

THE GRAVITY OF LBNP EXERCISE: LESSONS LEARNED FROM IDENTICAL TWINS IN BED FOR 30 DAYS

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INTRODUCTION

Microgravity leads to cardiovascular deconditioning in humans, which is manifested by post-flight reduction of orthostatic tolerance and upright exercise capacity (Watenpaugh and Hargens, 1996). During upright posture on Earth, blood pressures are greater in the feet than at heart or head levels due to gravity's effects on columns of blood in the body (Hargens *et al.*, 1992). During exposure to microgravity, all gravitational blood pressures disappear. Presently, there is no exercise hardware available for space flight to provide gravitational blood pressures to tissues of the lower body.

Lower-body musculoskeletal loss is experienced by crew exposed to long-term space flight (Thornton and Rummel, 1977; Whedon *et al.*, 1977; Schneider *et al.*, 1989; Arnaud and Morey-Holton, 1990; Morey-Holton *et al.*, 1996). Presently, exercise protocols and equipment for astronauts in space are unresolved (Greenleaf *et al.*, 1989; Convertino, 1990) and previous calculations suggest that all exercise in space to date has lacked sufficient loads to maintain preflight bone mass (Cavanagh *et al.*, 1992). Although treadmill exercise with bungee cords (about 2 h per day) was a common exercise for cosmonauts during long-duration Mir missions, biomechanical loads on musculoskeletal tissues of the lower body are only about 60-70% of those present on Earth (Whalen, 1993). One example of this lack of effectiveness is the three Mir 18 crewmembers, which varied widely in amount of exercise performed, while post flight muscle volumes (LeBlanc *et al.*, 1996) and bone resorption (Smith *et al.*, 1999) were nearly identical in all crewmembers. Theoretically, an integrated countermeasure for

extended exposure to microgravity should combine high loads on the musculoskeletal system with normal regional distributions of transmural pressure across blood vessels and stimulation of normal neuromuscular locomotor patterns.

We have postulated that LBNP exercise may prevent bed rest- and microgravity-induced deconditioning by simulating gravity. Static ground reaction force (GRF) in a LBNP chamber is a product of the body cross-sectional area at the waist seal (A_{xy}) and the pressure differential between the external ambient and internal chamber environments (ΔP), where $\Delta P = \text{LBNP}$:

$$\text{GRF} = A_{xy} \cdot \Delta P$$

For the average male subject, an additional GRF of about one equivalent body weight (BW) is generated for each 100 mm Hg of LBNP when the negative pressure acts only through the cross-sectional area of the subject's waist (Hargens *et al.*, 1991). The LBNP exercise concept avoids the discomfort of localized high pressures typical of bungee cord harness systems by distributing the net force of the air pressure uniformly over the entire upper surface of the body. By expanding the area through which the pressure produces force, we found that the amount of negative pressure required to generate one BW could be decreased. If the waist seal area equals twice the subject's waist cross-sectional area, the negative pressure necessary to produce one BW decreases from 100 mm Hg to 53 ± 2 mm Hg (Watenpaugh *et al.*, 1994). The reduced negative pressure required to generate one body weight of force lowers the risk of excessive footward fluid redistribution, syncope, hernia, and petechiae associated with higher levels of LBNP (Wolthius *et al.*, 1974).

We hypothesized that 40 minutes of supine treadmill running per day in a LBNP chamber at 1.0 to 1.2 body weight (approximately 50 - 60 mm Hg LBNP) with a 5 min resting, nonexercise LBNP exposure at 50 mm Hg after the exercise session will maintain aerobic fitness, orthostatic tolerance, and selected parameters of musculoskeletal function during 30 days of bed rest (simulated microgravity). This paper is an interim report of some of our findings on 16 subjects.

METHODS

In our recent studies, we evaluated supine LBNP treadmill exercise to prevent loss of physiologic function in microgravity simulated by 30 days of head-down tilt bedrest. Eight sets of identical twins (12 males, 22-31 years and 4 females, 21-25 years) remained in 6° head-down tilt (HDT) bedrest for 30 days to simulate prolonged microgravity. Eight subjects were randomly selected to exercise supine in an LBNP chamber for 40 minutes six days per week

(EX group), while their twin siblings served as non-exercise controls (CON) (Fig. 1).

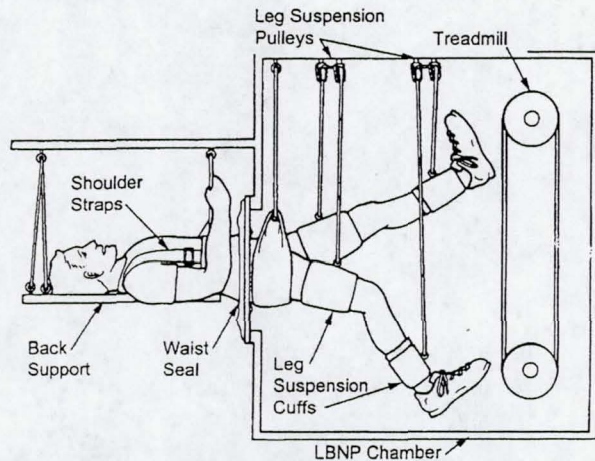


Figure 1. Schematic diagram of the Earth-based LBNP chamber. A back support and leg suspension system is used to reduce the effects of gravity while exercising in the supine position.

Pressure within the exercise LBNP chamber was adjusted to increase load, hence increasing exercise intensity. During supine treadmill exercise, LBNP (52-63 mmHg) was applied to produce footward forces equivalent to those for upright running on Earth at 1.0-1.2 times body weight (BW) and subjects performed an interval exercise protocol (40-80% peak exercise capacity [VO_{2pk}]). Five minutes of resting LBNP followed each exercise session. Pre- and post-bedrest, subjects completed orthostatic tolerance, plasma volume, upright treadmill stress test to volitional fatigue, muscle area and strength, bone maker and bone density tests. Statistical significance was set at $p < 0.05$.

RESULTS

Because of the page limitation of this communication, we are unable to report all of our positive findings in six sets of male twins and two sets of female twins. Maximal exercise responses (VO_{2pk}) were compared using repeated measures ANOVA (Fig. 2). Leg and spine muscle strengths were measured by Biodex and MedX dynamometers, respectively (Fig. 3, 4). Using MRI, cross-sectional area (CSA) and spinal length of iliopsoas spinal muscle at L4/5 were compared between CON and EX groups before and after 30 days bedrest (Fig. 5, 6). Biochemical markers of bone and calcium metabolism were also monitored (Fig. 7). Regional bone mineral density (BMD) and bone mineral content (BMC) were determined using Dual Energy X-ray Absorptiometry (Lunar Corp. DPX-IQ) on each subject before and after HDT bedrest (Table 1). Before and after 30 days HDT bedrest, orthostatic tolerance and plasma volume (I^{125} -albumin technique) were determined (Fig. 8, 9).

Peak Oxygen Consumption (mean \pm SD)

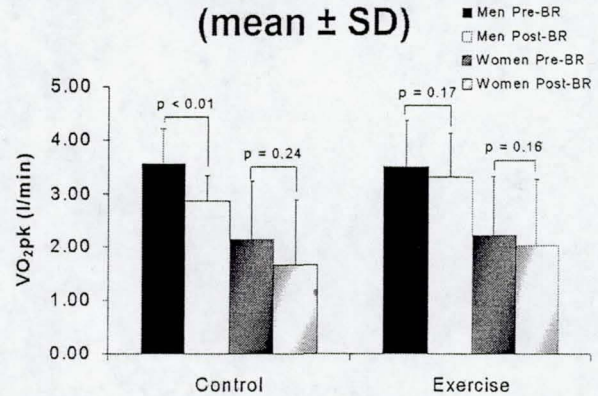


Figure 2. Peak oxygen consumption (VO_2) decreased significantly in control male subjects ($p < 0.01$). VO_2 was preserved in males receiving daily LBNP supine exercise ($p = 0.17$).

Isokinetic Knee Strength (mean \pm SD)

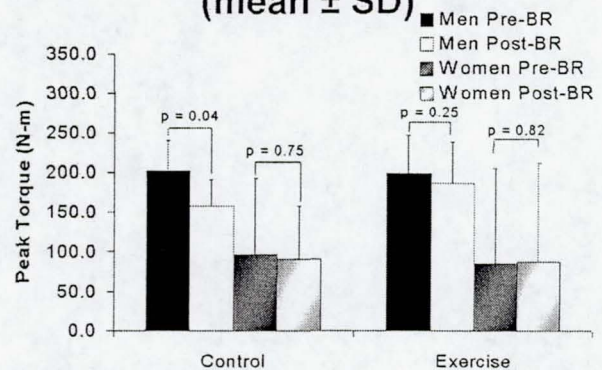


Figure 3. Isometric knee strength (extension, peak torque) decreased significantly in control male subjects ($p = 0.04$). Knee strength was preserved in males receiving daily LBNP supine exercise ($p = 0.25$).

Change in Spine Strength (mean \pm SD)

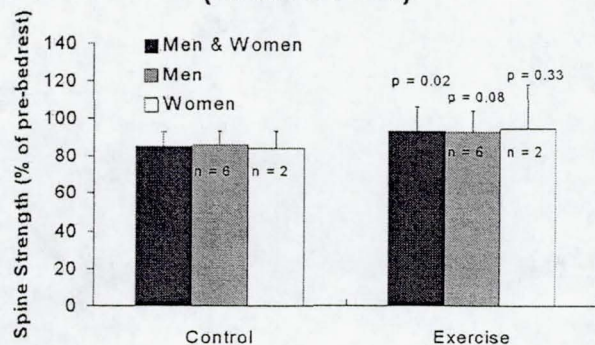


Figure 4. Although the decrease in spine strength after 30 days bedrest was not significant in the control group, the group receiving daily supine LBNP exercise had significantly higher strength after bedrest than the control group (men and women combined, $p < 0.05$).

Spinal Muscle CSA (L4/5) by MRI (mean ± SD)

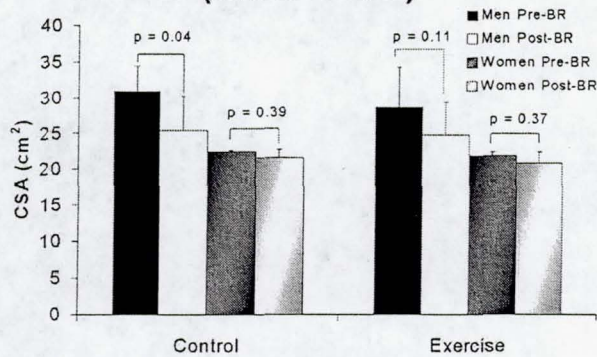


Figure 5. The cross-sectional area (CSA) of spinal muscle at the L4/5 level decreased significantly in the control group ($p = 0.04$) but not in the group receiving daily supine LBNP exercise ($p = 0.11$) after 30 days of bedrest (men).

Spinal Length by MRI (mean ± SD)

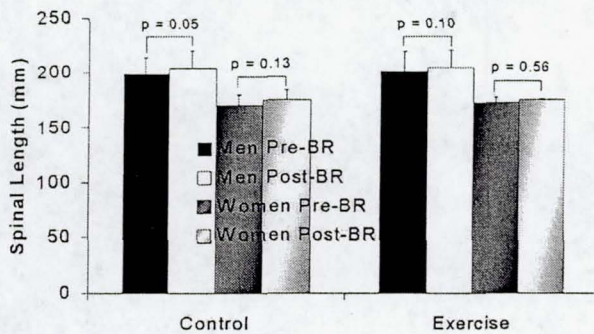


Figure 6. Spinal length increased significantly in the male control group ($p = 0.05$) but not the group receiving daily supine LBNP exercise ($p = 0.10$).

Urinary n-Telopeptide (mean ± SD)

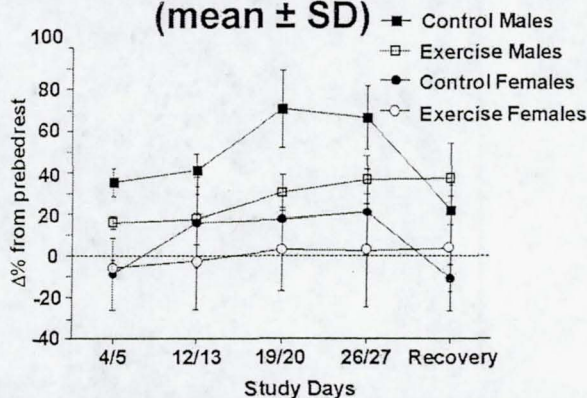


Figure 7. Urinary n-telopeptide excretion during bed rest in control (solid) and exercised (open), male (square) and female subjects (circle). This index of bone resorption was increased ($p < 0.005$) during bed rest in control subjects, but not LBNP-exercised subjects. This suggests protection by LBNP exercise against the increase in bone resorption typically seen in simulated and actual weightlessness.

Region	Control		Exercise	
	D BMD	p-value	D BMD	p-value
Spine	-2.6%	0.02	-1.1%	0.70
Ribs	+4.8%	< 0.01	+3.1%	0.26
Heel	-3.0%	0.55	+1.0%	0.99

Table 1. Significant changes in bone mineral density (BMD) and heel ultrasound were observed in control subjects in the spine and ribs, but not in subjects receiving daily supine LBNP exercise. Data presented include only male subjects (additional female subjects are required to resolve differences with statistical power). Increased BMD in the upper body may be related to cephalad fluid and pressure shifts.

Orthostatic Tolerance (mean ± SD)

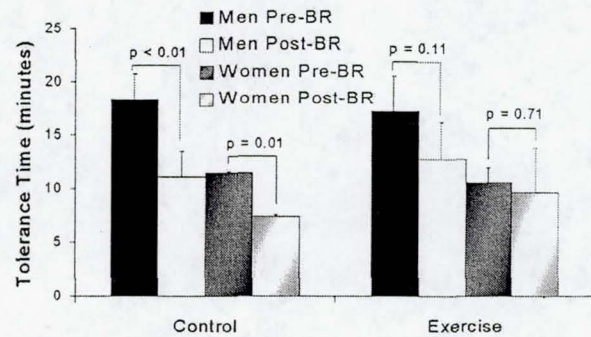


Figure 8. Orthostatic tolerance time to presyncope was significantly reduced in control groups (men $p < 0.01$, women $p = 0.01$). Orthostatic tolerance was protected in the groups receiving daily supine LBNP exercise (men and women).

Plasma Volume (mean ± SD)

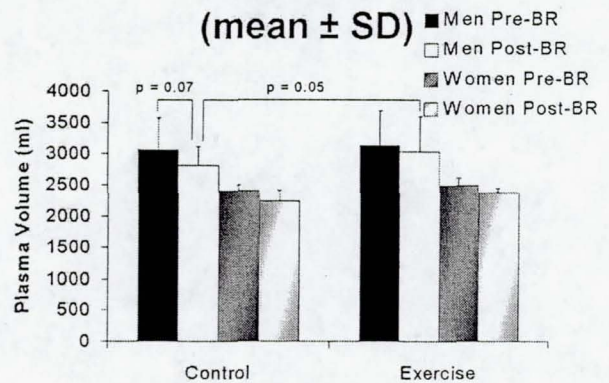


Figure 9. Although the decrease in plasma volume in the control group (men) during 30 days of bedrest was not significant ($p = 0.07$), the plasma volume of the control group (men) was lower than that of the group receiving daily supine LBNP exercise (men) (borderline significance at $p = 0.05$).

DISCUSSION

Our treadmill exercise protocol within LBNP plus a short period of post-exercise LBNP maintains orthostatic responses, plasma volume and upright exercise capacity during bedrest. This high intensity weight-bearing, artificial-gravity exercise also preserves muscle and bone parameters in the legs and spine. Other important physiologic adaptations to

gravity are maintained as well. These results document the efficacy of our apparatus and exercise protocol for maintaining physiologic structure and function in males during long-duration microgravity as simulated by 30 days of HDT bedrest. More studies of female identical twins are needed.

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