Simulation of circulation response to gravitational changes during spaceflight

Zan Ahmad[1], Karen M. Ong[1,2], Charles Puelz[1,3] Rebecca S. Blue[2], Charles S. Peskin[1]

Courant Institute of Mathematical Sciences, New York University[1]
University of Texas Medical Branch[2]
Pediatric Cardiology Division, Baylor College of Medicine[3]

Description:

This project presents zero-dimensional computer models for blood flow in the context of spaceflight, focusing on launch and landing. In contrast, previous attempts at first-principle modeling of the cardiovascular system's behavior during spaceflight have emphasized the circulation in microgravity or post-spaceflight orthostasis [1,2]. Our methodologies consist of a steady-state model that considers averaged values for physiological parameters and a multicompartmental pulsatile blood flow model that is fully time-dependent. Systemic and pulmonary arteries and veins are modeled as compliance chambers, and the elements that connect said chambers operate as linear resistors, equipped with valves as needed. The systemic circulation is partitioned into upper and lower parts to allow for the effects of gravity, which are accentuated during launch and landing. We consider the case of partial collapse of the systemic veins as they enter the thorax, allowing for changes in intrathoracic pressure from anti-G-straining maneuvers (AGSM). Both models include a feedback controller that monitors upper systemic arterial pressure as well as stroke volume and adjusts heart rate and systemic venous reserve volume to keep the monitored variables constant. Biometric data from centrifuge subjects was collected to calibrate our model to various spaceflight scenarios [3].

References:

[1] Mohammadyari, Parvin, Giacomo Gadda, and Angelo Taibi. "Modelling physiology of hemodynamic adaptation in short-term microgravity exposure and orthostatic stress on Earth." *Scientific reports* 11.1 (2021): 1-13.

[2] Summers, R. L., and T. G. Coleman. "Computer systems analysis of the cardiovascular mechanisms of reentry orthostasis in astronauts." *Computers in cardiology*. IEEE, 2002.

[3] Blue, Rebecca S., et al. "Tolerance of centrifuge-simulated suborbital spaceflight by medical condition." *Aviation, space, and environmental medicine* 85.7 (2014): 721-729.