Available online at www.sciencedirect.com
ScienceDirect
PERGAMON
Acta Astronautica 63 (2008) 722–726
ACTA ASTRONAUTICA
www.elsevier.com/locate/actaastro

Systems analysis of the mechanisms of cardiac diastolic function changes after microgravity exposure

Richard Summers[a,*], Thomas Coleman[a], Platts Steven[b], David Martin[c]

[a]*University of Mississippi Medical Center, Jackson, MS, USA*
[b]*National Aeronautics and Space Administration Johnson Space Center, Houston, TX, USA*
[c]*Wyle Laboratories, Houston, TX, USA*

Received 17 May 2007; received in revised form 2 January 2008; accepted 20 February 2008
Available online 16 April 2008

Abstract

Detailed information concerning cardiac function was collected by two-dimensional and M-mode echocardiography at 10 days before flight and 3 h after landing in astronauts returning from shuttle missions. A comparative analysis of this data suggests that cardiac diastolic function is reduced after microgravity exposure with little or no change in systolic function as measured by ejection fraction However, the mechanisms responsible for these adaptations have not been determined. In this study, an integrative computer model of human physiology that forms the framework for the Digital Astronaut Project (Guyton/Coleman/Summers Model) was used in a systems analysis of the echocardiographic data in the context of general cardiovascular physiologic functioning. The physiologic mechanisms involved in the observed changes were then determined by a dissection of model interrelationships. The systems analysis of possible physiologic mechanisms involved reveals that a loss of fluid from the myocardial interstitial space may lead to a stiffening of the myocardium and could potentially result in some of the cardiac diastolic dysfunction seen postflight. The cardiovascular dynamics may be different during spaceflight.

Keywords: Diastolic function; Microgravity; Digital Astronaut

1. Background

The potential risks associated with cardiovascular deconditioning during spaceflight have been a central concern in the study of the human physiologic adaptation to the microgravity environment [1]. Changes in cardiac diastolic function have recently been noted after short duration spaceflight in returning astronauts. However, the mechanisms responsible for these adaptations have not been determined. Physiologic adaptation to the microgravity environment is complex and requires an integrative perspective for a more complete understanding. In this study, a systems analysis approach using a detailed computer model of physiologic functioning was employed to examine the possible mechanisms involved in the observed changes [2,3].

2. Methods

Astronauts from Shuttle missions lasting from 9 to 16 days were evaluated at 10 days before flight and approximately 3 h after landing by either two-dimensional echocardiography (Philips HDI 5000, Bothel, WA) or M-mode echocardiography (Genesis II, Biosound, Indianapolis, IN). Measurements of isovolumic relaxation time (IVRT), left ventricular E/A changes E'/A' tissue

* Corresponding author. Tel.: +1 601 984 5586;
fax: 1 601 984 5583.
E-mail address: rsummers@pol.net (R. Summers).

0094-5765/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.actaastro.2008.02.010

Doppler imaging and flow propagation velocity (color M-mode) were used in the evaluation of diastolic function. For systolic function evaluations, ejection fractions were measured using the Teicholz formula. The results were compared as absolute values through statistical analysis using a paired t test (preflight vs postflight) at a level of significance of $p < 0.05$. The NASA Johnson Space Center Institutional Review Board approved experimental protocol and all subjects gave their written informed consent.

3. Systems analysis of experimental findings using the Digital Astronaut

The data were examined through a systems analysis approach using a derivative of a well-established computer model of circulatory functioning previously described in the literature that is currently serving as the framework for the Digital Astronaut Project [4–6]. The computer model incorporates the physiologic responses to changes in pressures, flows and hydraulics within the circulatory system as affected by gravitational forces. Myocardial muscle progression to atrophy or hypertrophy in reaction to the circulatory load conditions is also included in the model. This methodology allows us to develop a sophisticated approach to hypothesis formulation and a detailed analysis of this very complex physiologic process. Such a technique has been used successfully to understand mechanisms pertaining to hypertension, fluid volume control and myocardial structural changes that were not intuitively obvious otherwise [7,8]. By this method we can support our conclusions regarding the experimental findings through an exacting and quantitative approach. The analytic procedure involves recreating the experimental protocol of exposure to spaceflight, returning to earth and subsequent reacclimization to 1-G for a virtual astronaut in a simulation environment. Utilizing the rich detail of the model, the particulars of the physiologic adaptations to these perturbations were examined including an analysis of the relative changes in the constituents of the myocardium (electrolytes and solid and fluid elements). Overall sequential changes in cardiac structure and function were recorded during the time course of the simulated protocol.

4. Results

Data collected in returning 27 shuttle astronauts suggests that cardiac diastolic function is reduced in this environment. There were statistically significant changes in diastolic function as determined by IVRT (29% increase), left ventricular E/A ratio (12% decrease) and flow propagation velocity (15% decrease) (Fig. 1). There was also an observed decrease in the E'/A' ratio by tissue Doppler imaging (8% decrease) though this was not determined to be statistically

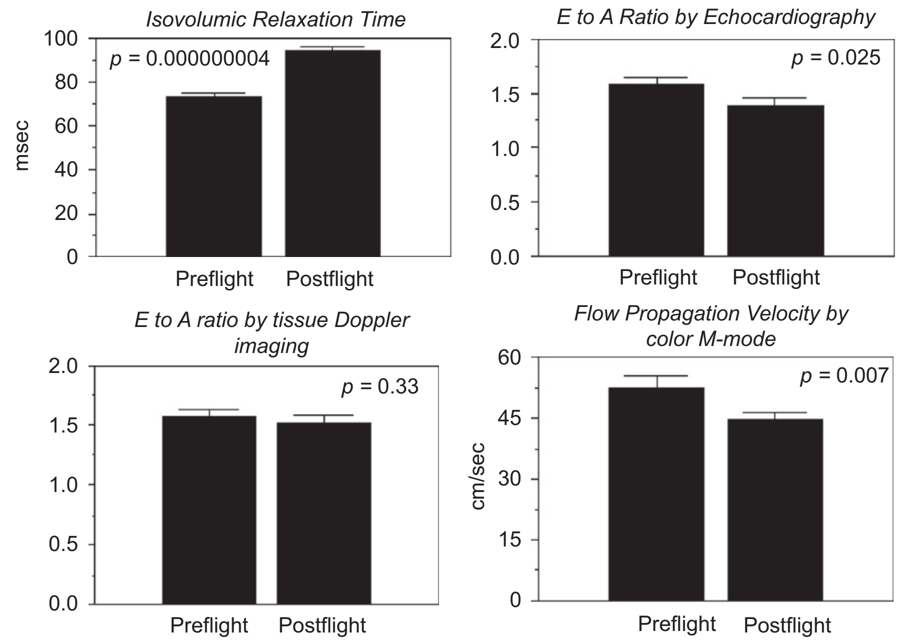

Fig. 1. Measurements of diastolic function by four different methods in shuttle astronauts ($n = 27$) returning from short-duration missions.