Impedance cardiography assessment during body immersion in a high concentrated water solution of magnesium chloride simulating space microgravity: a pilot study

Impedance cardiography assessment during body immersion in a high concentrated water solution of magnesium chloride simulating space microgravity: a pilot study

Impedance cardiography assessment during body immersion in a high concentrated water solution of magnesium chloride simulating space microgravity: a pilot study

AH Dell'Osa[1*], A Fois[2], A Cerina[3], F Pili[3], A Manuello Bertetto[4], F Velluzzi[5], G Bellomi[5], M Palmas[5], M Ruggiu[5], S Melis[5], F Tocco[5] and A Concu[6]

[1] Applied Electronic and Biomedicine Lab, University of Ushuaia, Argentina
[2] Nomadyca Ltd, Remote Biosignals Unit, Mulago Hospital, Kampala, Uganda
[3] Acquaforte Thalasso & Spa Medical Team, Forte Village Resort, Cagliari, Italy
[4] Dept of Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, Italy
[5] Dept of Medical Sciences and Public Health, University of Cagliari, Italy
[6] AC Technologies Ltd, Bioimpedance Devices Manufacturing, Cagliari, Italy

*E-mail: ahdellosa@untdf.edu.ar

Abstract. In 14 healthy subjects (9 males and 5 females, 32±15 years) a beat-by-beat cardiodynamic profile was acquired with impedance cardiography during 10 minutes while lying supine and relaxed in a bed and then in a bath tub with a high concentration of $MgCl_2$ reaching density 1/3 times more than sea. While in the tub, an increase in ventricular preload index (+47%) with reduction in contractility (-17%) and arterial pressure (-5%) occurred like as in space flights. So this method could be seen as a new way to simulating space fly at ground.

1. Introduction

During space flight astronauts are exposed, among other things, to microgravity and the cardiovascular system that relies on the earth's gravity, leads to substantial changes.

While on Earth there is a hydrostatic gradient, based on gravity, that interferes with the pressure of body fluids so in standing posture the pressure in the lower limbs is higher than that inside the thorax and cranial cavities, in space, due to the absence of gravity, there is a fluid shift of the hydrostatic gradient which gives rise to uniform pressure values throughout the body which, in turn, leads to a movement of fluids towards the trunk and head [1].
Since space flight experiments are not frequent and are very expensive, researchers are trying to find terrestrial models that can best simulate what happens to the human cardiovascular system during space travel, in order to understand what morpho-functional changes the heart and blood vessels undergo in the absence of gravity.

Considering that one of the most striking features of being in space is that of floating freely inside stations, it may be that by reproducing on earth the conditions of floating on the surface of a fluid, one can induce cardiovascular adjustments similar to those that occur in space [2].

In this experiment, aiming to identify a new and inexpensive method for the terrestrial simulation of space flight, healthy subjects were invited to lie supine on the surface of a bath tub containing a highly concentrated aqueous solution of magnesium chloride ($MgCl_2$), an inorganic salt with a very high density from which a strong hydrostatic thrust can be generated that acts from the bottom upwards and therefore tends to make the body float on the surface of the tub's water. While in the tub, cardiodynamic variables were detected, non-invasively and beat by beat, using a portable impedance cardiograph of our own built [3].

2. Methods

2.1 Subjects

The subjects recruited for this experiment were 14 of which 5 females and 9 males. The mean values ± SD of the anthropometric variables were: height = 170.5±8.5 cm, body mass = 66.9±10.5 kg, age = 32±15 years. Before experimentations a team's doctor subjected them to an anamnestic interview, then they declared informed consent about the experimental procedure.

2.2 Water's saline solution

The fluid in the tub was Tyrrhenian Sea water supplemented with magnesium chloride ($MgCl_2$), this latter obtained naturally through a process of sedimentation and evaporation over time of the Sea water under the sun whose final residue is a highly concentrated $MgCl_2$ solution. This supplemented water had assumed a density of 1.35 g/ml or 31% higher than oceans. So, a body supinely immersed in this fluid undergoes a great hydrostatic thrust from the bottom upwards, the strength of which depends on the density of the water, such as to make it float on the water surface. In fact, the subject in Figure 1 appeared to float on the water with much of its anterior body surface out of the water. Furthermore, since the tub with the experimental solution (located at the SPA of the Forte Village Resort in Italy) was in the open air having temperatures ranging between 20°C and 22°C, the water inside it was heated to a constant temperature of 38°C in order to avoid as much as possible the activation of the subjects' thermoregulation mechanisms from which homeostatic interferences could arise in their cardiovascular profile. In fact, it has been shown that a thermal gradient of only 1°C between the body core and the water applied for only 10 min, as was in these experiments, would seem of not affect the body temperature control mechanisms [4]. However, no body temperature control was possible in Wt.

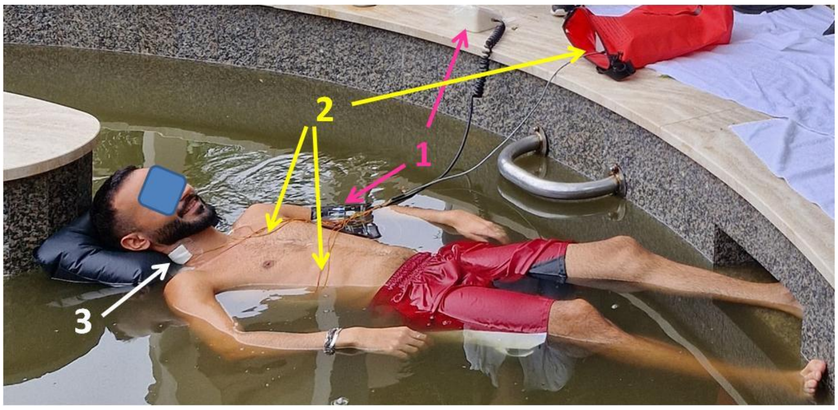

Figure 1. A tested subject in supine position floated on the tub containing a high density water solution of magnesium chloride. The fuchsia arrows (1) show the connection tube between the automatic sphygmomanometer placed on the edge of the tub and its waterproof cuff tightened around his left arm. The yellow arrows (2) show the electrical cables that start from the disposable electrodes on his chest and neck and go up to the portable impedance cardiograph which is inserted inside a red waterproof bag. The white arrow (3) indicates one of the 8 bioimpedance electrodes and is attached to the root of the neck being covered with a waterproof patch.

2.3 Experimental protocol

A home-made impedance cardiograph (E-Physio: previously validated comparing SV data with those of a NCCOM3-BoMed device by Bland & Altman plot and showing limits of agreement within +7 and -8 ml [3]) was here utilized to assess the main cardiodynamic variables beat-to-beat and non-invasively. It implements a single-frequency (65 kHz) evaluation board (ADAS-1000, Analog Devices, USA) which contains an alternating current supply at a constant value of 1mA [3]. E-Physio allows to calculating the left ventricle stroke volume (SV) by applying the Sramek-Bernstein equation [3]. E-Physio assessed the thoracic electrical impedance (Zt) by connecting itself with a subject through 8 ECG disposable electrodes, 4 of which lies in the plane of the neck roots muscles and the other 4 in the plane of the xiphoid process of the sternum.

Each subject performed -in temporal succession- 2 tests for the detection of Zt, each lasting 10 min. In the first test in a medical office, i.e. the dry test (Dt), the subject is placed relaxed in supine position. Here the Zt values were recorded beat-to-beat and were measured arterial pressure (MABP) and heart rate (HR) with an automatic arm sphygmomanometer both at the 1st and 10th minute. Approximately 15 minutes after the Dt finished, the second test started, i.e. the water test (Wt). In the Wt the subject was immersed in supine position into the water of the tub, with $MgCl_2$, where the same measurements as the Dt were carried out. In the Wt, electrodes were waterproofed using surgical 15×10 cm patches (Plastod, Italy). Figure 1 clearly shows this experimental condition. In Dt and Wt, it was decided to analyse 3 heartbeats that occurred both within the second and ninth minute from the start of the respective test, therefore with a total of 6 heartbeats for each tested subject (as a total of 84 beats), in order to verify any possible time-dependent drifts in the variables of interest. Anyway, visual checking of all Zt tracks did not show evaluable beat-to-beat changes in both Dt and Wt conditions.

3. Results

Firstly, no statistically significant differences in the variables of interest between the beginning and the end of the tests were found. Instead, the Wt evaluable beats (67) versus Dt ones (79) showed SV significantly lowered up to 66% and this despite the significant increase of the ventricular preload indicated by the strong reduction in EDLVVII (-47% respect to Dt) which, in turn, is given by the value assumed by thoracic impedance Zt at the end of diastole [3]. In fact, it has been demonstrated that Zt decreases linearly with the increase in ventricular preload [5]. Thus, the heterometric mechanism of SV increase established by the Frank-Starling law would seem to have lost some of its effectiveness during the Wt despite the significant increase in ventricular afterload represented by PVRI (+49%) here obteined as the ratio between MABP and CO. CO decreased quantitatively little but the percentage reduction is significant (-15%) in Wt. The homeometric mechanism for the increase in SV which, as is known, depends on the activity of the sympathetic innervation of the heart, also seemed to be deficient since the contractility of the heart, here evidenced by the MSERI obtained as the ratio of SV versus the ventricular ejection time (VET), was significantly reduced in Wt (-17%) compared to Dt.

Table 1. Mean values ±SD of cardiovascular variables during both dry (Dt, n=79) and water (Wt, n=67) tests. Student's *t* test for independent samples was applied to compare Dt versus Wt conditions and when P<0.05 the conditions differences were considered as statistically significant.

Experimental Conditions	SV (ml)	EDLVVII (Ω)	MSERI (ml s^{-1})	PVRI (Torr l^{-1} min^{-1})	CO (l min^{-1})	HR (beats min^{-1})	MABP (Torr)
Dt	40.9* ±16.6	33.4* ±7.0	113.3* ±49.3	49.9* ±24.0	2.0* ±0.7	59.2† ±11.4	87.5* ±11.1
Wt	27.0 ±15.3	15.8 ±3.6	94.6 ±46.1	74.3 ±49.0	1.7 ±1.1	60.2 ±14.3	83.6 ±9.4

[a] Dt: dry test, Wt: water test, SV: left ventricle stroke volume, EDLVVII: inverse index of left ventricle end diastolic volume, MSERI: mean systolic ejection rate index, PVRI: peripheral vascular resistance index, CO: cardiac output, HR: heart rate, MABP: mean arterial blood pressure, (*) Dt-Wt: P<0.05; (†) Dt-Wt: P>0.05.

4. Discussion and Conclusion

The 10-minute immersion in hyperdense water due to the high concentration of $MgCl_2$, gave rise to a significant reduction in MABP (-4.6%) while no changes occurred in HR, also leads to considering the possibility of an antihypertensive therapeutic effect of this experimental protocol which could be independent from the baroreflex balance between MABP and HR.

Possible similarities could exist among the cardiovascular adjustments here observed while lying for 10 minutes on hyperdense water and what happens while being in space: 1) the consistent increase in blood concentration in the thorax here demonstrated by the large reduction in Zt (represented by the EDLVVII) is in agreement with the observed upward shift of body fluids in astronauts upon they entering microgravity space [6]; 2) a vagal predominance have been demonstrated during short-duration space missions [7] which agrees with here shown Wt induced reduction in the MSERI or our chosen contractility index; 3) a reduction of systolic and diastolic blood pressure found in astronauts while flying in space [6] agrees with the here observed fall in MABP during the Wt test respect to the Dt one. Finally, since data from Capelli et al. [8] concerning cardiovascular responses after prolonged head-down tilt at bed rest, i.e. a gold-standard of terrestrial symulation of microgravity, showed SV and MABP decrease as was here observed in the Wt, it can be reasonably stated that our protocol based on body immersion in water with a high concentration of $MgCl_2$ could represent a new terrestrial simulation model of microgravity suitable for identifying targeted therapies to prevent conditions of arterial hypotension that occur during space flights.

References

[1] Baran R *et al* 2022 *Biomedicines* **10** 59
[2] Watenpaugh D E 2016 *J. Appl. Physiol.* **120** 904
[3] Tocco F *et al* 2012 *J. Phys. Conf. Ser.* **407** 012026
[4] Brunt V E and Mison C T 2021 *J. Appl. Physiol.* **130** 1684
[5] Luepker R V 1973 *Am. Heart J.* **85** 83
[6] Zambetta R M *et al* 2024 *Front. Physiol.* **15** 1438089
[7] Goldberger A L *et al* 2017 *Am. Heart J.* **128** 202
[8] Capelli *et al* 2008 *Eur. J. Appl. Physiol.* **104** 909