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Original Article

Bone mineral and lean tissue loss after long duration space flight

A. LeBlanc[1], V. Schneider[2], L. Shackelford[2], S. West[1], V. Oganov[3], A. Bakulin[3], L. Voronin[3]

[1]Baylor College of Medicine, [2]Johnson Space Center, Houston, Texas, USA, [3]Institute of Biomedical Problems, Moscow, Russia

Abstract

The loss of bone and muscle is a major concern for long duration space flight. In December of 1989, we established a collaboration with Russian colleagues to determine the bone and lean tissue changes in cosmonauts before and after flights on the Mir space station lasting 4-14.4 months. Eighteen crew members received a lumbar spine and hip DEXA scan (Hologic 1000W) before and after flight; 17 crew members received an additional whole body scan. All results were expressed as percent change from baseline per month of flight in order to account for the different flight times. The pre-and post-flight data were analyzed using Hotelling's T^2 for 3 groups of variables: spine, neck of femur, trochanter; whole body BMD and subregions; lean (total, legs, arms) and fat (total only). A paired t-test was used as a follow-up to the Hotelling's T^2 to identify the individual measurements that were significantly different. These data define the rate and extent of bone and lean tissue loss during long duration space flight and indicate that the current in-flight exercise program is not sufficient to completely ameliorate bone and muscle loss during weightlessness.

Keywords: Bone Loss, Lean Tissue Loss, Bone Mineral Density, Weightlessness

Introduction

Based on theoretical considerations, bone and muscle atrophy was identified as a potential problem even before manned space flight. During the Skylab flights lasting 29 to 84 days, calcium balance was performed in-flight along with pre- and post-flight single photon densitometry of the arm and calcaneus[1,2].

These early experiments confirmed that bone loss might indeed be a problem for long duration space flight. All of the data regarding bone loss since Skylab comes from the long duration Soviet/Russian and more recently Shuttle/Mir missions. The Soviets measured the os calcis bone density in cosmonauts before and after missions lasting 75 to 184 days and demonstrated losses ranging from -0.9% to -19.8% with the degree of loss roughly associated with mission duration[3]. Computed tomography has been used to estimate bone mineral changes in four cosmonauts after missions up to seven months in length demonstrating vertebral bone loss from 0.3% to 10.8%[4,5].

A formal collaboration between the American and Russian space agencies to comprehensibly measure the bone mineral of cosmonauts was begun in 1989. In January 1990, a dual photon device (Hologic 1000W) was obtained and sent to Star City (Cosmonaut training center), Russia to measure the cosmonauts before and after long duration flights aboard the MIR space station. We have previously reported on the BMD changes in 7 cosmonauts after long duration space flight[6].

Corresponding author: A. LeBlanc, Baylor College of Medicine, Houston, Texas, USA. E-mail: aleblanc@bcm.tmc.edu

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Methods

Cosmonauts

This report summarizes the measurements made from 1990 to 1995 on 18 cosmonauts involving 12 missions measured before and after missions lasting from 4 to 14.4 months. Three of the 18 cosmonauts flew an additional mission approximately 2 years after the first flight. The data from the second flights are treated as a separate group and are not included in the analysis of the 18. Generally the flight length varied between 126 and 197 days; in two individuals flight length was considerably longer, 311 and 438 days. Seventeen of the cosmonauts were male and one was female. The cosmonauts were generally scanned twice before flight at approximately 4-6 months and at about 30 days before launch and within the first week of landing. The scan performed just prior to flight was used to establish the baseline for that flight.

BMD scans

The instrument used for this study was a dual photon X-ray absorptiometer (Hologic 1000W, Waltham, Mass.). The scanning protocol that was adopted for this project was dictated in part by the limited time available for scanning; one hour per cosmonaut per session. The scanning protocol was as follows: lumbar spine, left hip, left tibia, and whole body in that order. Eighteen crew members received a lumbar spine and hip DEXA scan (Hologic 1000W) before and after flight; 17 crew members received an additional whole body scan. Acquisition method for the lumbar spine, whole body and hip were the same as those recommended by the manufacturer. The spine scan always included at least L1-L4. The whole body scans were analyzed by both the standard and enhanced software; only the enhanced data will be presented in this report. Some of the early whole body scans were obtained without a simultaneous soft tissue bar and therefore the head values for some of the crew members could not be processed using the enhanced software. The acquisition and analysis protocol for the tibia scan used a modified version of the spine protocol. The Hologic spine phantom was run periodically, and on each day a scan was acquired.

Space flight exercise program

The Russian exercise program has been in place for a number of years including the time during which the data reported in this study were collected. The cosmonauts are required to maintain physical fitness through a series of exercises consisting of bungee cord resistive exercises, bicycle ergometer, and running on a treadmill[7]. The in-flight exercise program is formed around a 4 day cycle in which 3 days are used for prescribed exercise with the fourth day used for optional exercise or rest according to personnel preference. On each exercise day, the crew exercises in two 1-1.5 hour sessions for a total of 2-3 hours. The design of the exercise protocol takes into account the personal preferences of the crew member, however, in general during the early phase of the flight (first month) exercise on the cycle-ergometer (target heart rate of 160-180 beats/min.) is emphasized while toward the end of the mission treadmill exercise is accentuated. Bungee cords are used to secure the crew member to the treadmill with a force of about 0.6 times the body weight on earth. In addition to the above exercise, strength training for 10-30 minutes per day with elastic expanders throughout the mission are used to condition specific muscle groups. An elasticized suit providing passive resistance on the antigravity muscles of the legs and torso is worn for up to 8 hours per day.

Statistical analysis

The main hypotheses of interest were comparisons of measurements immediately pre-flight and post-flight. Since the length of time between measurements was not constant, the results were expressed as percent change from baseline per month of flight in order to account for the different flight times. All statistical comparisons were made using the total percent change during flight. Prior to statistical analysis a subset of the data, believed to be the most important of the collected data, were chosen. This was done to reduce the number of tested sets to increase the power to detect true differences, i.e., to avoid a high probability of a Type I error for multiple comparisons with 18 subjects.

To further minimize this problem, the pre-and post-flight data were analyzed using Hotelling's T^2 for 3 groups of variables: spine, femur neck, trochanter; whole body BMD and subregions; lean (total, legs, arms) and fat (total only). Hotelling's T^2 was used to make an overall comparison of the percentage changes for the selected variables. This test is a multivariate extension of the paired t-test which simultaneously compares the percentage differences for all variables to a vector of zeros. A statistically significant result indicates that some difference or linear combination of differences is not equal to zero. After a significant result, individual t-tests were performed to identify specific variable differences. Individual paired t-tests were performed on the secondary variables of interest. No multiple comparison adjustment was made for these comparisons. Therefore,

Variable	N	%/Month	SD
BMD Spine	18	-1.06*	0.63
BMD Neck	18	-1.15*	0.84
BMD Troch	18	-1.56*	0.99
BMD Total	17	-0.35*	0.25
BMD Pelvis	17	-1.35*	0.54
BMD Arm	17	-0.04	0.88
BMD Leg	16	-0.34*	0.33
Lean Total	17	-0.57*	0.62
Lean Leg	16	-1.00*	0.73
Lean Arm	17	0.00	0.77
Fat Total	17	+1.79	4.66

*p<0.01

Table 1. BMD and lean tissue change after 4-14.4 months of spaceflight.

Variable	N	% Change/Month	SD (slope)
BMD Spine	8	-0.87*	0.13
BMD Neck	8	-0.82*	0.17
BMD Troch	8	-1.04*	0.17
BMD Total	8	-0.35*	0.13
BMD Pelvis	8	-1.26*	0.22
BMD Arm	8	-0.61	0.39
BMD Leg	8	-0.43*	0.17
Lean Total	6	-1.04*	0.26
Lean Leg	6	-3.03*	0.35
Lean Arm	6	+0.91	0.56

* p<0.05

Table 2. BMD and lean tissue change after 4 months of bed rest without exercise.

First Flight

Cosmonaut	Spine	Neck	Trochanter	Total	Pelvis	Arm	Leg
1	-0.89	-0.73	-1.03	-0.43	-1.68	-0.55	0.18
2	-1.59	-1.90	-2.15	-0.40	-1.00	-0.33	-0.04
3	-0.56	-0.76	-0.90	-0.02	-1.48	2.03	-0.39
Mean	-1.01	-1.13	-1.36	-0.28	-1.39	0.38	-0.08
SD	0.52	0.67	0.68	0.23	0.35	1.43	0.29

Second Flight

Cosmonaut	Spine	Neck	Trochanter	Total	Pelvis	Arm	Leg
1	-1.35	-1.71	-1.32	-0.13	-1.88	1.37	0.09
2	-0.91	-0.67	-0.90	-1.01	-0.69	-0.18	-0.47
3	-1.10	-1.17	-1.33	0.00	-0.87	1.59	-0.20
Mean	-1.12	-1.18	-1.18	-0.38	-1.15	0.93	-0.25
SD	0.22	0.52	0.25	0.55	0.64	0.96	0.20

Table 3. Selected BMD values for cosmonauts with two flights, percent change per month.

although a p value of <0.05 is used for significance, results with p values between 0.01 and 0.05 should be judged with caution.

Results

Table 1 gives the number of cosmonauts (N), the mean percent change/month of flight and standard deviation (SD) for the individual variables. The rates of loss between the spine, femur neck, trochanter and pelvis ($p>0.05$) were not significant while the difference between the spine and whole body was significant ($p<0.001$). For the two cosmonauts who spent significantly more than the average (188 days) time in space (311 and 438 days), the rate of bone loss from the spine (0.68 and 0.51 %/month) were about half the overall average, possibly indicating a decreasing rate of loss, while the changes in the femur (neck, 1.92 and 1.04; trochanter, 1.07 and 1.46 %/month) were similar to the overall average. The BMD changes in the one woman cosmonaut were similar to the average for the group. Other regions of interest not included in the original analysis, but subsequently tested using a paired t-test were: tibia, -0.22 ± 0.90%/month, NS; intertrochanter, -1.24 ± 0.74%/month, $p<0.001$; wards, -0.70 ± 1.39%/month, $p=0.03$; head, +0.09 ± 0.40%/month, NS.

Table 2 gives published long duration (120 days) bed rest data for comparison to space flight[8,9]. No exercise countermeasure, however, was used during bed rest. The BMD changes during bed rest without exercise are similar to, if not less than, space flight which included the exercise countermeasure program described above. Lean tissue loss during bed rest appears to be greater than space flight suggesting that the exercise program may ameliorate muscle loss during flight although not completely. Table 3 gives selected BMD data for the three crew members who flew two flights. The data for the two flights appear similar.

Conclusions

These data define the bone and lean tissue loss during long duration space flight which included an extensive exercise countermeasure program.

Additionally these results indicate that the current in-flight exercise program is not sufficient to completely ameliorate bone and muscle loss during weightlessness.

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