HIGHLIGHTED TOPIC | Analogs of Microgravity: Space Research without Leaving the Planet

WISE 2005: Aerobic and resistive countermeasures prevent paraspinal muscle deconditioning during 60-day bed rest in women

Jacquelyn A. Holt,1 Brandon R. Macias,1 Suzanne M. Schneider,2 Donald E. Watenpaugh,3 Stuart M. C. Lee,4 Douglas G. Chang,1 and Alan R. Hargens1

1Department of Orthopaedic Surgery, University of California, San Diego, California; 2University of New Mexico, Albuquerque, New Mexico; 3Department of Integrative Physiology, University of North Texas Health Science Center, Fort Worth, Texas; and 4Wyle Science, Technology, and Engineering Group, Houston, Texas

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Holt JA, Macias BR, Schneider SM, Watenpaugh DE, Lee SMC, Chang DG, Hargens AR. WISE 2005: aerobic and resistive countermeasures prevent paraspinal muscle deconditioning during 60-day bed rest in women. J Appl Physiol 120: 1215–1222, 2016. First published February 18, 2016; doi:10.1152/japplphysiol.00532.2015.—Microgravity-induced lumbar paraspinal muscle deconditioning may contribute to back pain commonly experienced by astronauts and may increase the risk of postflight injury. We hypothesized that a combined resistive and aerobic exercise countermeasure protocol that included spinal loading would mitigate lumbar paraspinal muscle deconditioning during 60 days of bed rest in women. Sixteen women underwent 60-day, 6° head-down-tilt bed rest (BR) and were randomized into control and exercise groups. During bed rest the control group performed no exercise. The exercise group performed supine treadmill exercise within lower body negative pressure (LBNP) for 3–4 days/wk and flywheel resistive exercise for 2–3 days/wk. Paraspinal muscle cross-sectional area (CSA) was measured using a lumbar spine MRI sequence before and after BR. In addition, isokinetic spinal flexion and extension strengths were measured before and after BR. Data are presented as means ± SD. Total lumbar paraspinal muscle CSA decreased significantly more in controls (10.9 and after BR. Data are presented as means using a lumbar spine MRI sequence before and after BR. In addition, days/wk. Paraspinal muscle cross-sectional area (CSA) was measured

Spaceflight and bed rest (simulated microgravity) result in paraspinal muscle atrophy (29), decreased spinal curvature (7), swelling of intervertebral discs (7), and increased body length (6, 7, 44).

Few data document spaceflight- or bed rest-induced alterations in paraspinal muscle morphology and strength. Short-duration (17 days) spaceflight results in a 10% decrease in paraspinal muscle volume (23). Similarly, 30 days of simulated microgravity using 6° head-down tilt (HDT) bed rest reduces paraspinal cross-sectional area (CSA) by 7.7% (29). These decrements in paraspinal muscle cross-sectional area are associated with a 15% reduction in trunk flexion strength (20). Therefore spaceflight-induced spinal deconditioning may increase the risk of intervertebral disc herniation (21, 52) and back pain (4, 9, 10, 13, 16, 17, 21) upon return to gravity.

On Earth in the upright posture the lumbar spine bears ~50% body wt load (7, 22). The paraspinal muscles, which include the psoas, quadrates lumborum, erector spinae, and multifidus, provide postural support and enable ambulation in a gravitational environment (8, 31, 36, 49). These paraspinal muscles are important for the initiation and control of gait and the support of upper extremity movement (32, 34). The erector spinae, the largest paraspinal muscle, is the prime contributor to spine extension (32, 34). These paraspinal muscles are critical to function in a gravitational environment.

Back pain during and after spaceflight is hypothesized to result from spinal adaptations to altered gravitational fields. Microgravity-induced back pain is a common complaint of astronauts; 68% report mild to moderate back pain during their mission (37). Several studies on Earth demonstrate that back pain and paraspinal muscle atrophy present together (4, 9, 10, 13, 16, 17, 21), but the relationship between pain and atrophy remains unclear (10, 33, 48). However, CSA of the paraspinal muscles is 10% less in chronic low-back pain patients compared with healthy controls (18), and patients with low-back pain have 15% weaker paraspinal muscle extension strength than healthy individuals (25). Therefore information regarding paraspinal muscle structure and function during simulated microgravity may help elucidate the etiology of back pain during spaceflight.

On Earth, bed rest studies are an accepted analog of microgravity used to study musculoskeletal deconditioning of the spine and lower extremities (19). Short-duration, 16-day HDT,

NEW & NOTEWORTHY

Aerobic and resistive exercise that promotes musculoskeletal loading through the spine may be beneficial during prolonged spaceflight to mitigate the effects of microgravity and maintain cross-sectional area and strength of the lumbar paraspinal muscles.

EXPOSURE TO MICROGRAVITY eliminates daily gravitational loads to the spine and therefore results in spinal deconditioning.

Address for reprint requests and other correspondence: B. Macias, Wyle Science, Technology, and Engineering Group, 2400 NASA Parkway (HAC/261), Houston, TX 77058. (e-mail: brandon.r.macias@nasa.gov)

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Exercise Prevents Paraspinal Muscle Deconditioning • Holt JA et al.

Exercise countermeasures. The overall study protocol and exercise countermeasure have been described in detail previously (15, 27, 39). Briefly, the exercise group participated in supine treadmill exercise with lower body negative pressure (LBNP) for 3–4 days/wk and flywheel resistive exercise for 2–3 days/wk (Fig. 1). A detailed exercise schedule was published previously (27).

During the supine LBNP treadmill exercise, subjects performed interval training at 40–80% of their pre-bed rest peak oxygen consumption. The negative pressure in the LBNP chamber was adjusted to produce a footward force equivalent to the pre-bed rest body weight. The footward force consists of three primary forces: the axial force on the body produced by the suction, the spinal loading force from the shoulder straps that attach to the waist seal, and smaller elastic forces produced by stretching the elastic waist seal traction at

Fig. 1. Exercise countermeasures used by subjects during 60 days of bed rest. A: supine treadmill exercise within lower body negative pressure (LBNP), used to generate increased heart rate and foot ground reaction forces equivalent to upright treadmill exercise. B: flywheel resistive exercise device used to perform leg and calf press exercises while in 6° head-down tilt.

Overall study design. Sixteen healthy, nonsmoking women participated in a 60-day, 6° HDT bed rest study. The women were matched according to pre-bed rest aerobic fitness level (peak oxygen uptake) and then randomly assigned to one of two groups, exercise (n = 8) and control (n = 8). The exercise group performed aerobic treadmill exercise within LBNP and flywheel resistive exercise; the control group did not participate in any countermeasures. The two groups were similar in pre-bed rest height (exercise 164.9 ± 2.5 cm, control 162.8 ± 2.2 cm; mean ± SE), weight (exercise 58.1 ± 2.2 kg, control 55.8 ± 1.4 kg), aerobic fitness (exercise 39.0 ± 0.7 ml·kg⁻¹·min⁻¹, control 38.0 ± 1.7 ml·kg⁻¹·min⁻¹), and age (exercise 33 ± 1 yr, control 34 ± 1 yr) (15, 27, 39, 40).

MATERIALS AND METHODS

The University of California, San Diego, Institutional Review Board, the NASA Johnson Space Center Committee for the Protection of Human Subjects, and the local ethics committee, Comité de Protection des Personnes de Toulouse, France, reviewed and approved this study. Prior to participation, subjects received verbal and written explanation of the study procedures and provided written informed consent.

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Exercise Prevents Paraspinal Muscle Deconditioning • Holt JA et al.

the hips. LBNP treadmill exercise provides 60–65% body wt axial loads on the lumbar spine during supine exercise (7). Paraspinal muscle activation occurs as the subject works to maintain their posture with each footward force during exercise with shoulder straps.

Flywheel exercise provides resistance to eccentric and concentric action using the inertia of the flywheels (2, 3, 45, 46). This exercise device utilizes two wheels, each with a mass of 2.74 kg and inertia of 0.0719 kg·m². The subject pushes against the shoulder pads to slide the sled along the bed during exercise, providing spinal loading. Flywheel resistive exercise was performed at 6° HDT. Subjects completed a warm-up period prior to exercise composed of 10 min of light cycling and then submaximal leg press and calf press repetitions. Exercise consisted of maximal concentric and eccentric leg press and calf press repetitions. Subjects performed four sets of seven leg press repetitions and four sets of 14 calf press repetitions with 2 min of rest between each set. Subjects were provided real-time visual feedback of their performance for each repetition as well as verbal encouragement (47).

Muscle cross-sectional area. Paraspinal muscle CSA was evaluated pre- and post-bed rest with axial images at the L3/L4 intervertebral disc levels acquired using a 1.5 T MRI and analyzed using Image J software (ImageJ 1.48v, National Institutes of Health) (38) to measure CSA of the paraspinal muscles. The following paraspinal muscles were measured: multifidus, erector spinae, quadratus lumborum, psoas, and erector spinae + multifidus. Erector spinae was not separated into the iliocostalis and longissimus because the fascial boundary could not be identified in most images (9a, 30). The spinous process was used as a landmark to identify the midsagittal plane. Each muscle was identified and measured using the fascia between the muscles (Fig. 2). All images were magnified to 200% during analysis to improve visualization of the muscle boundaries. Measurements were made using the polygon selection tool starting at the inferior edge of the muscle and continuing in a clockwise fashion along the fascia surrounding the muscle. Each measurement represents the average of four analyses (outlines), with a coefficient of variation of 0.4%. The averages of the four measurements obtained on the left and right sides were summed to acquire the total bilateral CSA. Total paraspinal muscle CSA was calculated by summing the CSAs of each individual paraspinal muscle. The analysis was conducted by one individual (J.H.), who was blinded to time and group assignments.

Muscle strength. Muscle strength was determined pre- and post-bed rest by measuring peak torque during spinal flexion and extension using an isokinetic dynamometer (HUMAC NORM, CSMi, Stoughton, MA). Subjects were secured into the testing device in an upright standing position, with the knees slightly flexed and secured with thigh and lower leg padded bolsters. Additionally, a strap was secured across the hips to minimize movement. Subjects were secured to the lever arm of the trunk testing device with pads located across the pectoral muscles. Subjects were instructed to hold the handles on this pad to prevent arm movement. Thus torques developed during trunk extension and flexion were produced only by the trunk musculature. Alignment of the subject to the dynamometer was recorded so that it could be reproduced during subsequent sessions. The dynamometer was calibrated each day before testing using the manufacturer-provided procedures. Gravity correction was used to remove the effect of body, limb, and adapter weight from torque measurements. Using the procedures described here, these isokinetic tests have a high degree of reliability (intraclass correlation coefficient >0.96) in our laboratory.

Before isokinetic testing was conducted, subjects pedaled a cycle ergometer at a workload of 25–50 W at a cadence of 60–80 rpm for 5 min. Thereafter, subjects performed five warm-up repetitions of trunk extension and flexion at ~50% maximal effort and then two to three maximal repetitions. Subjects stood quietly for 2 min of rest before data collection. Subjects then performed five maximal effort repetitions. Isokinetic speeds were set to 1.05 rad/s (60°/s), and the range of motion was limited to 0 to 1.57 rad (0° to 90°), with 0 rad (0°) representing the angle at the hip between the trunk and the thighs while standing. Subjects were instructed to perform a maximal effort with each repetition. If the test operator’s visual data display indicated a nonmaximal effort, an additional repetition was performed. In addition, testing was performed in one direction only at a time [similar to that described by Lee et al. (27)] to focus the subject’s attention on proper form and motion. The peak torque achieved during each repetition was determined, and the average of the five repetitions was taken to be representative maximal strength and reported as newton meters (N·m). Tests were conducted 18 and 9 days before bed rest and again 6 days after the end of bed rest. Pre-bed rest testing was scheduled early in the pre-bed rest period to prevent interference with other testing protocols. Post-bed rest strength tests were conducted after the primary measures of other studies were completed and to coincide with approximate timing of testing performed for International Space Station (ISS) astronauts after long-duration missions (27). The first pre-bed rest test was considered a familiarization session. The peak torques from the second pre-bed rest test and the post-bed rest test were used for analysis.

Back pain questionnaire. Subjects were provided a daily questionaire in the afternoon to report any pain or discomfort during the previous 24 h. Subjects were asked to specify the location and describe the nature of any pain or discomfort. The subjective data were reviewed and summarized daily for each subject over the course of the 60 days of bed rest. Any day during which back pain or discomfort was reported was recorded as a painful day. Subjects were asked to report general back pain and back pain that occurred during or immediately after exercise. Pain reported as occurring during or immediately after exercise was classified as pain associated with exercise. Two analyses were completed for painful days reported by the exercise group: pain not associated with exercise and all pain (pain not associated with exercise and pain associated with exercise).

Statistical analyses. Repeated measures ANOVA was used to compare the main effect of time (pre- vs. post-bed rest), intervention (exercise vs. control), and interaction of time by intervention for all paraspinal muscle CSAs, strength, and pain using SPSS 9.0 (SPSS, Chicago, IL). Significance was set at $P < 0.05$. If a significant main effect was found, then pairwise comparisons were conducted to test for individual differences by muscle, time, and intervention. Bonferroni corrections were used to control for multiple comparisons. Data are reported as means ± SD.

RESULTS

Total CSA of the four paraspinal muscles was not significantly different between control and exercise groups before bed rest. Sixty days of bed rest reduced total CSA of the
paraspinal muscles in both groups. However, the magnitude of loss in total CSA of the paraspinal muscles was significantly less in the exercise group compared with the controls (P = 0.014). Total paraspinal muscle CSA at L3/L4 was decreased by 10.9 ± 3.4% in the controls and 4.3 ± 3.4% in the exercise group (P < 0.001) (Fig. 3).

The individual paraspinal muscles each responded differently to bed rest and the exercise countermeasure. The magnitude of loss for each muscle was significantly different from that of each other muscle (P < 0.001). Multifidus and quadratus lumborum CSA decreased in both groups (P = 0.001) (Table 1). Erector spinae CSA decreased significantly in the control group but not the exercise group after bed rest (P < 0.001). Bed rest induced the greatest average loss in erector spinae CSA (378 mm²) (P = 0.002). However, this loss in CSA was mitigated by the exercise countermeasures (Fig. 4).

Lumbar strength as determined by peak torque during flexion and extension decreased significantly from pre- to post-bed rest in the control group. Exercise countermeasures attenuated lumbar extension strength loss during bed rest, but not flexion strength. Extension mean peak torque did not decrease in the exercise group (−4.3 ± 4.5%, P = 0.306); however, torque was reduced in the control group (−16.6 ± 11.2%, P = 0.008; Table 2 and Fig. 5). Lumbar flexion mean peak torque decreased during bed rest in both the exercise (−14.7 ± 20.4%; P = 0.156) and control group (−18.5 ± 20.5%; P = 0.255).

Seven subjects, four controls and three exercisers reported back pain during bed rest. The most consecutive days of back pain reported by one subject in the control group was 15 days and in the exercise group was 3 days. The average number of painful days (not including pain related to exercise) was significantly less in the exercise group (1 ± 1 day; mean ± SD) than in controls (4 ± 6 days) (P = 0.003) (Fig. 6). Three exercise subjects reported pain specifically associated with exercise interventions. Two reported back pain after and/or during flywheel exercise. One subject reported back pain following LBNP treadmill exercise. The exercise group reported an average of 2 ± 3 days of pain, and controls reported an average of 4 ± 6 days of pain (P = 0.054), including pain associated with exercise.

### Table 1. Mean cross-sectional area of paraspinal muscle at L3/L4

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Control</th>
<th>Exercise</th>
<th>Control</th>
<th>Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multifidus (M)</td>
<td>1,313 ± 231</td>
<td>1,050 ± 182*</td>
<td>1,386 ± 250</td>
<td>1,221 ± 232*</td>
</tr>
<tr>
<td>Erector Spinae (ES)</td>
<td>3,167 ± 356</td>
<td>2,759 ± 300*</td>
<td>3,118 ± 289</td>
<td>3,096 ± 306#</td>
</tr>
<tr>
<td>M+ES</td>
<td>4,485 ± 392</td>
<td>3,854 ± 409*</td>
<td>4,601 ± 674</td>
<td>4,295 ± 545#</td>
</tr>
<tr>
<td>Quadratus</td>
<td>783 ± 194</td>
<td>726 ± 187*</td>
<td>811 ± 119</td>
<td>737 ± 99*</td>
</tr>
<tr>
<td>Lumbarorum</td>
<td>1,700 ± 340</td>
<td>1,632 ± 332</td>
<td>1,834 ± 233</td>
<td>1,781 ± 233</td>
</tr>
<tr>
<td>Total</td>
<td>6,963 ± 426</td>
<td>6,168 ± 536*</td>
<td>7,150 ± 749</td>
<td>6,836 ± 683#</td>
</tr>
</tbody>
</table>

Values are means ± SD. All units mm². *Significantly different from pre-bed rest. #Significantly different from controls.

### DISCUSSION

Flywheel resistive exercise and supine LBNP treadmill exercise attenuate paraspinal muscle atrophy, lumbar extensor strength loss, and back pain during 60 days of 6° HDT bed rest in women. Bed rest significantly decreased paraspinal CSA and lumbar strength in both groups. These results indicate that paraspinal muscle deconditioning occurs during 60 days of bed rest. Further, the incidence of back pain was reduced by 80% in the exercise subjects. The present findings expand on the benefits of flywheel resistive and LBNP treadmill exercises to protect the musculoskeletal and cardiovascular systems during 60 days of simulated microgravity in women (15, 27, 40).

**Effect of bed rest.** Total paraspinal muscle CSA loss during bed rest in the control group is similar to previous shorter-duration bed rest studies. In this study, total paraspinal muscle cross-sectional area decreased 10% after 60 days of bed rest. Previous bed rest studies report 3–10% paraspinal muscle cross-sectional area loss (4, 5, 7, 24). Although bed rest is an accepted analog for spaceflight for many physiological adaptations (19), it may not unload the spine to the same extent as microgravity. Unfortunately, there are a limited number of spaceflight lumbar paraspinal muscle deconditioning reports. LeBlanc et al. studied four crew members after 17 days of spaceflight and 14 crew members after 16–28-wk spaceflights (23). They found a 5% decrease in psoas muscle volume after 17 days of spaceflight and 10.8% decrease in psoas muscle volume after 16–28 wk of spaceflight (23). The bed rest model is the accepted analog for spaceflight (19); however, bed rest subjects still experience gravity. The subjects are instructed to minimize the magnitude and duration of work during bed rest. However, back muscles may be activated when the subjects rotate in bed, transition to gurneys, and prop the head up to eat. Therefore spaceflight may produce more rapid declines in back muscle size and strength, compared with the same duration in bed rest.

Bed rest results in loss of CSA of total lumbar paraspinal muscle as well as CSA of each individual paraspinal muscle. Erector spinae has the largest absolute decrease in CSA (378 mm²) during bed rest. However, the percentage decrease in the multifidus CSA (20%) is greater than the percentage decrease in the erector spinae CSA (12.8%). In the present study, bed rest produced the largest magnitude losses in the multifidus and erector spinae CSA, compared with a moderate decrease in the...
quadratus lumborum and minimal change in the psoas. Similarly, previous bed rest studies report significant multifidus CSA decrements of 11.1% (4) and 14.2% (16) and erector spinae CSA loss of 7.7% (7) and 8.8% (4). Bed rest appears to have a more moderate impact on quadratus lumborum loss (0 – 8.9%) (4). However, bed rest effects on the psoas are mixed; two studies report an increase in psoas CSA (4, 24), while another reports a 7.7% loss (7). Therefore the present and prior data suggest that disuse results in greater-magnitude multifidus and erector spinae CSA losses.

Interestingly, the degree of atrophy during bed rest was not uniform across the paraspinal muscles. Muscle fiber composition may explain this paraspinal muscle-specific response, as suggested to contribute to differential rates of atrophy of the lower leg (1). The lumbar erector spinae (at the belly of the lateral tract of the iliocostalis/longissimus) at the level of the third lumbar vertebra is primarily composed of type I fibers (men 65%; women 63.6%) (32). However, the fiber composition of the individual muscles of the erector spinae and the psoas remains unclear. The high level of erector spinae type I muscle fibers is consistent with disuse-induced decrements in muscle cross-sectional area. Human (1) and animal (43) models of disuse demonstrate preferential muscle atrophy of type I-dominant muscles (soleus) compared with the type II-dominant muscles (plantaris and gastrocnemius). Therefore the greater-magnitude reductions of CSA following bed rest in the present study in the erector spinae and multifidus, compared with the psoas and quadratus lumborum, may be partially explained by fiber type composition. A less likely but possible explanation is differential unloading of the spine during bed rest and the allowance of some work against gravity during bed rest. Subjects were allowed to prop their head up slightly when eating and move to a gurney for transport. Thus mild and limited contractions during bed rest activities may explain some of the deconditioning differences of the paraspinal muscles and variation between studies. Alternatively, marked deconditioning of one paraspinal muscle may result in overloading or compensation by another muscle. For instance, multifidus atrophy may elicit increased, compensatory erector spinae activity. Although paraspinal muscle activity is not necessary for postural maintenance in unloaded environments, these muscles still must stabilize the trunk during limb movement (32, 34). Therefore paraspinal muscles should be evaluated individually rather than as an entire group, especially when evaluating countermeasures for spaceflight.

Table 2. Peak torque pre- and post-bed rest for flexion and extension test

<table>
<thead>
<tr>
<th>Test</th>
<th>Control</th>
<th>Exercise</th>
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<tbody>
<tr>
<td>Flexion peak torque, N m</td>
<td>110 ± 8</td>
<td>78 ± 5*</td>
</tr>
<tr>
<td>Extension peak torque, N m</td>
<td>188 ± 13</td>
<td>146 ± 10*</td>
</tr>
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</table>

Values are means ± SD. *Significantly different from pre-bed rest. #Significantly different from controls.
The reduction in the paraspinal muscle cross-sectional area corresponds with back muscle strength deficits. The magnitude of decrease in back muscle extensor strength was significantly larger in the control group (22–29% decrease) than in the exercise group (11–13% decrease), a result similar to findings from short-duration (28-day) studies (7, 29). This attenuated strength loss in the exercise group may be partially explained by the subjects working to maintain postural spine stability during treadmill exercise with shoulder strap loading (7, 29).

Sixty days of bed rest (nonexercise) produced greater-magnitude losses in flexion strength (−22%) and extension strength (−29%) compared with losses (−15%) observed after short-duration (28 days) bed rest (29). Following long-duration ISS missions, trunk extension and flexion were reduced, −6.3% and −8.1% after 2 wk of recovery (11). After 30 days of recovery, trunk extension strength was similar to preflight levels (−0.08%), but flexion strength was still impacted (−5.6%) (11). Maximal trunk strength measures for standard Medical Operations testing generally occurs 14 days after spaceflight because of the frequent reports of low-back pain among ISS astronauts. Therefore paraspinal CSA measures soon after landing enable muscle atrophy quantification and an indication of the level of functional impairment, although it is generally recognized that muscle strength loss exceeds the level of muscle atrophy. Future spaceflight exercise prescriptions should include flexion and extension components to protect spine muscle strength.

Bed rest-induced back pain was reported in half of the control subjects. Our results are similar to previous reports in which 63% of control subjects reported low-back pain during bed rest (19). In a survey of astronauts, 68% reported back pain during their mission (51). Our data further support the idea that spinal unloading induces back pain in healthy individuals. However, with exercise-based spinal loading during simulated microgravity the incidence of back pain is reduced. Therefore spaceflight exercise countermeasures applied throughout the mission, and specifically early during gravitational transition periods, may help reduce incidence of pain.

Effect of countermeasures. The present data demonstrate that combined flywheel resistive exercise and treadmill exercise within LBNP partially mitigate bed rest-induced paraspinal muscle atrophy. Previous reports demonstrate the effectiveness of these individual countermeasures on the musculoskeletal system (3, 7, 15, 26, 50). LeBlanc et al. (23) report that exercise countermeasures previously used during spaceflight did not provide sufficient spinal loading to prevent atrophy of the paraspinal muscles. The present combined exercise protocol, however, mitigated 80% of the bed rest-associated reduction in total lumbar paraspinal muscle CSA.

The combined exercise protocol preserved some extensor but not flexor strength during bed rest. The erector spinae is the largest and strongest spinal extensor. The preservation of strength is likely a direct result of the combined exercise protocols’ effect on the erector spinae. Flexion of the spine involves the psoas as well as the abdominal muscles, with the abdominal muscles being the main flexors. The exercise intervention may not have sufficiently loaded the abdominal muscles to maintain strength. A previous report from our labora-

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Fig. 5. Exercise attenuated the percentage loss in mean (± SD) peak torque lumbar extension strength (A) but not the percentage loss in mean (± SD) peak torque trunk flexion strength (B). *Significant decrease from baseline to after bed rest (P < 0.05). #Significantly different from control (P < 0.05).

Fig. 6. Days with reported back pain in control and exercise groups over duration of 6° head-down-tilt bed rest.
tory demonstrates that LBNP treadmill exercise protects isometric flexion strength loss at angles near full flexion (29). The combined exercise protocol, however, did not provide the same protection of lumbar flexion. Implementation of LBNP treadmill exercise in microgravity would eliminate the need for a back support and suspension system, therefore providing more “normal” spine loading then during an analog. The present flywheel resistive exercise prescription may not provide sufficient spinal loading to maintain lumbar flexion during bed rest. However, extension strength was preserved with the combined protocol. Moreover, this preservation of extension strength corroborates mitigation of erector spinae CSA loss using this combined exercise countermeasure during bed rest.

The combined exercise protocol decreased back pain experienced by subjects during bed rest. Fewer exercise subjects reported back pain, and those that did report back pain reported fewer days of pain than controls. Paraspinal muscle atrophy is thought to contribute to back pain (3, 9, 9a, 10, 43, 44, 46). The reduced back pain may be due to the preservation of the paraspinal muscle mass and function from the combined exercise countermeasures. Several subjects reported pain with the flywheel exercise that may have been soreness resulting from exertion or loading, poor positioning on the device, or bed rest. The single subject who reported pain with treadmill and LBNP only reported the pain during one exercise session. Therefore spaceflight exercise countermeasures that protect back strength may help reduce back pain.

Limitations. Some limitations of this study should be noted. Although bed rest is an accepted model of spaceflight, subjects work against gravity during some bed rest activities, as discussed above. The study was conducted only in women, thereby not allowing for direct gender comparisons. The CSA data were limited to two spinal levels. However, CSA measures at this lumbar intervertebral disc level enable analysis of multiple muscle compartments, and back pain is frequently reported at the lumbar region (19). In addition, abdominal muscle groups important to spinal flexion were not studied. Moreover, two different exercise countermeasures were employed together as a single “integrated” countermeasure, such that the separate effects of flywheel resistive exercise vs. LBNP treadmill exercise cannot be determined. This was an international bed rest campaign with many investigative teams that limited timing of testing during the recovery from bed rest. Scheduling limitations and conflicts with other measures resulted in our strength measurement being scheduled on recovery day 6. It is possible that muscle cross-sectional area may have recovered to an unknown extent during this period, and thus our measurements underestimate the true amount of bed rest-induced atrophy. For example, following 16–28 wk of actual microgravity exposure, the intrinsic back muscles recovered by 14%, and psoas recovered by 50% by 2–4 days after landing (23).

Conclusions. Aerobic and resistive exercise that promotes musculoskeletal loading through the spine may be beneficial during prolonged spaceflight to mitigate the effects of microgravity and maintain cross-sectional area and strength of the lumbar paraspinal muscles. Increased exercise frequency, loads, or duration may provide further benefit, but this has not been systematically tested. The exercise countermeasure not only partially prevented muscleatrophy but also more importantly preserved trunk extensor strength. Further, the exercise countermeasure decreased pain associated with bed rest. In this healthy population the lumbar erector spinae, an important extensor of the spine, was the most atrophied during bed rest. Therefore preservation of lumbar paraspinal muscle structure and function may help reduce the incidence of back pain and disc herniation associated with spaceflight.

ACKNOWLEDGMENTS

Present address of B. Macias: Wyle Science, Technology, and Engineering Group, 2400 NASA Parkway (HAC/261), Houston, TX 77058.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS


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