11.7 vs. 75.4 ± 15.4 1/min; p = 0.045) and systemic vascular resistance index (2,051.3 ± 438.9 vs. 2,668.4 ± 856.2 dyn × s × cm^{-5} × m^2; p = 0.027). AMS was observed in six subjects (mild: n = 5, severe: n = 1). Three of them revealed symptoms suggesting an increased risk of HAPO and this subgroup (vs. subgroup without such symptoms) was characterised by higher thoracic fluid content index (baseline: 19.2 ± 0.9 vs. 17.9 ± 2.0 1/kOhm × m^2; p = 0.176, at high altitude: 20.8 ± 1.4 vs. 17.7 ± 1.6 1/kOhm × m^2; p = 0.018) and lower Heather index (baseline: 11.4 ± 2.0 vs. 18.2 ± 3.5 Ohm/s^2; p = 0.028, at high altitude: 9.2 ± 2.1 vs. 13.9 ± 4.4 Ohm/s^2; p = 0.028).

Conclusions: ICG may be a helpful, noninvasive tool in monitoring cardiovascular dysfunction occurring at high altitude, especially with breathing disorders.

Key words: altitude illness, high altitude pulmonary oedema, impedance cardiography

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INTRODUCTION

Altitude illness (altitude sickness) can take the form of acute mountain sickness (AMS), high altitude cerebral oedema (HACO) or high altitude pulmonary oedema (HAPO). It is a leading cause of unsuccessful mountaineering expeditions, but most importantly it is a serious threat to the health and indeed the life of mountaineers [1–5]. Extreme environmental and logistical conditions in high mountain regions considerably limit the possibility of invasive physiologic clinical research.

Impedance cardiography (ICG) is a noninvasive method of haemodynamic monitoring of the cardiovascular system, enabling the measurement of: (1) heart rate (HR); (2) indices of cardiac pump function, i.e. cardiac index (CI), stroke index (SI), and Heather index (HI); (3) thoracic fluid content (TFC)

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and thoracic fluid content index (TFCI), which characterise preload; and (4) systemic vascular resistance index (SVRI) which reflects afterload. ICG has been validated by close agreement between the impedance and invasive gold standard measurements of cardiac output (Fick method, thermodilution) at rest and during exercise [6, 7]. ICG has not been evaluated at high altitude before (in field settings), but because it is an easy, portable and noninvasive method, it seems to be a useful tool for haemodynamic monitoring in such extreme conditions.

The aim of this study was to evaluate the possible use of ICG in noninvasive monitoring of haemodynamic disturbances at high altitude.

METHODS

Study group

The study was performed in a group of 13 healthy participants (11 males, mean age 32.5 ± 7.5 years) of two spring expeditions to the Himalayas: the Nanda Devi East Expedition of 2009 (n = 5) and the Cho-Oyu Expedition of 2011 (n = 8).

ICG examinations were performed with the use of a Cardioscreen 1000 device (Niccomo system, Medis, Medizinische Messtechnik GmbH, Germany). The baseline measurements were performed before the expeditions: for the Nanda Devi East Expedition 2009 in the Military Institute of Medicine, Warsaw, Poland, 110 m above sea level; and for the Cho-Oyu Expedition 2011 in Kathmandu, Nepal, 1,325 m above sea level. Later, the subjects underwent several examinations in the high mountain environment and the data recorded at the highest altitude was analysed in this study: for the Nanda Devi East Expedition at 4,300 m, and for the Cho-Oyu Expedition 2011 at 4,900 m (two subjects) and 5,700 m (six subjects).

Impedance cardiography

ICG is based on the measurement of the electrical impedance of the thorax. Changes in blood volume cause changes in the impedance signal because blood is a better conductor than other tissue types. To carry out the impedance cardiography measurement, four electrically connected pairs of electrodes are applied to the thorax of the subject: at the base of the neck and at the level of the xiphoid process at both sides.

ICG was performed in the morning, in a supine position, after a 10-min-rest. ICG data was collected during 5 min of examination and exported by the measuring module (dimensions: 98 × 53 × 20 mm) connected by USB interface to a notebook computer equipped with Cardioscreen software. All the examinations were monitored and stored in a database.

The analysed haemodynamic parameters included (1) TFC and its index (TFCI) — calculated from basic impedance (Z0) as its converse ($TFC = 1000 \times Z0^{-1}$); (2) stroke volume (SV) and its index (SI) — calculated using the Sramek and Bernstein formula ($SV = V_{EPT} \times dZmax \times LVET \times Z0^{-1}$) accounting for weight, height and gender of the patient (variable V_{EPT}), the amplitude of the systolic wave of the ICG (dZmax) and left ventricular ejection time (LVET — the interval between opening and closing of the aortic valve); (3) cardiac output (CO) and its index — CI: a derivate of SV/SI and HR ($CO/CI = SV/SI \times HR$); and (4) SVRI ($SVRI = 80 \times [MAP\text{-}CVP] \times CI^{-1}$), where MAP is mean arterial pressure and CVP is central venous pressure (assumed 6 mm Hg); (5) Heather index (HI) — a derivate of TRC, the time interval between the R-peak of the ECG and the time of dZmax, called C-point of ICG wave ($HI = dZmax \times TRC^{-1}$), characterising the maximum contraction force of the left ventricle, corresponding to cardiac inotropism. A detailed analysis of the results from 5-min long records, including HR, CI, SI, HI, TFCI, diastolic (DBP) and systolic (SBP) blood pressure and SVRI was performed after the expedition.

Clinical evaluation

Before the haemodynamic measurements, the subjects were examined by a physician (Nanda Devi East Expedition 2009) or a qualified rescuer (Cho-Oyu Expedition 2011). HR was measured by heart auscultation and pulse palpation, BP by sphygmomanometer (then entered to the Cardioscreen software at the beginning of measurement), the lungs were auscultated and the abnormal lung sounds noted. The clinical state of the subjects and the grade of AMS was estimated using Lake Louise Score (LLS) — a self-reported questionnaire — taking into account nausea/vomiting, fatigue/weakness, dizziness and difficulty sleeping [8]. Symptoms (dyspnoea at rest, cough, weakness or decreased exercise performance, chest tightness or congestion) and signs (crackles or wheezing in at least one lung field, central cyanosis, tachypnoea, tachycardia) suggestive of HAPO were reported. Spot oxygen saturation (SpO_2) was also measured.

Statistical analysis

Statistical analysis of the obtained results was performed using Statistica 7.0 software (StatSoft Inc., USA). Normality of data distribution was checked by Shapiro-Wilk test. All the results were expressed as average values ± SD for continuous variables and number of patients as well as percentages for categorical variables. The comparisons were performed with use of t-Student tests for data of normal distribution and nonparametric tests (U-Mann Whitney test, Wilcoxon test) for data of distribution other than normal. $P < 0.05$ was considered statistically significant.

The study was approved by the Institutional Ethics Committee on human research and all the subjects gave their written informed consent.

RESULTS

High altitude influenced the haemodynamics of the subjects. Although the response to high altitude varied individually, some significant changes characterising the whole group were

Table 1. Haemodynamic parameters at baseline and at high altitude

Haemodynamic parameters	Baseline	At high altitude	P
Thoracic fluid content index [1/kOhm × m²]	18.2 ± 1.8	18.4 ± 2.0	0.745
Systolic blood pressure [mm Hg]	122.7 ± 9.3	118.9 ± 14.6	0.430
Diastolic blood pressure [mm Hg]	75.7 ± 5.7	72.3 ± 8.3	0.546
Cardiac index [L/min/m²]	3.24 ± 0.49	2.63 ± 0.66	0.013
Cardiac output [L/min]	6.13 ± 0.94	5.01 ± 1.37	0.006
Stroke index [mL/m²]	51.2 ± 10.3	35.5 ± 11.3	0.0007
Stroke volume [mL]	99.1 ± 25.0	68.0 ± 24.4	0.004
Systemic vascular resistance index [dyn × s × cm^{-5} × m²]	2,051.3 ± 438.9	2,668.4 ± 856.2	0.027
Heart rate [1/min]	64.1 ± 11.7	75.4 ± 15.4	0.045
Heather index [Ohm/s²]	16.6 ± 4.3	12.8 ± 4.45	0.006
Spot oxygen saturation [%]	98.3 ± 0.5	76.8 ± 7.4	0.0009

observed (Table 1). A stay at high altitude resulted in a significant decrease in SI/SV (n = 12; 92.3%), CI/CO (n = 12; 92.3%) and HI (n = 12; 92.3%). Concurrently, increases in HR (n = 11; 84.6%) and SVRI (n = 11; 84.6%) were observed. TFCI increased in five (38.5%) subjects, decreased in three (23.1%) and was almost stable (change ≤ ± 5%) in the remaining five (38.5%). As expected, SpO_2 values were lower for all the subjects.

At high altitude, six (46.2%) subjects suffered from AMS symptoms including one classified as severe AMS [LLS — 6 points: headaches (2), difficulty sleeping (2), fatigue (3)]. Three of them had breathing disorders suggesting increased risk of HAPO: dyspnoea at rest (n = 3), crepitations in auscultation (n = 1), tachypnoe (n = 1) and exhaustion (n = 3). Comparing the two subgroups — with and without symptoms of AMS — no significant differences in the area of haemodynamics were revealed. However, the subjects with breathing disorders were distinguished by higher TFCI (statistically significant difference at high altitude) and lower HI equally at baseline and high altitude (Figs. 1, 2, Table 2).

In one subject, who suffered severe AMS and HAPO, TFCI increased significantly at high altitude when the severe symptoms of altitude illness developed very quickly (18.6 vs. 20.9 1/kOhm × m²). This subject rejected the physician's recommendation to descend. In the period of adaptation (only slight efforts, no climbing), the symptoms reduced but still limited his physical capacity.

In correlation analysis, TFCI correlated with HI (r = –0.66, p = 0.015) (Fig. 3); no significant correlations with other haemodynamic parameters were observed.

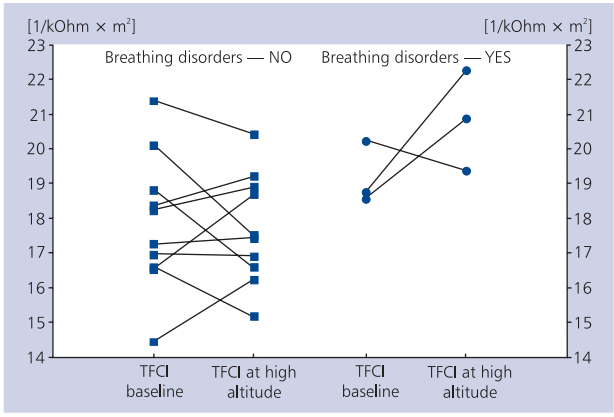

Figure 1. Change of thoracic fluid content index (TFCI) in subjects with and without breathing disorders

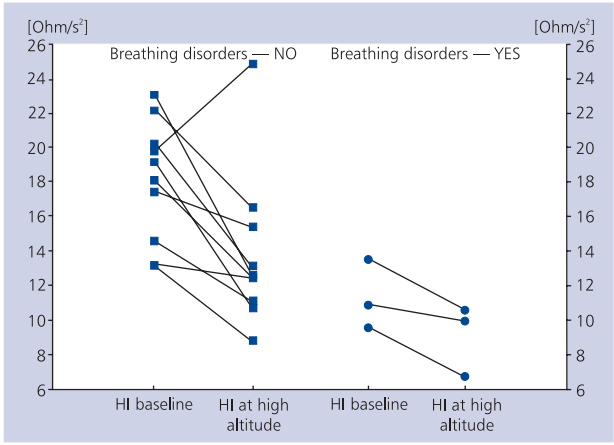

Figure 2. Change of Heather index (HI) in subjects with and without breathing disorders

DISCUSSION

The variety of cardiovascular responses to high altitude is related to many individual factors, such as level of endurance,

Table 2. Haemodynamic parameters in subjects with and without breathing disorders

Haemodynamic parameters	Breathing disorders — NO (n = 10)	Breathing disorders — YES (n =3)	P
TFCI baseline	17.9 ± 2.0	19.2 ± 0.9	0.176
TFCI at high altitude	17.7 ± 1.6	20.8 ± 1.4	0.018
SBP baseline	123.5 ± 10.3	120.0 ± 5.0	0.383
SBP at high altitude	118.0 ± 16.4	121.7 ± 7.6	0.864
DBP baseline	74.0 ± 5.2	81.7 ± 2.9	0.043
DBP at high altitude	72.0 ± 9.2	75.0 ± 5.0	0.665
CI baseline	3.35 ± 0.40	2.88 ± 0.69	0.310
CI at high altitude	2.65 ± 0.67	2.55 ± 0.77	0.829
CO baseline	6.31 ± 0.73	5.52 ± 1.50	0.218
CO at high altitude	5.04 ± 1.36	4.92 ± 1.71	0.904
SI baseline	54.0 ± 9.5	44.9 ± 9.51	0.310
SI at high altitude	33.9 ± 10.7	40.9 ± 13.7	0.398
SV baseline	102.9 ± 24.6	86.5 ± 26.6	0.339
SV at high altitude	64.6 ± 22.6	79.3 ± 32.1	0.383
SVRI baseline	1,922.4 ± 198.8	2,481.1 ± 785.8	0.237
SVRI at high altitude	2,613.6 ± 862.1	2,851 ± 994.3	0.692
HR baseline	63.8 ± 13.2	64.8 ± 5.9	0.735
HR at high altitude	79.0 ± 15.1	63.3 ± 10.7	0.128
HI baseline	18.2 ± 3.5	11.4 ± 2.0	0.028
HI at high altitude	13.9 ± 4.4	9.2 ± 2.1	0.028
SpO_2 baseline	98.3 ± 0.5	98.3 ± 0.6	0.932
SpO_2 at high altitude	75.5 ± 7.9	81.3 ± 3.2	0.310

CI — cardiac index [L/min/m^2]; CO — cardiac output [L/min]; DBP — diastolic blood pressure [mm Hg]; HI — Heather index [Ohm/s^2]; HR — heart rate [1/min]; SBP — systolic blood pressure [mm Hg]; SI — stroke index [mL/m^2]; SV — stroke volume [mL]; SpO_2 — spot oxygen saturation [%]; SVRI — systemic vascular resistance index [dyn × s × cm^{-5} × m^2]; TFCI — thoracic fluid content index [1/kOhm × m^2]

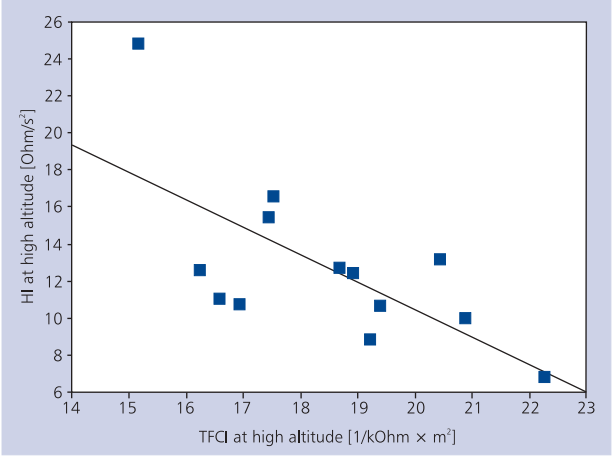

Figure 3. Correlation between thoracic fluid content index (TFCI) and Heather index (HI) at high altitude

individual neurohormonal control, and stress [2, 3, 9]. Due to the difficulties in conducting invasive physiologic research and analysis in the natural environment, there are no currently identified haemodynamic risk factors which would indicate the likelihood of developing altitude illness which could be used in practice.

ICG, a simple and reproducible method of noninvasive monitoring, was used in this study in order to identify thoracic fluid overload and other haemodynamic disturbances connected with altitude illness. ICG revealed an influence of high altitude on cardiac function. In almost all of the subjects, a decrease in SI and HI was observed. Low SI and HI was most likely due to reduced blood volume as an effect of the influence of neurohormonal factors (increased release of atrial natriuretic peptide, decreased synthesis of aldosterone), extravascular fluid distribution as well as reduced left ventricular volume and pressure [10, 11]. However, significantly decreased HI suggested the influence of high altitude on cardiac inotropism. This effect was more pronounced in subjects with breathing disorders. This group was characterised by lower HI both at high altitude and baseline, suggesting a relation between HI and clinical state. Concurrent increases in HR and SVRI appeared to be a compensatory mechanism related to sympathetic stimulation aimed at preserving CI and organ perfusion [3, 10, 11].

Despite a relevant reduction in intravascular volume, the value of TFCI did not follow these trends. Increases in TFCI were more frequent than decreases, and this effect was more pronounced in subjects with breathing disorders. Thus, the results of haemodynamic monitoring by ICG revealed the phenomenon of extravascular redistribution of chest fluid related to being in conditions of low atmospheric pressure [11]. This crucial mechanism appears to be the result of pulmonary arteriole constriction, increased pulmonary pressure and higher permeability of alveolar membranes. As a consequence, an increase in right ventricular overload and progressive reduction of SI can occur [1, 3].

Increased TFCI seemed to be a factor facilitating decreased tolerance of high altitude manifested by dyspnoea and fatigue. The correlation with HI supports this idea. Relative fluid overload with concurrent low inotropism could contribute to lower physical capacity. Subjects with high TFCI and low HI were found to be more susceptible to altitude illness.

Our results suggest the usefulness of ICG in identifying clinically important cardiovascular disturbances at high altitude. Although individual susceptibility to altitude illness can also be connected with other detectable factors, such as impaired endothelial function, decreased availability of nitric oxide and increased release of antidiuretic peptide, its use is currently limited to scientific research [10, 12].

It is worth mentioning that ICG is a well validated tool of cardiovascular monitoring, especially to indicate the development of thoracic oedema. Impedance methods have confirmed its usefulness in determining chest fluid content. Increased TFCI has been shown to be a risk factor for heart failure exacerbation [13] and the algorithms based on TFCI estimation are successfully used in implantable devices such as an implantable cardioverter-defibrillator or cardiac resynchronisation therapy as an additional option to predict heart failure exacerbation connected with fluid overload [14].

The ease of ICG measurements makes it feasible to perform in mountainous conditions. Although the device used in this study was stationary, portable impedance devices with wireless technology are now available (i.e. PhysioFlow®Enduro™, Manatec Biomedical, France). The minimal dimensions of the measuring module enable the construction of even more specialised telemetric monitoring systems, i.e. as a part of a mountaineer's uniform (a T-shirt or vest). It should be expected that continuous or periodical monitoring (determined by the rhythm of symptoms) performed with the use of distant data transmission to a special medical supervising centre could allow for an objective estimation of a mountaineer's clinical state and adequate therapeutic intervention. Such a strategy would eliminate the most frequent cause of high mountain accidents — a misleading self-rating of current physical condition and the risk of continuing the expedition.

However, in performing ICG measurements in the field, we confronted some problems. Environmental challenges included high humidity, extreme temperature and lack of a standardised place to perform the examination (i.e. a rocky base was an uncomfortable place to lie supine). Air humidity and high temperature (up to 40°C) at lower altitudes affected perspiration, which influenced electrode fixation, rendering them less adherent to the skin. On the other hand, at higher altitudes the measurements had to be performed in tents because of low temperature, and that resulted in poorer ICG quality. Logistical limitations should also be considered such as the lack of the electricity needed to power the notebook computer, as well as the need for a separate set of electrodes for each subject.

The main limitation of this study was the small group of examined subjects that limited use of statistical methods (we mostly used non-parametric tests). The difference between participants of the Nanda Devi East Expedition 2009 and the Cho-Oyu Expedition 2011 in the environmental conditions of baseline assessment (Warsaw vs. Kathmandu) could also cause a potential bias. However, observed trends in changes of haemodynamic parameters were for both subgroups comparable. The lack of availability of laboratory tests, especially haematocrit, could influence the results of haemodynamic parameters derived from Z0 and dZmax. Dehydratation, stimulated erythrogenesis and shift from intravascular fluid to the interstitial space can significantly increase haemoglobin and haematocrit [15]. To correct the influence of haemoconcentration on bioimpedance, the current value of haemoglobin should be entered into the ICG device software at the beginning of every measurement.

Undoubtedly, determining the usefulness of ICG in risk stratification of altitude illness demands further studies in larger groups, performed at higher altitudes in different regions of the world and — if possible — with more detailed and exact methods of evaluation. Other parameters potentially corresponding with ICG measurements (such as blood gas analysis, creatinine, urea and fluid balance estimation) should be considered as additional objectives in the clinical evaluation of subjects suspected of suffering altitude illness. However, the comparison of ICG measurements with other, most eligible diagnostic methods (chest X-ray, pulmonary artery catherisation, echocardiography) in field settings may be limited by methodological and bioethical constraints.

CONCLUSIONS

At high altitude, the response of the cardiovascular system is individualised; even potentially healthy subjects may develop cardiovascular dysfunction and subsequent altitude illness. The results of this study suggest that ICG may be a helpful, noninvasive tool in monitoring cardiovascular dysfunction occurring at high altitude, especially in the area of breathing disorders.

Conflict of interest: *none declared*

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Kardiografia impedancyjna w monitorowaniu zaburzeń hemodynamicznych związanych z przebywaniem na dużych wysokościach: wyniki wstępne

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Streszczenie

Wstęp: Choroba wysokogórska może przybierać postać ostrej choroby górskiej (AMS), wysokogórskiego obrzęku płuc (HAPO) i wysokogórskiego obrzęku mózgu. Jest zatem stanem zagrożenia zdrowia i życia uczestników wypraw wysokogórskich, a jej objawy często pojawiają się nagle, uniemożliwiając kontynuowanie wspinaczki. Równocześnie ekstremalne warunki środowiskowe istotnie ograniczają możliwość zastosowania obiektywnych metod monitorowania układu sercowo-naczyniowego (CV) w warunkach naturalnych. Kardiografia impedancyjna (ICG) jest nieinwazyjną metodą monitorowania hemodynamicznego układu CV, umożliwiającą ocenę m.in. częstości rytmu serca (HR), wskaźnika wyrzutowego (SI), wskaźnika rzutu sercowego (CI), wskaźnika Heather (HI) i zawartości płynu w klatce piersiowej (TFC). Mimo że brak dotychczas doniesień o jej zastosowaniu w warunkach wysokogórskich, jako proste i nieinwazyjne badanie, ICG wydaje się użytecznym narzędziem oceny układu CV w warunkach ekstremalnych.

Cel: Celem pracy była ocena możliwości wykorzystanie ICG w monitorowaniu zaburzeń hemodynamicznych związanych z przebywaniem na dużych wysokościach.

Metody: Badanie przeprowadzono u 13 uczestników (11 mężczyzn, średni wiek 32,5 ± 7,5 roku) dwóch wypraw wysokogórskich (Himalaje): Nanda Devi East Expedition (wiosna 2009) oraz Cho-Oyu Expedition (wiosna 2011). Analizie poddano zapisy ICG (Cardioscreen 1000, Niccomo system, Medis, Niemcy) dokonane przed rozpoczęciem wyprawy oraz na dużych wysokościach: 4300 m n.p.m. (Nanda Devi East Expedition) i 4900/5700 m n.p.m. (Cho-Oyu Expedition), oceniając równocześnie stan kliniczny badanych z wykorzystaniem skali punktowej ryzyka AMS (Lake Louise Score) i objawów mogących sugerować wystąpienie i/lub zagrożenie HAPO.

Wyniki: Adaptacja do przebywania na wysokości była zróżnicowana pod względem objawów klinicznych oraz funkcji hemodynamicznej układu CV. U większości badanych obserwowano obniżenie wartości SI (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), HI (16,6 ± 4,3 vs. 12,8 ± 4,45 Ohm/s^2; p = 0,006) oraz wzrost wartości HR (64,1 ± 11,7 vs. 75,4 ± 15,4 1/min; p = 0,045) i wskaźnika systemowego oporu naczyniowego (2051,3 ± 438,9 vs. 2668,4 ± 856,2 dyn × s × cm^{-5} × m^2; p = 0,027). U 6 (46,2%) badanych zaobserwowano AMS, w tym 3 z nich miało objawy sugerujące ryzyko HAPO: zaburzenia oddychania (n = 3), trzeszczenia nad polami płucnymi (n = 1), tachypnoe (n = 1) i zmęczenie (n = 3). Osoby te, w porównaniu z grupą bez tych objawów, charakteryzowały się wyższą wartością wskaźnika TFC (TFCI) w badaniu wyjściowym (19,2 ± 0,9 vs. 17,9 ± 2,0 1/kOhm × m^2; p = 0,176) oraz na dużych wysokościach (20,8 ± 1,4 vs. 17,7 ± 1.6 1/kOhm × m^2; p = 0,018) oraz niższą HI (wyjściowo: 11,4 ± 2,0 vs. 18,2 ± 3,5 Ohm/s^2; p = 0,028, na dużych wysokościach: 9,2 ± 2,1 vs. 13,9 ± 4,4 Ohm/s^2; p = 0,028). Obserwowano ujemną korelację TFCI z HI (r = –0,66; p = 0,015) na dużych wysokościach.

Wnioski: Odpowiedź układu CV na przebywanie na dużych wysokościach jest zróżnicowana i nawet u osób potencjalnie zdrowych mogą rozwinąć się zaburzenia hemodynamiczne oraz pełnoobjawowa choroba wysokościowa. Wyniki przedstawionych badań sugerują, że ICG może być przydatna w monitorowaniu funkcji układu CV w warunkach wypraw wysokogórskich. Przebywanie na dużych wysokościach wpływa istotnie na parametry funkcji mięśnia sercowego jako pompy, a obniżona wolemia wewnątrznaczyniowa i inotropizm miokardium, zwłaszcza ze współistniejącą wysoką zawartością płynu w klatce piersiowej, może się wiązać z podwyższonym ryzykiem wystąpienia objawowych zaburzeń układu CV. Wykonanie ICG w czasie wyprawy wysokogórskiej jest możliwe i przy zachowaniu odpowiedniej organizacji współpracy między badającym i badanymi może się odbywać nawet w niesprzyjających warunkach. Choć warunki pogodowe (wilgotność i temperatura powietrza, wiatr) oraz logistyczne (konieczność zasilania sprzętu, stosowania elektrod jednorazowych) narzucają szczególną staranność w przygotowaniu i wykonywaniu zapisów, to nie są to przeszkody dyskwalifikujące stosowanie tej metody monitorowania hemodynamicznego. Powyższe obserwacje zachęcają do dalszych badań nad zastosowaniem ICG w czasie wypraw wysokogórskich, zaplanowanych w większej grupie chorych oraz z wykorzystaniem innych dostępnych metod obiektywizacji adaptacji organizmu do przebywania w warunkach ekstremalnych.

Słowa kluczowe: choroba wysokogórska, wysokogórski obrzęk płuc, kardiografia impedancyjna

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