Paper ID: 68673
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IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM (A1)
Interactive Presentations - IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM (IP)

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NUMERICAL MODELING OF THE CARDIOVASCULAR CHANGES IN PARABOLIC FLIGHTS AT DIFFERENT POSTURES

Abstract

Parabolic flights serve as cheaper and more affordable Earth analogs of actual spaceflight in mimicking microgravity occurrence on humans. In past years, a considerable number of parabolic flight experiments were conducted with the purpose of collecting information regarding the human physiological coping with reduced gravity. In particular, the role of the cardiovascular system was widely investigated, although only simple and little invasive in vivo measurements were acquired (e.g., continuous heart rate, finger or brachial arterial pressure). Recently, catheterized monitoring of subjects' central venous pressure during a parabolic flight campaign showed fundamental discrepancies with respect to other ground experiments often considered as analogs of microgravity conditions (i.e., head-down bed rest study). Such findings established the significance of conducting accurate experiments to understand the actual cardiovascular response in free-falling conditions. In this perspective, numerical modeling was proposed as powerful alternative to in vivo measurements, by providing useful insights of the human cardiovascular system response under several pathological and extreme conditions (e.g., at different posture, under exercise or in the presence of different cardiovascular diseases such as heart failure, cardiac arrhythmias, etc.). In our work, we developed a multiscale mathematical model of the human circulation - including arterial, venous, peripheral microcirculation and cardiopulmonary circulation – and we simulated a conventional parabolic flight profile to assess the transient hemodynamic response of the system. The model was incorporated with short-term regulation mechanisms of blood pressure (arterial baroreflex and cardiopulmonary reflex) and flow (cerebral autoregulation), aimed at controlling the heart rate and contractility and vessels vasodilation and constriction state. The model was first validated by comparing the response of the most observed hemodynamic variables during each phase of flight (1g – 1.8g - 0g – 1.8g – 1g) – that is heart rate, arterial blood pressure, stroke volume, cardiac output and total peripheral resistance. Then, the transient hemodynamic behavior of the system during parabolic flight at different postures (i.e., supine, seated and standing) was investigated in terms of cardiac mechano-energetic indexes and oxygen consumption. We found that the seated and standing posture determined a much stronger response to gravity variation with respect to supine, also including a deep imbalance of the heart energy demand-supply ratio, especially during the hypergravity phases. Finally, we explored the role of augmented intracranial pressure as possible hemodynamic mechanism inducing long-term spaceflight visual impairment.