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EFFECTS OF ARTIFICIAL GRAVITY ON THE CARDIOVASCULAR SYSTEM: COMPUTATIONAL APPROACH

Abstract

The cardiovascular system experiences important changes during spaceflight in response to a weightlessness environment. These changes include the central fluid shift phenomenon, the reduction in total circulation blood volume, and a decrease in heart size, venous compliance, and baroreflex sensitivity. In general, this adaptation is successful. However, the re-adaptation process when crew members return to a gravity environment is more problematic, and orthostatic intolerance may occur.

Several countermeasures are currently in place. In general, they are system specific, focusing on one aspect of human deconditioning in space. In particular, cardiovascular countermeasures include aerobic exercise, fluid loading, the use of leg cuffs to reduce the amount of fluid shift from the lower extremities to the upper extremities, and the use of Lower Body Negative Pressure (LBNP) that induces a cardiovascular stress. However, despite the variety of countermeasures, their effectiveness in terms of maintaining preflight levels hasn't been demonstrated, and their specificity in just one physiological system makes their use difficult and time consuming. Artificial gravity is seen as an integrated countermeasure capable of challenging several physiological systems at the same time. In particular, short-radius centrifugation combined with exercise may be effective against cardiovascular deconditioning in space. However, the centrifuge configuration still needs to be selected in order to maximize its effectiveness.

In order to explore the cardiovascular responses to artificial gravity, we are developing a comprehensive lumped-parameter model to simulate the short-term transient hemodynamic response to artificial gravity exposure. The model consists of 21 compartments (including systemic circulation, pulmonary circulation, and the cardiac model), and the short-term cardiovascular control systems (arterial baroreflex and cardiopulmonary reflex). In addition, hydrostatic pressure sources located at each compartment account for the pressure gradient resulting from short-radius centrifugation. Furthermore, the cardiovascular effects of exercise are also captured by including the muscle pump and other factors. Preliminary results successfully replicate experimental data taken on the MIT compact-radius centrifuge. Future analysis includes a comparison between cardiovascular responses under constant gravity vs. artificial gravity, and a sensitivity analysis of key parameters such as angular velocity or the distance between the subject's head and the center of rotation.