COMPARISON OF ECHOCARDIOGRAPHIC MEASUREMENTS BEFORE AND AFTER SHORT AND LONG DURATION SPACEFLIGHT

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ABSTRACT

Previous echocardiography studies in astronauts before and after short duration (4 - 17 days) missions have demonstrated a decrease in resting left ventricular (LV) stroke volume (SV), but maintained ejection fraction (EF) and cardiac output. Similar studies before and after long duration (129 - 144 days) spaceflight have been rare and their overall results equivocal. The purpose of this work was to compare the echocardiographic measurements (M-mode, 2-D and Doppler) from short duration (n = 13) and long duration (n = 4) crewmembers. Compared to short duration astronauts, long duration crewmembers had a significantly greater percent decrease in EF ($+6 \pm 0.02$ vs. -10.5 ± 0.03, $p = 0.005$) and percent fractional shortening ($+7 \pm 0.03$ vs. -11 ± 0.07, $p = 0.015$), and an increase in LV end systolic volume (-12 ± 0.06 vs. $+39 \pm 0.24$, $p = 0.011$). These data suggest a reduction in cardiac function that relates to mission duration. As the changes in blood pressure and circulating blood volume (9% – 12%) are reported to be similar after short and long duration flights, the drop in EF after longer spaceflights is likely due to a decrease in cardiac function rather than altered blood volume.

Key words: spaceflight, deconditioning, echocardiography

Cardiovascular deconditioning (loss of adaptive capacity) in microgravity has long been an issue associated with human spaceflight (1-6). Operational concerns such as crewmember fitness and physical performance are critical determinants of mission success. While mission durations of 4-17 days have been typical in the Space Shuttle program, a smaller number of cosmonauts and astronauts have flown longer missions (>129 days) aboard the Russian Mir Space Station. These longer missions will become more common beginning in the year 2001, when crewmembers will be assigned to tours of duty of 90 days or more on the International Space Station. The International Space Station crewmembers will have to perform strenuous extravehicular activities to construct and maintain the station. In potential exploratory missions to Mars and beyond, humans will face increasingly longer exposures to microgravity. A mission to Mars, as currently envisioned, would involve significant physical challenges during extravehicular activity on the planet after having spent several months in microgravity deconditioning during the journey.

In addition to these in-flight physiological challenges, current requirements of all Space Shuttle crewmembers include the ability to egress the Shuttle to a safe distance in the event of an emergency landing. Significant microgravity-induced cardiac deconditioning, along with symptomatic orthostatic intolerance, may render this already demanding activity unfeasible. Approximately 20% of all astronauts do not successfully complete a standard tilt test (10 minutes at an 80° upright tilt) following landing because they experience orthostatic intolerance (7). This intolerance appears to be greatly exacerbated with increased mission durations, as 83% of astronauts returning from long duration missions could not complete a standard tilt test (7).

Whether significant decrements in cardiac function will further compromise performance of these activities during and after long duration flight is not known. Although orthostatic tolerance is influenced by cardiac performance, cardiac functional decrements have not been shown to be a major contributing factor following short duration flight (2). Nevertheless, the sustained lack of a gravitational challenge during long duration missions might adversely influence myocardial function due to the decreased workload on the heart.

To date, echocardiographic data obtained before and after short duration Shuttle flights have demonstrated preservation of cardiac functional parameters. It has been shown that short duration spaceflight is associated with decreased left ventricular (LV) stroke volume (SV); yet, ejection fraction (EF) and cardiac output were not decreased at rest postflight (2-4). Although echocardiographic data have been obtained within 24 hours of landing following long duration flights, we know of no prior reported ultrasound data obtained within the immediate postflight period (within 3 hours of landing) for these longer missions (8). The need for early data acquisition is important, as immediate clinical performance during this critical time period is a practical operational concern. It has also been noted that changes in some cardiovascular measurements have been shown to resolve within 48 hours of landing (2).

The purpose of this study was to determine if preflight to postflight echocardiographic findings were significantly different following long duration when compared to short duration spaceflight.

METHODS

Seventeen male astronaut subjects, ages ranging from 34 to 48 years, underwent echocardiography preflight and immediately postflight. Thirteen subjects flew on short duration Space Shuttle missions (4 - 17 days) and 4 flew on long duration missions (129 - 144 days). This study was approved by the Johnson Space Center Institutional Review Board.

Data were obtained approximately 10 days prior to flight, within 3 hours of landing, and 3 to 10 days postflight. Identical Biosound Genesis II (Biosound, Indianapolis, IN) echocardiographic systems were used for all data acquisition. Views and measurements used were consistent with the American Society of Echocardiography standards. Views included parasternal long axis and apical, with subjects in the left lateral decubitus position. M-modes were obtained from the parasternal long axis view. Following videotape recording, 4 frames of each M-mode were stored digitally for off-line analysis. Doppler measurements included mitral inflow recorded at the tips of the mitral leaflets. LV outflow Doppler was obtained from the apical window. Pulsed Doppler of the ascending aortic flow was obtained through the suprasternal approach. Three frames of each Doppler spectrum were stored digitally. All stored images were analyzed and averaged by 2 observers on either a Kodak-Microsonics ImageVue DCR or Microsonics DataVue II workstation (Indianapolis, IN). Parameters were selected based on functional relevance.

Ejection fraction was calculated as (LV end diastolic volume - LV end systolic volume)/LV end diastolic volume. Mass was calculated as 1.04 x [(diastolic interventricular septal thickness + diastolic LV posterior wall thickness + LV diastolic diameter)^3 - (LV diastolic diameter)^3] - 13.6. LV fractional shortening was calculated as (LV diastolic diameter - LV systolic diameter)/LV end diastolic diameter x 100. The calculation for LV volume was volume = (7.0/(2.4 + LV diastolic diameter)) LV diastolic diameter^3 (9). A Mann-Whitney Rank Sum Test was employed and significance determined by a p value of <0.05 when comparing short and long duration groups. Statistical values were calculated for percent changes for preflight to landing day and are presented as the mean ± standard error. Paired t tests were employed to determine the significance between days within each group. Significance was determined by a p value of

<0.05.

RESULTS

Table I shows the preflight, landing day, and recovery data for all subjects. Table II shows the percent change between preflight and landing day for both short and long duration flight. In contrast to short duration crewmembers who had a decrease in LV systolic volume and an increase in EF, long duration crewmembers showed an increase in LV systolic volume and a corresponding decrease in EF. In comparing short duration to long duration, the percent changes for preflight vs. landing day were statistically significant for LV systolic diameter ($p = 0.025$), LV systolic volume ($p = 0.011$), EF ($p = 0.005$), percent fractional shortening ($p = 0.015$), and LV posterior wall in diastole and systole ($p = 0.003$ and 0.015, respectively) with long duration flight.

Decreases in LV diastolic diameter and LV diastolic volume were observed following both short duration (-4% and -8%, respectively) and long duration (-1.3% and -3.5%, respectively) flights. There was also a decrease in posterior wall thickness in diastole ($p <0.05$) and a trend toward decreased thickness in systole in long duration subjects as compared with those from short duration. Doppler-derived SV and cardiac output were also decreased more following long duration missions (-17% and -12%, respectively), compared to short duration (-5% and -2%, respectively). When comparing the two groups, the differences between SV and cardiac output were not significant ($p = 0.157$ and $p = 0.429$, respectively). Cardiac output decreased despite a higher heart rate on landing day in long duration subjects (Table II). Other parameters that appeared to show a trend following long duration flight, but were not statistically different, included slight decreases in LV mass, right ventricular dimension, and left atrial diameter. An increase in the mitral E to A ratio (10%) after the long duration missions was observed, as was a decrease in mitral deceleration time (-17.9%). Heart rates were increased by approximately 16% following short duration missions, whereas after long duration missions the increase was only 6%. During the recovery period (3 - 10 days postflight), there was an overall trend toward a return to preflight values. None of the recovery parameters reached statistical significance when compared with preflight or landing day values.

DISCUSSION

This study evaluates the differences in echocardiographic findings between short and long duration spaceflight. Our results show a significant reduction in M-mode-derived EF and percent fractional shortening in long duration subjects as compared to short duration subjects ($p < 0.05$). With only a small decrease in diastolic volume, the decrease in EF and percent fractional shortening results from a significantly increased LV systolic chamber size. Doppler-derived SV and cardiac output were also decreased following long duration spaceflight. In a measure of LV compliance, long duration subjects had increased mitral E to A ratios and decreased mitral deceleration times. LV mass was slightly decreased in long duration subjects as has been previously reported during a head-down bedrest study (10). Taken together, these results imply a decrease in cardiac function following long duration spaceflight and suggest that mission duration may play a role in cardiac deconditioning.

Previous studies that included echocardiography before and after spaceflight have predominantly dealt with subjects who flew on short duration missions. Investigators have shown decreases in LV diastolic volume and SV, but maintained EF and cardiac output (2, 3). LV mass was also decreased in short duration subjects, but these results were not shown to be significant (3). Recovery from such changes has differed between studies. Following 4- to 5-day flights Mulvagh et al. reported cardiac changes that were resolved within 48 hours (2). In contrast, Bungo et al. reported a more delayed recovery of 1 to 2 weeks following flights of 5 to 8 days (3). Despite the differences in the recovery data, both studies showed minimal difference between preflight and recovery data. The results from short duration subjects in the present study are similar to those of the previous studies.

Echocardiography has also been previously performed before and after long duration spaceflight on both American and Soviet/Russian missions. The results from the long duration flights have been equivocal. Atkov et al. studied 15 cosmonauts before, during and after (within 24 hours of landing) flights onboard the Soviet Union Space Stations ranging from 75 to 185 days. The results of this study varied widely, with EF changes from pre- to postflight ranging from –6% to +34% (8). This range led to an overall improvement in EF of 7% being reported following flight. M-mode echocardiography was performed on 3 astronauts before and after an 84-day flight onboard the American Skylab 4 in 1974 (5). The findings from the present study included reduced SV and LV diastolic volume and mass. Contrary to the previous studies, data from this investigation showed a significant reduction in EF as well as a significant increase in LV systolic volume. Unlike earlier studies, our results included spectral Doppler data that appeared to show similar trends as that acquired from the imaging data (reduced SV and cardiac output).

During spaceflight, the demands on the heart are probably reduced compared to preflight. This reduction could be attributed to a number of factors. The absence of gravity reduces the perfusion demand for skeletal muscles involved in maintaining upright posture. Overcoming the gravity-induced hydrostatic gradient involved in perfusing areas distal to the heart is eliminated. In addition to this hydrostatic gradient, for a subject in the supine position, there is gravity-induced pressure on the chest wall, which potentially increases intrathoracic pressure and central venous pressure. In microgravity, this pressure is removed, resulting in decreases in intrathoracic pressure and central venous pressure, thus possibly aiding venous return. Buckey et al. showed that during the first 9 hours of spaceflight central venous pressure is decreased relative to preflight levels (11). Similar findings have been reported during the microgravity induced by parabolic flight (12). Under these new conditions, it is reasonable to assume that the heart would adapt, reaching a new, less dynamic equilibrium point.

With a decrease in cardiac output or peripheral arterial resistance, one would also expect activation of neurohumoral reflexes. Atrial naturetic factor might be expressed by initial distention caused by decreases in venous pooling and increased blood volume in the thorax. This should produce an antagonist effect upon the renin-angiotensin system. Over the longer duration, unloading of high-pressure baroreceptors in the LV, carotid sinus, and aortic arch would generate afferent signals stimulating the brain cardioregulatory centers. The efferent sympathetic nervous system would subsequently stimulate the release of renin and angiotensin II (and by effect also aldosterone). Concurrent stimulation of the supraoptic and paraventricular nuclei would result in arginine vasopressin release. Aldosterone has been implicated in myocardial fibrosis and angiotensin II, in addition to constricting blood vessels and stimulating aldosterone release, also causes remodeling of cardiac myocytes (13).

The unloading of the heart resulting from a decrease in blood volume would naturally decrease ventricular volume. The resultant decreased wall stress might subsequently affect diastolic function with resultant loss of diastolic negative pressure and decreased ventricular distensibility (14).

Compounded with these conditions was the fact that the long duration subjects in this study underwent a decrease in aerobic activity as they were often unable to follow the recommended exercise regimen, sometimes for weeks at a time. This relative inactivity would decrease chronotropic and pressure work of the myocardium. Although during short duration flight, astronauts also do not necessarily exercise strenuously. Therefore any potential effect would have been less noticeable due to the limited duration of these missions. Taken together, these factors provide potential mechanisms that could lead to progressive deconditioning of the heart in microgravity.

Upon return to gravity, there was an increase in mean arterial pressure in both short and long duration subjects compared to preflight (Table II). This increase in blood pressure could partially explain a decrease in SV as the heart is working against a greater afterload. However, similar increases in mean arterial pressure were noted in both the short and long duration subjects. Thus, it appears that afterload has little effect on the relative decrease in SV following short vs. long duration spaceflight. The decrease in plasma volume also was between -9% and -12% in both short and long duration crewmembers (unpublished data, Janice M. Fritsch-Yelle), indicating that changes in plasma volume were also unlikely to have been responsible for the difference in SV between groups. The effect of gravity on the chest wall has been shown to have measurable effects on the central venous pressure (11). Central venous pressure in space has only been studied in relation to short duration flight, but if central venous pressure remains reduced throughout long duration flight, the additional time spent in microgravity would lead to a heart more thoroughly adapted to a reduced intrathoracic pressure. A chronic state of decreased intrathoracic pressure could potentially lead to remodeling of the heart. This remodeling could potentially account for the smaller decrease in LV diastolic volume following long duration when compared to short duration flight. With LV diastolic volume approximately at preflight levels and a decrease in demand for blood (reduced EF and SV), the LV systolic volume would be larger than preflight, similar to our findings.

Long duration-induced cardiac remodeling may also explain why the mitral E to A ratio in long duration flight tended to increase (10%). The mitral E to A ratio is a measure of the relative contributions of ventricular relaxation and atrial contraction to LV filling. We initially believed that the decrease in plasma volume would lead to diminished preload and result in a decreased E to A ratio. The increased E to A ratio following long duration flight was not expected and would suggest increased cardiac compliance. This idea is supported by a study that was performed on rhesus monkeys in simulated microgravity (10° head-down tilt for 4 days). These authors found increased cardiac compliance and decreased LV contractility after head-down tilt (15). However, with LV diastolic volume at nearly preflight levels, and an increased LV systolic volume (i.e. decreased EF), LV diastolic relaxation would necessarily be somewhat restricted as compared to preflight, reducing the potential atrial contraction component to LV filling.

A quick recovery of functional parameters postflight would argue against structural myocardial changes and support neurohumoral effects. Autonomic regulation of cardiovascular function has been shown to be altered on landing day following short duration spaceflight (16, 17). Plasma catecholamine levels are increased on landing day in short duration flight subjects; this may explain the significant increase in heart rate (16-18). In contrast, it appeared the heart rate response was attenuated in long duration flight subjects. Taken together, the data indicate that autonomic regulation of cardiac function may be decreased in long duration flight subjects which may also contribute to the observed decrease in cardiac function (EF). This could also play a role in suboptimal postflight cardiac performance (17). A previous study of heart rate variability was unable to define the relative changes in the effects of the autonomic nervous system with long duration flight (19).

The small number of subjects available for this study does not allow extrapolation of its results to a larger population. Additional studies are required, with a larger and more diverse subject pool, to determine whether changes observed in this study are reproducible and, if so, what factors (gender, exercise, diet, or cabin environment) alleviate or exacerbate cardiovascular deconditioning.

Our study assumes that the environments of the Space Shuttle and Mir Space Station did not influence the cardiovascular system in any way beyond the effects of microgravity. It is widely known, however, that Mir has experienced numerous environmental problems. These included, at their most extreme, ethylene glycol leaks, a fire, disturbances in carbon dioxide balance, and very high humidity. It is not known whether these and other environmental factors could have impacted cardiac performance.

Certain newer techniques, such as tissue Doppler imaging or color flow propagation, were not used due to limitations of the available equipment. It is certainly recognized that these techniques could help better characterize the changes in cardiac structure and function. The relatively older equipment and the existing protocol necessitated the calculation of ventricular volumes from M-mode. Although this technique is not accurate as an absolute measure of LV volume in disease conditions, it does provide a dependable measure of healthy, symmetrically shaped hearts, especially in a longitudinal study.

CONCLUSIONS

The most interesting findings of our study were the greater long duration reductions in EF, SV, and cardiac output, and an increase in LV systolic volume when compared to short duration spaceflight. These findings suggest greater cardiac deconditioning with long duration than with short duration spaceflight. This raises important concerns regarding progressive reduction in cardiac function with increased mission duration. The findings from Doppler evaluation of SV and cardiac output support the findings from the M-mode and two-dimensional LV evaluation. The exact cause or causes of these findings cannot definitively be determined from this study and need to be confirmed with a larger group of long duration crewmembers, including in-flight echocardiography. If this trend is borne out in subsequent studies, it could have an important impact on mission duration decisions, as well as on countermeasure programs.

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REFERENCE LIST

1. Pottier JM, Patat F, Arbeille P, Pourcelot L, Massabuau P, Guell A et al. Cardiovascular system and microgravity simulation and inflight results. Acta Astronaut. 1986;13:47-51.

2. Mulvagh SL, Charles JB, Riddle JM, Rehbein TL, Bungo MW. Echocardiographic evaluation of the cardiovascular effects of short-duration spaceflight. J.Clin.Pharmacol. 1991;31:1024-26.

3. Bungo MW, Goldwater DJ, Popp RL, Sandler H. Echocardiographic evaluation of space shuttle crewmembers. J.Appl.Physiol. 1987;62:278-83.

4. Lathers CM, Riddle JM, Mulvagh SL, Mukai C, Diamandis PH, Dussack L, et al. Echocardiograms during six hours of bedrest at head-down and head-up tilt and during space flight. J.Clin.Pharmacol. 1993;33(6):535-43.

5. Henry WL, Epstein SE, Griffith JM, Goldstein RE, Redwood DR. Effect of prolonged space flight on cardiac function and dimensions. In: Johnston RS, Dietlein LF, eds Volume NASA SP-377. Washington,D.C.: National Aeronautics and Space Administration, 1977:366-71.

6. Nixon JV, Murray RG, Bryant C, Johnson RL, Jr., Mitchell JH, Holland OB, et al. Early cardiovascular adaptation to simulated zero gravity. J.Appl.Physiol. 1979;46(3):541-48.

7. Reyes C, Freeman-Perez S, Fritsch-Yelle J. Orthostatic intolerance following short and long duration spaceflight. FASEB J. 1999;13:A1048.

8. Atkov OYu, Bednenko VS, Fomina GA. Ultrasound techniques in space medicine. Aviat.Space Environ.Med. 1987;58:A69-A73.

9. Teichholz LE, Kreulen T, Herman MV, Gorlin R. Problems in echocardiographic volume determinations: echocardiographic- angiographic correlations in the presence of absence of asynergy. Am.J.Cardiol. 1976;37:7-11.

10. Levine BD, Zuckerman JH, Pawelczyk JA. Cardiac atrophy after bed-rest deconditioning: a non-neural mechanism for orthostatic intolerance. Circulation 1997;96:517-25.

11. Buckey JC, Jr., Gaffney FA, Lane LD, Levine BD, Watenpaugh DE, Wright SJ et al. Central venous pressure in space. J.Appl.Physiol 1996;81:19-25.

12. Pantalos, G., Hart, S., Mathias, M. K., Sharp, D., Watenpaugh, D. E., Buckey, J., and Hargens, A. Venous and esophageal pressure in humans during parabolic flight. FASEB 13(4), A108. 1999.

13. Schrier RW, Abraham WT. Mechanisms of disease: hormones and hemodynamics in heart failure. N.Engl.J.Med. 1999;341:577-85.

14. Zile MR, Tomita M, Ishihara K, Nakano K, Lindroth J, Spinale F et al. Changes in diastolic function during development and correction of chronic LV volume overload produced by mitral regurgitation. Circulation 1993;87:1378-88.

15. Koenig SC, Convertino VA, Fanton JW, Reister CA, Gaffney FA, Ludwig DA, et al. Evidence for increased cardiac compliance during exposure to simulated microgravity. Am.J.Physiol 1998;275:R1343-R1352.

16. Whitson, P. A., Charles, J. B., and Williams, W. J. Human sympathoadrenal response to standing after space flight. FASEB 7, A620. 1993.

17. Fritsch-Yelle JM, Whitson PA, Bondar RL, Brown TE. Subnormal norepinephrine release relates to presyncope in astronauts after spaceflight. J.Appl.Physiol. 1996;81:2134-41.

18. Whitson PA, Charles JB, Williams WJ, Cintròn NM. Changes in sympathoadrenal response to standing in humans after spaceflight. J.Appl.Physiol. 1995;79(2):428-33.

19. Goldberger AL, Bungo MW, Baevsky RM, Bennett BS, Rigney DR, Mietus JE, et al. Heart rate dynamics during long-term space flight: Report on Mir cosmonauts. Am.Heart J. 1994;128:202-04.

MINI ABSTRACT

Comparison of Echocardiographic Measurements Before and After Short and Long Duration Spaceflight.

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Echocardiographic findings before and after short and long duration spaceflight were compared. Decreases in ejection fraction, stroke volume, cardiac output and an increase in left ventricular systolic volume are suggestive of a decrease in cardiac function related to mission duration.

Table I Echocardiographic parameters (mean ± SE) before flight, on landing day and 2-4 days after landing (recovery) for short and long duration flight crew members. * = $p < 0.05$ from preflight within a group.

	Short duration (n=13)			**Long duration (n=4)**		
	Preflight	**Landing day**	**Recovery**	**Preflight**	**Landing day**	**Recovery**
RVDD (cm)	2.60 ± 0.12	2.61 ± 0.16	2.45 ± 0.16	1.99 ± 0.23	1.81 ± 0.26	1.98 ± 0.26
IVSD (cm)	1.00 ± 0.04	1.03 ± 0.03	1.08 ± 0.04	0.92 ± 0.06	0.90 ± 0.06	0.98 ± 0.04
IVSS (cm)	1.39 ± 0.04	1.45 ± 0.05	1.47 ± 0.04	1.33 ± 0.07	1.31 ± 0.13	0.96 ± 0.15
LVDD (cm)	5.28 ± 0.16	5.09 ± 0.11	5.15 ± 0.13	5.41 ± 0.24	5.34 ± 0.25	5.13 ± 0.15
LVDS (cm)	3.27 ± 0.12	3.02 ± 0.08	3.12 ± 0.09	3.14 ± 0.23	3.35 ± 0.22	3.02 ± 0.20
FS (%)	38.00 ± 0.01	41.00 ± 0.01	39.00 ± 0.01	42.00 ± 3.20	37.58 ± 1.33	42.00 ± 2.29
LVPWD (cm)	**0.87 ± 0.02**	**0.93 ± 0.02**	**0.95 ± 0.01**	**1.00 ± 0.06**	**0.86*± 0.04**	**0.95 ± 0.04**
LVPWS (cm)	1.58 ± 0.05	1.61 ± 0.04	1.66 ± 0.04	1.66 ± 0.09	1.43 ± 0.08	1.46 ± 0.04
MCS (circ/sec)	1.08 ± 0.03	1.17 ± 0.04	1.07 ± 0.03	1.28 ± 0.09	1.14 ± 0.09	N/A
LAD (cm)	3.70 ± 0.11	3.71 ± 0.09	3.65 ± 0.14	3.67 ± 0.16	3.52 ± 0.08	3.65 ± 0.23
MASS (gm)	232.00 ± 15.00	231.00 ± 12.00	246.00 ± 15.00	219.00 ± 37.00	192.00 ± 15.00	196.00 ± 11.00
LVVD (ml)	136.00 ± 9.60	123.00 ± 6.70	127.00 ± 7.30	147.00 ± 23.00	139.00 ± 15.00	128.00 ± 9.20
LVVS (ml)	43.00 ± 4.40	35.00 ± 2.30	40.00 ± 3.10	40.00 ± 5.60	52.00 ± 5.70	35.00 ± 3.90
EF (%)	**68.00 ± 1.40**	**71.00*± 0.01**	**69.00 ± 0.01**	**73.00 ± 3.00**	**65.00*± 2.95**	**72.00 ± 0.71**
PV (M/sec)	0.83 ± 0.04	0.90 ± 0.03	0.87 ± 0.04	0.83 ± 0.04	0.88 ± 0.12	0.98 ± 0.03
DVI (cm)	0.17 ± 0.01	0.16 ± 0.01	0.20 ± 0.01	0.15 ± 0.01	0.17 ± 0.01	0.17 ± 0.01
E/A Ratio	1.74 ± 0.14	1.70 ± 0.07	1.84 ± 0.13	1.39 ± 0.11	1.53 ± 0.17	1.57 ± 0.22
E (M/sec)	0.60 ± 0.03	0.61 ± 0.02	0.60 ± 0.03	0.57 ± 0.05	0.67 ± 0.12	0.61 ± 0.06
A (M/sec)	0.37 ± 0.02	0.36 ± 0.01	0.38 ± 0.02	0.42 ± 0.04	0.41 ± 0.07	0.40 ± 0.02
AT (sec)	0.08 ± 0.01	0.08 ± 0.01	0.10 ± 0.01	0.08 ± 0.02	0.11 ± 0.01	0.08 ± 0.01
DT (sec)	0.22 ± 0.02	0.19 ± 0.04	0.60 ± 0.01	0.48 ± 0.04	0.28 ± 0.04	0.29 ± 0.05
Ao PV (M/sec)	0.98 ± 0.04	0.94 ± 0.04	0.97 ± 0.06	1.10 ± 0.20	0.93 ± 0.15	0.96 ± 0.04
Ao AT (sec)	0.12 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	0.08 ± 0.01	0.11 ± 0.03	0.11 ± 0.05
Ao DT (sec)	0.29 ± 0.04	0.23 ± 0.01	0.25 ± 0.01	0.25 ± 0.01	0.19 ± 0.01	0.24 ± 0.01
HR (bpm)	**54.33 ± 2.15**	**62.31*± 3.71**	**54.00 ± 2.10**	**59.00 ± 5.50**	**63.00 ± 3.50**	**70.00 ± 3.00**
SBP (mmHg)	**113.15 ± 2.49**	**122.31*± 3.25**	**118.30 ± 3.49**	**113.75 ± 3.67**	**125.25 ± 4.77**	**118.75 ± 2.73**
DBP (mmHg)	73.23 ± 1.52	79.85 ± 2.89	75.08 ± 1.73	63.00 ± 5.93	75.75 ± 1.97	68.50 ± 2.58
MAP (mmHg)	**86.54 ± 1.47**	**94.00*± 2.88**	**89.49 ± 1.82**	**79.92 ± 5.13**	**92.25 ± 2.76**	**85.25 ± 2.39**
SV (ml)	**89.77 ± 5.60**	**81.01*± 4.80**	**93.47 ± 6.90**	**93.59 ± 14.70**	**72.33 ± 6.13**	**88.46 ± 7.99**
CO (l/min)	4.98 ± 0.26	5.02 ± 0.27	5.08 ± 0.37	5.28 ± 0.58	4.62 ± 0.52	6.33 ± 0.53
TPR (mmHg/l/min)	17.57 ± 0.86	19.48 ± 1.16	18.49 ± 1.29	15.75 ± 1.69	21.16 ± 3.25	13.57 ± 2.06
Weight (lb)	178.00 ± 6.53	170.00 ± 5.79	176.00 ± 6.51	176.00 ± 5.77	164.00 ± 7.40	171.00 ± 5.31

Table II Comparison of changes in echocardiographic parameters between short and long duration flights. Each column represents the percent change from preflight to landing day. * = $p < 0.05$ between short and long duration flights. ** = $p < 0.01$ between short and long duration flights.

	Short duration (n=13)	**Long duration (n=4)**
	Δ %	Δ %
RVDD (cm)	2.00 ± 0.06	-4.30 ± 0.07
IVSD (cm)	5.00 ± 0.04	1.10 ± 0.09
IVSS (cm)	6.00 ± 0.02	-1.50 ± 0.01
LVDD (cm)	-4.00 ± 0.02	-1.30 ± 0.01
LVDS (cm)	**-7.00 ± 0.02**	**7.40* ± 0.05**
FS (%)	**7.00 ± 0.03**	**-11.00** ± 0.07**
LVPWD (cm)	**9.00 ± 0.03**	**-14.20** ± 0.01**
LVPWS (cm)	**2.00 ± 0.02**	**-14.00* ± 0.05**
MCS (circ/sec)	8.00 ± 0.05	-11.00 ± 0.08
LAD (cm)	0.00 ± 0.02	-3.60 ± 0.03
MASS (gm)	3.00 ± 0.07	-1.20 ± 0.08
LVVD (ml)	-8.00 ± 0.04	-3.50 ± 0.06
LVVS (ml)	**-12.00 ± 0.06**	**39.00** ± 0.24**
EF (%)	**6.00 ± 0.02**	**-10.50** ± 0.03**
PV (M/sec)	12.00 ± 0.05	5.90 ± 0.07
DVI (cm)	2.00 ± 0.10	8.70 ± 0.21
E/A Ratio	5.00 ± 0.09	10.30 ± 0.18
E (M/sec)	3.00 ± 0.07	15.30 ± 0.17
A (M/sec)	3.00 ± 0.07	-3.10 ± 0.08
AT (sec)	-3.00 ± 0.08	52.10 ± 0.67
DT (sec)	1.00 ± 0.07	-16.90 ± 0.08
Ao PV (M/sec)	4.10 ± 0.03	-13.20 ± 0.09
Ao AT (sec)	-7.00 ± 0.05	-5.40 ± 0.11
Ao DT (sec)	-13.00 ± 0.15	-27.40 ± 0.15
HR (bpm)	15.70 ± 0.09	6.00 ± 0.10
SBP (mmHg)	6.96 ± 2.47	8.93 ± 3.12
DBP (mmHg)	6.64 ± 4.12	16.60 ± 3.90
MAP (mmHg)	6.76 ± 3.45	13.20 ± 2.80
SV (ml)	-5.00 ± 0.03	-17.40 ± 0.05
CO (l/min)	-2.30 ± 0.07	-12.20 ± 0.09
TPR (mmHg/l/min)	7.13 ± 5.93	25.00 ± 3.44
Weight (lb)	-2.87 ± 2.99	-2.57 ± 3.28