Original research

Study of effects of simulated space flight factors and use of infusion liquids on human hemodynamics with the use of the Cardiocode method

Olga K.Voronova[1], Mikhail Y. Rudenko[1*], Vladimir A. Zernov[1]

[1] Russian New University, 105005, Russia, Moscow, 22 Radio St.

[*] Corresponding author: Phone: +7 (8634) 31-24-03. E-mail: cardiocode@mail.ru
Submitted: 02 April 2013
Accepted: 28 April 2013
Published online: 30 May 2013

Aims

The aim is to study the effect of simulated space flight factors on the human central hemodynamics and evaluate the effectiveness of colloid and crystalloid infusions in microgravity simulation using the Cardiocode method.

Materials and methods

Test subjects were six men aged 20 to 35 without chronic somatic diseases. Antiorthostatic hypokinesia with an angle of 15 ° (ANOH-15) simulated the weightlessness was used. Diuretics were used to simulate hypovolemia in the test individuals. During ANOH-15 the colloid and crystalloid intravenous infusions were applied. Central hemodynamics parameters were measured by Cardiocode method.

Results

Background quantitative and qualitative central hemodynamics parameters were obtained, several individual characteristics of blood flow regulation were identified.
The effects of space flight factors, ground-based simulated with antiorthostatic hypokinesia, on the human hemodynamics were investigated.

Conclusion

The Cardiocode method allowed obtaining the information about the effects of simulated space flight factors and different infusion fluids on the human central hemodynamics.
The efficacy of crystalloid and colloid infusions for the correction of central hemodynamics abnormalities in test subjects in microgravity was positively evaluated.

Keywords

Cardiocode • Hemodynamics • Simulated space flight • Antiorthostatic hypokinesia • Hypovolemia • Microgravity

Imprint

Olga K. Voronova, Mikhail Y. Rudenko, Vladimir A. Zernov. Study of effects of simulated space flight factors and use of infusion liquids on human hemodynamics with the use of the Cardiocode method; Cardiometry; No.2; May 2013; p.124-135; doi: 10.12710/cardiometry.2013.2.124135 Available from: http://www.cardiometry.net/issues/no2-may-2013/simulated-space-flight-factors.pdf

Introduction

The further progress in cosmonautics, the prospects for long-term interplanetary missions dictate us today the necessity of the development and improvement of the system of medical services for orbital flights. Prolonged space missions require further adjustments and corrections of the preventive measure system, improving the system of medical selection of cosmonauts and astronauts, elaboration of absolutely new methods of diagnostics and treatment of cosmonauts both during their space missions and their adaptation to new tasks of the existing medical equipment systems already admitted to be used in space medicine (1).

One of the biggest challenges for the nearest future, which has been discounted up to the present day, is devising of new methods of intensive therapy and eventual surgical treatment to be used on board a space ship during long-term space missions in case of emergency. As to the orbital flights, in case of necessity of a surgical treatment, or in case some critical health conditions occur, there exists always the possibility to interrupt the space flight and return the critically ill person to the Earth within the possible shortest time. But it is just another case with interplanetary missions: there is no way of doing the same. Therefore, this makes the elaboration of a new reliable medical service system all the more important for its use during long-term space flights, including creation of new concepts and development of new methods of on-board surgical treatment of cosmonauts or astronauts in critical cases, if any.

One of the most significant components of surgery and intensive therapy during a space flight is infusion therapy. The existing equipment systems and facilities make possible to use the infusion therapy even under the weightlessness conditions. But at the same time, it should be noted that there are no data on impacts of various infusion liquids on parameters of the central and the peripheral hemodynamics, including data on their impacts on blood microcirculation and tissue gas exchange processes in the microgravity environment during a space flight.

There is a huge amount of data collected by experts which are related to issues on re-distribution of liquids in the body under the microgravity conditions (2), changes in water-salt exchange in the organism (3,4), tissue metabolism, effects of weightlessness both on the central and the peripheral hemodynamics (5). An efficiency of the use of infusion liquids under the space flight conditions has not been studied until now.

In the microgravity environment, when the parameters of the central and the peripheral blood circulation, the volumes of circulated blood and microcirculation indices are changed and when liquids in the cosmonaut's body are re-distributed, the effects of the use of infusion liquids might differ significantly from those expected. This factor should be considered in specifying tactics of infusion therapy under the space flight conditions.

Upon investigations of effects of colloid and crystalloid intravenous infusions on various parameters of the central and peripheral hemodynamics, we are able to optimize to a large extent all algorithms of intensive therapy in some surgical cases and some cases of critical health states under the weightlessness conditions.

In this connection it should be noted that it is advisable to carry out a number of ground-based experiments in order to identify some impacts of a simulated space flight on the efficiency of different infusion liquids used there.

The ground-based simulation of the microgravity is widely used both for training of cosmonauts and conducting of medical and technological experimentation under the microgravity conditions. There exist some different ways of how to imitate and simulate the weightlessness conditions on ground.

In medical studies, for the purpose of the microgravity simulation, most commonly used are methods simulating a lack of blood hydrostatic pressure in the organism. In particular, one of the microgravity models is restricting of test subjects to head down tilt bed rest which is called antiorthostatic hypokinesia (ANOH).

This article is presenting some results of an experimental study on the effects of factors of a space flight with the use of a ground-based simulation on the organism, with the utilization of the antiorthostatic hypokinesia (ANOH) at a tilt angle of 15°.

For conducting of such studies, the issues on methods of assessment, control and monitoring of the state of the cardiovascular system are of great importance.

In pursuing these aims, obtaining of reliable measurement data on the central hemodynamics by noninvasive technologies is really a very challenging idea.

In the above ANOH studies, in order to evaluate the responses of the human cardiovascular system to the simulated space flight conditions in combination with the support of the infusion liquids, we applied a new diagnostics method based on an application of the Cardiocode device (6).

The Cardiocode device offers an innovative noninvasive measuring technology that delivers noninvasively volumetric parameters of hemodynamics, based on the heart cycle phase analysis. This technology has its origin in a new theoretical model of blood flow via blood vessels in the organism.

This noninvasive technology makes possible to obtain not only values of phase-related parameters of hemodynamics, but to provide qualitative assessments of functional and structural changes, including hemodynamic changes in various parts of the cardiovascular system, as well.

Materials and methods

The aim of the experimental study with the use of the Cardiocode device & technology was to reveal and assess impacts and effects of a simulated space flight on the human cardiovascular system and evaluate the efficiency of the use of colloid and crystalloid intravenous infusions under the microgravity conditions.

Issue 1 was to reveal changes in the central hemodynamics of a human due to exposure factors of the simulated space flight (during a short-term ANOH and under conditions of in case of intentionally produced loss of fluid); Issue two was assessing the efficiency of the use of colloid and crystalloid intravenous infusions in test subjects with hypovolemia in order to correct abnormalities of the central and peripheral hemodynamics under conditions simulating microgravity effects (antiorthostatic hypokinesia at a tilt angle of 15° (ANOH -15°).

Six individuals (males) without any chronic somatic diseases, aged from 20 to 35, participated in the experimental study.

The antiorthostatic hypokinesia at a tilt angle of 15° (ANOH-15°) during 21 hours was taken as the model simulating the weightlessness conditions (microgravity).

The state of hypovolemia in the hypokinetic subjects was produced with the use of diuretics (furocemide).

During the ANOH-15° test, the above test subjects received colloid (infucol 10%) and crystalloid (glucose 5%) infusions via intravenous therapy.

The study comprised three sets of the experiment as follows:

- Set 1 of the 21 hour ANOH-15° test, no infusions were received. The liquid loss state was simulated with the use of the diuretics within the ANOH 14th hour.
- Set 2 of the 21 hour ANOH-15° test, when the test subjects received the colloid infusion (infucol 10%) via intravenous therapy within the ANOH 17th hour (500 ml during 1 hour). The liquid loss state had been produced with the use of the diuretics within the ANOH 14th hour.
- Set 3 of the 21 hour ANOH-15° test, when the test subjects received crystalloid infusion via intravenous therapy (glucose 5%) within the ANOH 17th hour (500 ml during 1 hour). The liquid loss state had been produced with the use of the diuretics within the ANOH 14th hour.

It should be noted that all test subjects were involved in the above three sets of the experiment. An interval between the tests for each individual was 5 to 7 days.

All test participants were subjected to orthostatic tests both before the ANOH-15 and after it covering all 3 sets of the experimental study (orthostatic test is referred to as the OT – passive vertical position on tilt table).

Changes in the central hemodynamic parameters during the experiment were recorded and evaluated with the utilization of the device Cardiocode. The experimental studies were carried out in line with the following testing schedule.

1. Set 1, no infusion received:

Background recumbent position
Minute 1, OT upright position
Minute 4, OT upright position
Minute 8, OT upright position
Minute 12, OT upright position
Minute 15, OT upright position
Minute 30, ANOH-15°
Morning hours, ANOH-15°
Day hours, ANOH-15°
Evening hours, ANOH-15°
Horizontal recumbent position, before OT
Minute 1, OT upright position
Minute 4, OT upright position
Minute 8, OT upright position
Minute 12, OT upright position
Minute 15, OT upright position

2. Sets 2 and 3, infusion receiving

Background recumbent position
Minute 1, OT upright position
Minute 4, OT upright position
Minute 8, OT upright position
Minute 12, OT upright position
Minute 15, OT upright position
Minute 30, ANOH-15°
Morning hours, ANOH-15°
ANOH-15° before receiving infusion
ANOH-15°, minute 15 of receiving infusion
ANOH-15°, minute 30 of receiving infusion
ANOH-15° , minute 45 of receiving infusion
ANOH-15° , minute 60 of receiving infusion
Evening hours, ANOH-15°
Horizontal recumbent position, before OT
Minute 1, OT upright position
Minute 4, OT upright position
Minute 8, OT upright position
Minute 12, OT upright position
Minute 15, OT upright position

In the test subjects recorded were ECGs and Rheograms at times specified by the above experiment schedule (s. Fig. 1 herein).

Figure 1. *ECG, ECG first-order derivative and Rheogram recorded with the PC-assisted device Cardiocode.*

On the basis of the recorded ECG and Rheo curves, the appropriate heart cycle phase structure for every individuals was automatically identified and the relevant parameters of the central hemodynamics were calculated (6).

Results

The basic (recorded before the experiment) quantitative and qualitative characteristics of the cardiovascular system performance in all test subjects were within the norm. Certain individual peculiarities of blood flow regulation not referring to pathology were noted.

Influence of simulated space flight factors and infusion liquid injection on hemodynamics of the test subjects

Before evaluating the influence of infusion of colloid and crystalloid solutions on central hemodynamics, it is necessary to understand how hemodynamic parameters change under the influence of the simulated space flight factors. Analysis of parameters of central hemodynamics in the test subjects calculated with the Cardiocode device showed that the most significant changes during the experiment can be observed in the following parameters:

SV – stroke volume, ml;
MV – minute volume, l;

PV1 – volume of blood entering the ventricle in the early diastole, which is the characteristic property of the suction function of the ventricle, % of SV;

PV2 – volume of blood entering the left ventricle in the systole phase, which is the characteristic property of the contraction function of the atrium, % of SV;

PV5 – volume of blood (SV fraction) pumped by the ascending aorta as peristaltic pump which is the characteristic property of the aortic tonus, % of SV.

Heart rate, HR

Hemodynamic parameters the values of which are given as percentage of stroke volume provide a better understanding of cardiac output formation than the absolute values. Thus, percentage ratio of volumes PV1 and PV2 shows the process of the heart filling with blood, in particular, whether the ventricle or the atrium are to a greater degree responsible for diastole. Volume PV5 characterizes the contribution of the aorta to blood ejection from the ventricle in the systole phase.

The diastole contributes to formation of cardiac output significantly. Without heart relaxation and diastole there would be no contraction and systole phase. An increase in the heart rate serves as a protection tool of the human body and assists in maintaining sufficient blood supply of body organs and tissues under conditions of increased loads. The inner structure of the cardiac cycle changes as well, and the functions are redistributed among the atria, ventricles and large vessels which take part in cardiac output formation. As investigations showed, under these conditions the interrelation of diastolic phase volumes changes, volume PV2 increases significantly and the atrium load on myocardium increases as well. In case of high pulse rate the ventricles are filled with blood only during the systole phase. Thus, the compensation mechanism works.

We will pay attention to the analysis of diastolic heart function considering the interrelation of volumes PV1 and PV2 as diagnostic criterion. The subject whose ventricles are filled in bed rest position during the early diastole phase possesses greater compensation capabilities.

Let us consider the general scheme of the dynamics of the central hemodynamic parameters of the test subjects during the experiment. Then we shall consider some individual characteristics.

It should be noted that the mentioned scheme can be observed in practically every test subject with only minor deviations. It is only the intensity of changes that is different.

A clear-cut response to orthostatic load preceding and following antiorthostatic hypokinesia (ANOH) as well as preceding and following the infusion therapy is typical for all test subjects.

Let us consider the scheme of dynamics of central hemodynamic parameters. The most significant changes during all three sets of the experimental study in all test subjects are as follows.

1. Position: recumbent bed rest.

Volume PV1 is larger than volume PV2 in absolute terms as well as in relative values. This means that the heart is filled mostly by means of the ventricle activity.

2. Orthostatic test before the ANOH-150 and after it

Stroke volume SV decreases, minute volume MV rises compared with the background. The heart rate increases significantly. The interrelation of diastolic phase volumes PV1 and PV2 change, PV2 increases significantly. That means that the ventricle is filled with blood due to the atrial systole. The myocardium load of the atrium occurs whereas the influence of the ventricle on cardiac output formation decreases. The ECG curves of certain test subjects show negative T waves. The Rheo curve changes as well (a diastolic wave rises).

3. Antiorthostatic hypokinesia at an angle of 15° (ANOH-15°)

Stroke volume SV decreases compared with the orthostatic test, minute volume MV rises, the heart rate decreases. The interrelation of diastolic blood volumes changes, PV1 increases and PV2 decreases. With bed rest position of the subjects the heart is filled with blood easily, and an active function of the atrium is not necessary.

The use of furosemide during the 14th hour of the ANOH does not lead to significant changes of central hemodynamic parameters. The volume of the venous bed increases at the same time decreasing blood supply to lesser circulation. This can soothe the condition of the subject experiencing the antiorthostatic hypokinesia during several hours.

4. Blood volume PV5 (% of SV) changes ranging from 11% to 16% in all test subjects. Thus, aorta constantly contributes to cardiac output under the influence occurring in the process of experiments.

5. Infusion therapy.

In the course of colloid and crystalloid intravenous infusions the changes of values of central hemodynamic parameters are not significant. However, during infucol colloid infusion an increase in the minute volume MV against the infusion background is observed in all test subjects. It can indicate increase in volume of blood circulation as a result of the infusion. In the process of glucose crystalloid infusion an increase in the MV is observed in four test subjects, test subjects No 4 and No 5 being exception. The reason of this difference can be explained as follows. Colloid infusions are kept better in vascular bed than crystalloid infusions. Thus, colloid infusion influences the central hemodynamics.

6. Orthostatic test after the ANOH-150.

Table 1 presents values of the central hemodynamic parameters in all test subjects during the orthostatic test following ANOH in the course of three sets of the experimental studies. Thus, it is easier to evaluate the influence of infusions upon acceptability of the orthostatic test following the zero-G-conditions simulation.

Table 1.

Values of central hemodynamic parameters of the test subjects influenced by orthostatic test following ANOH-15°

Test subject No	hemodynamic parameters	Set 1 without infusion	Set 2 colloid intravenous infusion	Set 3 Crystalloid intravenous infusion
1	MV, l	6,7 - 7,2	6,0 - 6,6	5,9 - 6,6
	PV1 %	37 - 44	48 - 55	30 - 53
	PV2 %	56 - 63	44 - 52	47 - 70
	heart rate	121 - 132	108 - 116	111 - 123
2	MV, l	6,3 - 6,9	6,1 - 6,7	-
	PV1 %	15 - 40	37 - 55	-
	PV2 %	60 - 85	45 - 63	-
	heart rate	105 - 115	87 - 100	-
3	MV, l	5,4 - 6,2	7,8 - 8,1	5,5 - 5,9
	PV1 %	49 - 58	41 - 54	52 - 59
	PV2 %	42 - 51	46 - 59	41 - 48
	heart rate	98 - 109	104 - 111	91 - 102
4	MV, l	5,1 - 5,8	4,8 - 5,4	4,9 - 5,3
	PV1 %	57 - 69	63 - 71	65 - 72
	PV2 %	31 - 43	29 - 37	28 - 35
	heart rate	93 - 107	79 - 96	79 - 89
5	MV, l	5,1 - 7,3	6,8 - 7,3	5,4 - 7,1
	PV1 %	16 - 51	8 - 20	23 - 61
	PV2 %	49 - 84	80 - 92	39 - 77
	heart rate	102 - 130	123 - 136	90 - 129
6	MV, l	5,5 - 6,8	6,5 - 6,9	5,7 - 6,6
	PV1 %	35 - 56	32 - 41	26 - 49
	PV2 %	44 - 65	59 - 68	51 - 74
	heart rate	99 - 125	116 - 129	107 - 121

The criteria for selection of test subjects best prepared to adaptation to the conditions of a space flight and re-adaptation upon return to the Earth

When selecting the candidates for a space flight it is reasonable to take into account at least three criteria as listed below:

- an acceptable ability to bear overloads during the start;
- an acceptable ability of adaptation to weightlessness;

• availability of a body compensatory reserve required for return to the Earth and re-adaptation to the normal gravity conditions.

This is certainly a very difficult task. Much more information is needed to solve it. We can only offer a sort of prognostication, when using the results of the analysis of circulatory system response to the effects of simulated space flight factors in the above mentioned completed experiment.

The ability of every test individuals to be adapted to the weightlessness conditions is beyond any doubt. But their ability of re-adaptation to the Earth normal gravity conditions after a space flight raises far more questions.

Antiorthostatic hypokinesia at an angle of 15° (ANOH-15°) is a model of weightlessness in these experiments. The analysis of the data on hemodynamics changes during the ANOH showed that the ratio of diastolic phase volumes changes towards an increase in the PV1 blood volume and a decrease in the PV2 blood volume, i.e., the atria are discharged.

The orthostatic test carried out after the ANOH can be considered as a model of return to the normal gravity on the Earth after the weightlessness conditions. It is evident that it leads to a sharp increase in the heart rate and the PV2 parameter. It also implies a sudden overloading of atrial myocardium.

After a long-term stay in the weightlessness environment in a real space flight, the fact described above can play a significant role in the re-adaptation of a cosmonaut to the Earth gravity.

Taking it into account, a better ability to tolerate the orthostatic test under conditions of the simulated ground-based weightlessness can be considered as one of the criteria for the selection of test subjects for a real space flight.

This study allows drawing some general conclusions only and tracing some tendencies of the human cardiovascular system response to the space effects simulated in the experiment.

Discussion and conclusions

In conclusion, we would like to summarize the results of the conducted experimental study.

First, the Cardiocode method used for the experimental study allowed us to obtain most valuable qualitative and quantitative data on the effects of simulated space flight factors and infusion fluids on the human central hemodynamics. It has been found that the use of colloid and crystalloid infusions in the test subjects with hypovolemia in the microgravity environment is a very effective measure for coping with undesirable space flight effects.

Second, despite the complex theoretical concept of hemodynamics, the new noninvasive method of measuring phase-related volumetric parameters of hemodynamics has been successfully implemented in a very easy way, with the use of the small-sized portable PC-assisted device Cardiocode. So, this device can be used to obtain information not only during a cosmonaut preflight training, but also during a real space flight.

Third, the Cardiocode technology can be successfully used to evaluate and monitor the effectiveness of the developed preventive measures to avoid hemodynamic abnormalities in cosmonauts in the weightlessness environment.

Fourth, the possibility of obtaining a complete set of quantitative and qualitative parameters featuring the performance of the various circulatory system segments allows using the Cardiocode method developed by the authors hereof for evaluating the effects of various external factors, including those of a space flight, on the human cardiovascular system.

List of abbreviations

ANOH - a definite position of the person in bed, when the upper part of the body is located below the horizontal line, the so-called antiorthostatic position or antiorthostatic hypokinesia (weightlessness simulation);

OT - orthostatic test (passive vertical position on a tilt-table);

ECG - electrocardiogram;

Rheo - rheogram.

Statement on ethical issues

Research involving people and/or animals is in full compliance with current national and international ethical standards.

Author contributions

All authors prepared the manuscript and read the ICMJE criteria for authorship, M.Y.R. drafted the manuscript. All authors read and approved the final manuscript.

Conflict of interest

None declared.

References

1. Bogomolov VV, Egorov AD, Goncharov IB, Kovachevich IV, Yarmanova EN, Kozlovskaya IB. Some clinical aspects of a piloted mission to mars. Aerospace and environmental medicine. 2003;37(5):30-6. PubMed ID: 14730730.

2. Gazenko OG, Pestov ID, Makarov VI. Mankind and space. Moscow: Nauka; 1987.

3. Grigoriev AI, Egorov AD. The effects of prolonged spaceflights on the human body. Advances in Space Biology and Medicine. 1991;1:1-35. PubMed ID: 1669425.

4. Grigoriev AI, Kotovskaya R, Fomina G. Cardiovascular system performance characteristics in space flight conditions. Cardiovascular pathology Current state of the problem: Media Medica; 2009. p. 38-52.

5. Grigoriev AI, Larina IM, Noskov VB. Effects of space flights on the state of water-electrolyte balance regulation. I M Sechenov Russian Physiological Journal. 2006;92(1):5-17.

6. Rudenko MY, Voronova OK, Zernov VA, Kolmakov S, Makedonsky D, Mamberger KK, et al. Theoretical Principles of Heart Cycle Phase Analysis. München, London, New-York: Fouqué Literaturverlag. 336 p. ISBN 978-3-937909-57-8.