

EFFECTIVENESS OF ARTIFICIAL GRAVITY AND ERGOMETRIC EXERCISE AS A COUNTERMEASURE — COMPARISON BETWEEN EVERYDAY AND EVERY OTHER DAY PROTOCOLS

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ABSTRACT

Effectiveness of centrifuge-induced artificial gravity and ergometric exercise as a countermeasure to space deconditioning, including cardiovascular deconditioning, myatrophy, and osteoporosis, induced by 20 days of head-down bedrest, was examined in 12 healthy men in 2006, and 8 healthy men in 2007. Bedrest was performed with 2300 kcal of diet. Water intake was recommended more than the urine volume in a previous day. A new protocol for artificial gravity with ergometric exercise was adopted, with 1.6 G of artificial gravity at heart level and 60 W of exercise every day in 2006, and every other day in 2007. The load was suspended when subjects complained all-out, and was continued until 30 min cumulative total load time. Gravity was stepped up by 0.2 G or exercise load was stepped up by 15 W alternately when the subject endured the load for 5 min. Gravity tolerance was examined by using centrifuge, and anti-G score was determined before and after the bedrest. Not all result has been analyzed, however, effectiveness of artificial gravity with ergometric exercise was evidenced in orthostatic tolerance, physical fitness, cardiac function, myatrophy, and bone metabolism in everyday protocol, but not in every other day protocol. We concluded this everyday protocol was effective in cardiovascular deconditioning myatrophy, and bone metabolism.

1. INTRODUCTION

We have previously reported that artificial gravity (AG) of 1.4G with ergometric exercise (EX) of 60 W every day could prevent space deconditioning to some extent. Next year, we proposed the protocol of step-wise increment of the load for 30 min, and showed the effectiveness of the step-up protocol to prevent several deconditionings caused by simulated microgravity, -6° head-down bedrest.

In the year of 2007, we compared the parameters the loads of the AG and EX between the everyday protocol and the every other day protocol, and examined whether AG with EX should be loaded everyday or might be enough to be loaded every other day to prevent the space deconditioning.

2. METHODS

1) Loading protocol

We employed “AG and EX step-up method” for the loading protocol, namely, starting with AG of 1.4G at the heart level and ergometric exercise of 60W as the initiating load, the load is to be increased to the next step if the subject endured the load for 5 min, AG was stepped up by 0.2 G, and EX load was stepped up by 15W alternately. The load is suspended when subjects complains exhaustion, and is continued until cumulative total load time reaches 30 min.

In 2006, we adopted the method with “everyday protocol,” and in 2007, with “every other day protocol.” In every other day protocol, AG with EX was loaded on the days of 1, 2, 3, 5, 7, 9, 11, 13, 15, 17, 19, 20. These protocols were applied to the countermeasure group (CM), and we compared them with the control group (CONT).

2) Bedrest

Bedrest was employed as the simulated microgravity for the subject to be exposed. Twelve healthy young men was selected as the subjects (CM: 6, CONT: 6) in 2006, and eight (CM: 4, CONT: 4) in 2007.

Three days prior to the bedrest schedule, subjects were asked to come to the laboratory, and pre-examination was performed for 3 days. On the 4th day, they were confined to -6° head-down bedrest for 20 days. Daily urine output and defecation were measured, and the same volume of water was encouraged to drink on the next day. Calorie intake was adjusted to 2,300 kcal, and they were separately fed to the subjects at 0700, 1200, and 1800.

Subjects were asked to urinate or defecate on the bed, and their head-elevation was prohibited. Body cleaning was made every day by care staff (nurse students).

3) Measured variables

3-1) Anti-G score

Orthostatic tolerance was evaluated by anti-G score, which was defined as the sum of [applied AG at the heart] \times [time for application (sec)], while the AG was loaded at 1G for 10 min, 1.2G for 5 min, 1.4G for 5 min... until the subject requested stoppage.

3-2) *Circulating blood volume*

Blood sampling was made from the cubital vein in every morning to estimate the circulating blood volume by using Dill and Costillo's formula.

3-3) *Sympathetic response to postural change*

Before and after the bedrest, subjects were challenged head-up tilt to observe the microneurographically recorded muscle sympathetic nerve activity (MSNA) at supine (0°), 30°, and 60° tilted positions for 15 min each with blood pressure measured with Finapres.

MSNA and blood pressure were continuously monitored through the tilt and the changes were compared before and after the bedrest.

3-4) *Physical fitness*

Respiration-circulation response was evaluated using ergometric exercise with Douglas bag, and maximal oxygen uptake (VO_{2max}) and endurance time to exhaustion (ET)

3-5) *Echocardiographic cardiac dimension*

Before and after the bedrest, end-diastolic volume, end-systolic volume, stroke volume, cardiac output, ejection fraction, and fractional shortening were measured to evaluate the cardiac function.

3-6) *Myatrophy*

Muscle size was evaluated with MRI cross-sectional method. Before and after the bedrest, the cross section of the quadriceps femoris and calf muscles were measured, and compared. Muscle volume was assessed by measuring the impedance between the joints.

Muscle performance was assessed by the maximal voluntary contraction force, velocity, and endurance.

3-7) *Bone metabolism*

Bone metabolism was assessed by measuring the urinary deoxypyridinoline as a marker of bone decalcification. Before the bedrest, on the 10th day of the bedrest, and after the bedrest.

3-8) *Effects on the immune and inflammatory system*

We measured white blood count (WBC), noradrenaline, adrenaline, dopamine, interleukin-6, serum protein, C reactive protein (CRP), and compared the CM and CONT, before and after the bedrest.

3. RESULTS

1) *Orthostatic tolerance*

The anti-G score everyday protocol was changed from 841 ± 197 vs 829 ± 258 to 789 ± 163 vs 268 ± 68 (CM vs CONT), showing that the everyday CM could suppress the bedrest-induced orthostatic intolerance, whereas every other day CM could not, since anti-G score changed from $1,025 \pm 553$ vs 816 ± 358 to 655 ± 355 vs 306 ± 273 (CM vs CONT).

2) *Circulating blood volume*

By encouraging to drink the same amount of water as the urine volume on the previous day, CM group showed no significant difference between the pre- and post-bedrest circulating blood volume, whereas CONT group decreased by 5% in everyday protocol.

Every other day CM group decreased the circulating blood volume by 4%, which shows no significant difference from that of CONT group.

3) *Sympathetic response to tilt*

Tilt-induced excitation was preserved by CM in everyday and every other day protocols, and there were no significant difference.

4) *Physical fitness*

VO_{2max} was increased in everyday CM, but was decreased in CONT in 2006. ET to exhaustion was elongated in everyday CM, but was shortened in CONT. However, in every other day protocol, both CM and CONT decreased in VO_{2max} and ET.

5) *Echocardiographic Cardiac dimension*

By everyday protocol in 2006, end-diastolic volume was decreased in CONT, while it was increased in CM. End-systolic volume was also decreased in CONT, whereas it was increased in CM. Ejection fraction and fractional shortening were increased in CONT, and decreased in CM. These indicate enhanced cardiac function in CM, and reduced in CONT.

On the other hand, every other day protocol in 2007 showed no constant results.

6) *Myatrophy*

With MRI, cross section of the quadriceps femoris was revealed to be maintained in CM, whereas not in CONT. With impedance method, femoral muscle volume was maintained in CM, but calf muscle volume was reduced in both groups. Muscle function was maintained in CM but not in CONT.

7) *Bone metabolism*

Urinary deoxypyridinoline was significantly suppressed in CM as compared with CONT by everyday protocol, while enough suppression was not observed in every other day protocol.

8) *Immune and inflammatory system*

In everyday protocol, increases in WBC and CRP in CONT were suppressed in CM.

4. CONCLUSION

Space deconditioning was prevented to some extent by cumulative 30 min step-up load of artificial gravity with ergometric exercise everyday. Efficient and stable device should be settled in the International Space Station.