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Cardiovascular autonomic control after short-duration spaceflights

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Abstract

After spaceflight, astronauts sometimes suffer a variable degree of reduced orthostatic tolerance. Although many studies have addressed this problem, many aspects remain unclear. Also, it is unknown how long the cardiovascular system needs to recover from short duration spaceflights.

The scope of the present study was to determine a long-term follow-up of cardiovascular control up to 25 days after spaceflight under control conditions in five astronauts using heart rate variability, blood pressure variability and baroreflex sensitivity (BRS) indices.

In standing position heart rate after spaceflight was significantly higher compared with pre-flight (R+1: 99 (SD 9) BPM vs L-30: 77 (SD 3) BPM; $p < 0.001$). At the same time high frequency modulation of heart rate was extremely depressed (R+1: 70 (SD 334) ms^2 vs L-30: 271 (SD 68) ms^2; $p < 0.01$), as was BRS: (R+1: 5 (SD 1) vs L-30: 10 (SD 2) ms/mmHg, $p < 0.05$). These changes had largely recovered after 4 days upon return to Earth. Orthostatic blood pressure control was well maintained from the first day after landing.

The decrease in BRS and in vagal heart rate modulation following short-duration spaceflight appear to constitute an adequate autonomic neural response to restored gravity. After 4 days upon return to Earth, vagal heart rate modulation is almost completely recovered to the pre-flight level. The findings of the present study demonstrate that the decrease in vagal heart rate modulation in standing position should not be characterised as some kind of cardiovascular deconditioning, but rather as the normal response to orthostatic stress after spaceflight.

Keywords: Microgravity; Space medicine; Autonomic modulation

1. Introduction

Spaceflight induces many changes in the human body [1,42,41]. Especially after return to Earth, this causes physiological problems for astronauts. The inability to stand for prolonged periods, with the risk of fainting, and reduced orthostatic tolerance [34] can be considered as some of the most problematic conditions from an operational point of view. The degree of lack of orthostatic tolerance varies a lot from subject to subject. Despite the large amount of studies devoted to solving this problem, or to elucidate the mechanisms behind it, many aspects are still unclear.

In space, most studies agree on diminished vagal baroreflex gain together with an increase in vagal heart rate control [13,24], which is probably due to an

Abbreviations: ANS, autonomic nervous system; BRS, baroreflex sensitivity; BPM, beats per minute; BPV, blood pressure variability; CO, cardiac output; HRV, heart rate variability; ISS, international space station; LBNP, lower body negative pressure; MNSA, muscle nerve sympathetic activity; NA, noradrenaline; SV, stroke volume

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increase in stroke volume (SV) in the first days of spaceflight [31,33]. At the same time however, muscle sympathetic nerve activity (MSNA) has been shown to be higher in microgravity, as demonstrated with lower body negative pressure (LBNP) experiments, Valsalva manoeuvres, handgrip and cold pressor tests [13,22,17,15]. The increased sympathetic drive was supported by measurements of platelet norepinephrine in space [10].

After return to Earth the human body has to readapt to gravity. At this moment, the most likely cause of decreased orthostatic tolerance after spaceflight is a limitation of compensatory elevation in vascular resistance upon standing [9,21]. This can be related to a hypoadrenergic responsiveness as supported by lower or equal values of plasma noradrenaline (NA) levels postflight compared to preflight in orthostatic intolerant subjects [40]. At the same time changes in the baroreflex might contribute to reduced orthostatic tolerance [12,20,11,18]. Reduced vagal–cardiac efferent neural outflow in combination with reduced cardiovagal baroreflex gain have been described in relation with reduced orthostatic tolerance [20]. On the contrary, astronauts that are able to complete a stand test show increased levels of plasma NA after spaceflight [21,40]. The sympathetic dominance after spaceflight might result from the decreased SV and cardiac output (CO) upon standing [31,39].

Although symptoms of reduced orthostatic tolerance disappear rather quickly after return from space, the autonomic control system may recover more slowly, the duration of which is still unclear. Yet, most studies have performed a follow-up of astronauts and cosmonauts from the first day after landing up to 1 week [13,19,22,9,29,35,16,27]. However, some studies have shown that cardiovascular control mechanisms were not yet restored in full by that time. Nevertheless, only very few studies have performed post-flight measurements up to between 10 and 18 days.

Using a simple paced-breathing protocol, we recently showed that 25 days of recovery after short-duration spaceflight is sufficient to restore vagal–cardiac outflow to pre-flight conditions [38]. However, the time course of recuperation within this period of 25 days remains uncertain. The scope of the present study was to determine a long-term follow-up of cardiovascular control up to 25 days after spaceflight under control conditions.

We studied heart rate modulation, blood pressure modulation and baroreflex sensitivity (BRS) before, during and after spaceflight using heart rate variability (HRV) and blood pressure variability (BPV) indices in five astronauts who had spent 10–11 days in space [3]. According to the above information, the hypothesis was tested that decreased vagal–cardiac control early post-flight will last more than 2 weeks after return but will be restored completely upon 25 days after landing.

2. Methods

2.1. Subjects

This study was performed during three scientific ESA-Soyuz missions to the International Space Station (ISS) (Odissea, Cervantes and Delta: 10–11 day missions). Five male astronauts were studied before, during and after spaceflight. Mean age of the subjects at the time of the pre-flight data collection was 40 (SD 3) years, height 180 (SD 4) cm and weight 76 (SD 10) kg. In space the astronauts had a busy scientific schedule and had no physical exercise programme. Upon return there was also no specific rehabilitation programme, in their spare time they were advised to rest.

The experiment protocol was approved by the local ethical committee and the ESA Medical Board. Each subject was informed of the experimental procedures and signed an informed consent form. The study complies with the Declaration of Helsinki.

2.2. Experimental protocol

Pre- and post-flight: during the pre-and post-flight data collections a stand test was performed in the morning (before 11 AM). This test consisted of a supine period of at least 10 min for instrumentation, calibration and hemodynamic equilibrium, and 10 min recording in rest, followed by a 3–5 min sitting period and a 10 min standing period. Subjects were instructed to maintain their regular breathing depth and rhythm, which was verified by the operators and a respiratory sensor. The stand test was terminated after 10 min.

Pre-flight data collection was performed 1 month before launch (L-30). Post-flight data collections were performed at 1, 4, 9, and 25 days after return to Earth (R+1, R+4, R+9 and R+25). The tests were performed at ambient room temperature (21−23 °C) in a quiet room at the Gagarin Cosmonaut Training Center in Moscow, Russia. Late post-flight R+25; between 25 and 28 days after landing) data collection was performed in a temperature-controlled laboratory (21–23 °C) in the University Hospital Gasthuisberg of Leuven, Belgium. The subjects were asked to refrain from alcoholic or caffeinated beverages from at least 9 h before the measurements.