Magnetic Resonance Imaging Assessment of Trunk Muscles During Prolonged Bed Rest

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Study Design. Prospective longitudinal study.

Objective. To investigate, using magnetic resonance imaging (MRI), the influence of bed rest on the lumbopelvic musculature.

Summary of Background Data. Reduced gravitational loading and inactivity (bed rest) are known to result in significant change in musculoskeletal function, although little is known about its effects on specific muscles of the lumbopelvic region.

Methods. Ten healthy male subjects underwent 8 weeks of bed rest with 6 months of follow-up. MRI of the lumbopelvic region was conducted at regular time-points during and after bed rest. Using uniplanar images at L4, cross-sectional areas (CSAs) of the multifidus, lumbar erector spinae, quadratus lumborum, psoas, anterolateral abdominal, and rectus abdominis muscles were measured.

Results. Multifidus CSA decreased by day 14 of bed rest (F = 7.4, P = 0.04). The lumbar erector spinae and quadratus lumborum CSA showed no statistically significant difference to baseline across the time of bed rest (P > 0.05). The anterolateral abdominal, rectus abdominis, and psoas CSA all increased over this time. Psoas CSA increased by day 14 (F = 6.9, P = 0.047) and remained so until day 56, whereas the anterolateral abdominal CSA (F = 29.4, P = 0.003) and rectus abdominis CSA (F = 8.9, P = 0.03) were not statistically larger than baseline until day 56. On reambulation after completion of the bed rest phase, multifidus, anterolateral abdominal, and rectus abdominis CSA returned to baseline levels (P > 0.05) by day 4 of follow-up, whereas psoas CSA returned to baseline level after day 28 of the follow-up period.

Conclusions. Bed rest resulted in selective atrophy of the multifidus muscle. An increased CSA of the trunk flexor musculature (increases in psoas, anterolateral abdominal, and rectus abdominis muscles) may reflect muscle shortening or possible overactivity during bed rest. Some of the changes resemble those seen in low back pain and may in part explain the negative effects of bed rest seen in low back pain sufferers.

Key words: bed rest, inactivity, magnetic resonance imaging, trunk muscles, multifidus muscle, abdominal muscles. Spine 2007;32:1687–1692

The medical management of acute low back pain (LBP) sometimes includes the prescription of bed rest. A recent Cochrane Review, however, concluded that bed rest is of little benefit in the treatment of LBP. One study found that bed rest, in acute LBP, resulted in poorer outcomes at 3 months, as compared with maintaining activity as tolerated.2 It is difficult to investigate what mechanisms may underlie the potentially harmful effects of bed rest in acute LBP as, for example, muscular changes occur very rapidly in the presence of pain.3,4

Bed rest is used by Space Agencies as a model to simulate the effects of the loss of axial gravitational loading experienced during spaceflight.5–7 Bed rest studies have documented deconditioning effects on many organ systems.8 For the musculoskeletal system, findings have included bone demineralization in the weight-bearing skeleton9 and greater atrophy of the antigravity musculature of the leg.10 Although the muscles of the lumbopelvic (LP) region have not been investigated extensively in bed rest studies to date, one magnetic resonance imaging (MRI) study showed that, within a few weeks of bed rest, combined measurements of the multifidus and lumbar erector spinae muscles decreased in size by 9%.11

An understanding of how the human body copes with the forces of gravity allows predictions of the potential effects of bed rest. The double-S spinal curves of the human body allow the body to damp the vertical gravitational load and dissipate forces horizontally.12,13 This requires muscle action at the LP region to maintain the lordosis.14,15 At the sacroiliac joint, gravity generates a vertical shear force that is resisted by passive structures and by active compression from horizontally oriented muscles.16 The multifidus muscle is critical in providing the necessary control of the lumbar lordosis.15,17,18 With removal of axial gravitational loading through the spine during bed rest, the stimulus required for normal function of the multifidus muscle could be removed. Further-
more, positioning the lumbar spine in a flexed position (as often adopted in bed rest studies) could have additional adverse effects on multifidus function. It could be hypothesized that the multifidus muscle would be preferentially affected when compared with other LP muscles.

In subjects with LBP, evidence suggests that preferential atrophy of the multifidus muscle occurs. MRI, computerized tomography (CT), and ultrasound imaging studies have shown multifidus muscle atrophy in LBP subjects. When compared with the lumbar erector spinae and psoas muscles, selective atrophy of the multifidus muscle is seen in patients with chronic LBP. Preferential multifidus muscle atrophy also occurs at the level of symptoms in LBP. The multifidus muscle and the deep abdominal muscle, transversus abdominis, are known to be closely related to spinal stability and are also known to be impaired in LBP. In the superficial muscle systems, overactivity is commonly seen in LBP. A recent MRI study has shown increased cross-sectional area (CSA) in the anterolateral abdominal muscles of LBP patients. It has been suggested that such changes represent a functional adaptation to increase the stability of the lumbar spine and thus compensate for dysfunction in muscles more closely associated with spinal stability.

It is therefore possible that bed rest results in preferential atrophy of the multifidus muscle and that secondary changes occur in the superficial muscle systems. The aim of this study was to determine if a lack of axial gravitational loading related to the normal function of the multifidus would preferentially affect the muscle, similar to that seen in subjects with LBP, but in the absence of LBP and pathology. This information would provide insight into the role of the multifidus muscle in weight-bearing and the effects of bed rest on the LP musculature and could be of benefit to those who undergo prolonged bed rest for many medical conditions.

### Materials and Methods

The Berlin Bed Rest (BBR) Study was approved by the Ethical Committee of the CHARITE Campus Benjamin Franklin Hospital, Berlin, Germany, and by the Bundesamt für Strahlenschutz. It was organized between February 2003 and June 2004 at the Campus Benjamin Franklin.

**Procedures**

**Subject Recruitment.** Healthy men between 20 and 45 years of age were recruited for the study. Exclusion criteria included smoking, currently on medication, any relevant medical disorder, participation in competitive sports, and a body mass index below 20 or above 28.

Ten subjects were excluded from this study as they participated in an exercise intervention as part of another component of the BBR study. The average subject age was 33.4 ± 6.6 years, height was 185 ± 7 cm, and weight was 79.4 ± 9.7 kg.

**Bed Rest Protocol.** Ten subjects underwent 8 weeks of bed rest with 6-month MRI follow-up. Further details of the study have been published elsewhere. In brief, subjects were organized into five “campaigns” of two subjects each starting at staggered time-points. During the bed rest phase, subjects were not allowed to lift their trunk in bed greater than 30°. Subjects performed all activities related to hygiene in the supine position. During bed rest, subjects were also discouraged from moving excessively or unnecessarily. Force transducers placed in the bed supports and video surveillance monitored subjects’ compliance with the protocol. Anthropometric measures were conducted at the start and end of the bed rest period.

**MRI Protocol.** Baseline MRI assessments were conducted on the first day of bed rest (BR1) and then at 2 week intervals (BR14, BR28, BR42, and BR56) through to the end of the bed rest period. During the follow-up period (recovery, R+), scanning was conducted on the fourth day of follow-up (R+4), and then at regular intervals (R+14, R+28, R+90) through to 180 days after the bed rest period (R+180).

Subjects were instructed to void their bladder and bowel before imaging. To avoid tension on the anterior abdominal wall during imaging, subjects were positioned in supine lying with their knees and hips resting on a foam wedge. Transverse MR images at rest (a breath-hold at midexpiration) were acquired using a 1.5 Tesla Magnetom Vision system (Siemens, Erlangen, Germany). The imaging volume was then oriented to be perpendicular to the anterior abdominal wall and consisted of 10 slices at a thickness of 8 mm with an interslice distance of 0.5 mm. A fast gradient recalled echo sequence was used with TR = 4.8, TE = 2.3 milliseconds, FA = 70°, and NA = 2. The resulting image matrix for all images was 128 × 128 interpolated to 256 × 256. Total scanning time required 23 seconds which was within the breath-hold tolerance of all subjects.

**Measurements.** During offline image processing, the image slice placed at or closest to the center of the L4 vertebral body was chosen for analysis. If the scanning region was positioned off-center, two slices superior and inferior to the target position were chosen for analysis (measurements were then averaged). Offline MRI image measurement was conducted using ImageJ (version 1.36b, http://rsb.info.nih.gov/ij/). Bilateral CSA measurements (Figure 1) were conducted for the multifidus, lumbar erector spinae (ilio-costalis lumborum pars lumborum and longissimus thoracis pars lumborum), quadratus lumborum, psoas, rectus abdominis, and anterolateral abdominal muscles (external oblique, internal oblique, transversus abdominis). To ensure operator blinding to study time-point, each image was assigned a random number (www.random.org). One operator conducted all measurements, and the intraoperator reliability of the CSA measurements was high (intraclass correlation coefficients, range, 0.95 and 0.98 for each muscle; 3 repeated measurements of one image from each subject).

**Data Processing and Statistical Analysis.** The Statistical Package for the Social Sciences (version 14; www.spss.com) was used for implementing statistical analyses. Analysis of muscle CSAs, averaged across the left and right sides, was conducted separately for the muscle/muscle groups of multifidus, lumbar erector spinae, quadratus lumborum, psoas, rectus abdominis, and anterolateral abdominal muscles. Repeated-measures analysis of covariance (ANCOVA) with a Type I sums of squares model was used to test 1) the effect of “days in bed” on muscle size and 2) the effect of “recovery days” on muscle size. The factors of age, height, weight, and percentage...
change in weight from start to end of bed rest were used as covariates in the analyses. A priori contrasts were used in the analysis of the bed rest data to test change in muscle size from baseline to each fortnightly assessments (BR14, BR28, BR42, and BR56). During the recovery phase, the time period between assessments increased over time, and separate analyses were used to compare muscle size at baseline to recovery R + 4, R + 28, and R + 180. For descriptive purposes, the pattern of change for each muscle is graphed as the mean percentage change from baseline.

Assessment of the pattern of attrition across the recovery period was also conducted. Results of ANOVA indicated that at R + 90 the cases not assessed were significantly different from the cases assessed in terms of their data at other time periods (P < 0.05), and at R + 14 only half the sample was assessed. As this unduly biases the results in a small sample, the data for these two time periods were not considered representative of the total sample and were not reported. At recovery day 4 (n = 7), day 28 (n = 10), and day 180 (n = 8), the cases assessed were representative of the total sample (P > 0.05). At day 1, equipment failure resulted in 2 cases missing part of the assessment. Linear interpolation (using SPSS) of the total data set was used to estimate these 2 data points.

Results

Results of the analyses (Table 1) showed that, among the extensor muscles, compared with baseline, multifidus CSA decreased by day 14 of bed rest (F = 7.4, P = 0.04) and this association strengthened by day 56 (F = 33.1, P = 0.002), whereas the decrease in lumbar erector spinae CSA approached, but did not reach, a level of statistical significance in difference to baseline across the time of bed rest (P = 0.051). The quadratus lumborum muscle CSA showed no statistically significant difference to baseline across the time of bed rest (P > 0.05). The anterolateral abdominal muscles, rectus abdominis, and psoas CSA all increased over this time. Psoas CSA increased by day 14 (F = 6.9, P = 0.047) and remained so until day 56, whereas the increases in anterolateral abdominal CSA (F = 29.4, P = 0.003) and rectus abdominis CSA (F = 8.9, P = 0.03) were not statistically significant until day 56.

Analysis of the data from the recovery phase showed that the CSA of all the muscles returned to baseline levels (P > 0.05). In the case of multifidus, the anterolateral abdominal, and rectus abdominis muscles, this had occurred by the first postassessment (R + 4). In the case of the psoas muscle, this occurred at a later time, between the 28th and 180th day post bed rest assessment. To depict the relative differences between muscles in CSA changes, Figures 2 and 3 show the percentage change in CSA across the periods of the study.

Discussion

The results of this study showed a decrease in the CSA of the multifidus muscle in response to bed rest. Removal of the stimulus of normal axial gravitational loading through the spine is the most likely explanation for this finding. Studies from space research have also implicated the deep intrinsic muscles of the low back as susceptible to atrophy in microgravity conditions.11,38–40 LeBlanc et al 19 showed that a decrease in the combined CSA of the multifidus and lumbar erector spinae muscles of approximately 10% occurred quickly in a shuttle mission of only 17 days’ duration. Although muscle biopsies of the back muscles were not performed, results of biopsies of the soleus muscles from the same crewmembers showed a similar amount of atrophy to the lumbar muscles in the space mission, with a decreased fiber diameter of 8%.41

There are definite similarities in the response of the multifidus muscle to acute LBP and to bed rest. In response to bed rest, atrophy occurred quickly (within 2 weeks of the beginning of bed rest) and the atrophy of the multifidus muscle was statistically significant, whereas

<table>
<thead>
<tr>
<th>Muscle</th>
<th>BR1 Mean ± SD</th>
<th>BR14 Mean ± SD</th>
<th>BR28 Mean ± SD</th>
<th>BR42 Mean ± SD</th>
<th>BR56 Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multifidus</td>
<td>8.4 ± 1.3</td>
<td>7.5 ± 0.9*</td>
<td>7.6 ± 0.9*</td>
<td>7.5 ± 1.0*</td>
<td>7.2 ± 1.1**</td>
</tr>
<tr>
<td>Lumbar erector spine</td>
<td>16.1 ± 2.1</td>
<td>16.3 ± 3.3</td>
<td>14.7 ± 3.1</td>
<td>15.3 ± 2.3</td>
<td>15.2 ± 3.5</td>
</tr>
<tr>
<td>Quadratus lumborum</td>
<td>6.9 ± 0.1</td>
<td>7.0 ± 0.9</td>
<td>6.9 ± 1.1</td>
<td>7.1 ± 0.8</td>
<td>7.3 ± 1.1</td>
</tr>
<tr>
<td>Lateral abdominals</td>
<td>27.6 ± 5.8</td>
<td>28.3 ± 4.5</td>
<td>27.1 ± 3.8</td>
<td>28.2 ± 4.1</td>
<td>29.4 ± 5.5**</td>
</tr>
<tr>
<td>Psoas</td>
<td>16.2 ± 3.2</td>
<td>17.2 ± 3.0*</td>
<td>17.4 ± 3.6</td>
<td>17.6 ± 3.4**</td>
<td>17.6 ± 3.2</td>
</tr>
<tr>
<td>Rectus abdominis</td>
<td>7.3 ± 1.9</td>
<td>7.8 ± 1.6</td>
<td>7.5 ± 1.6</td>
<td>8.0 ± 1.4</td>
<td>8.3 ± 1.3*</td>
</tr>
</tbody>
</table>

*P < 0.05, **P < 0.005. SD, standard deviation.
Values are marginal means: adjusted for age, height, weight, % change in weight.
that of the lumbar erector spinae muscles was not. Acute LBP is also associated with rapid atrophy of the multifidus muscle. A recent experimental study conducted using a porcine model has investigated the changes that occur in the multifidus muscle following injury to the structures of the lumbar spine. Multifidus muscle size was measured 3 and 6 days after incisions into the L3–L4 disc. Results showed localized changes in the size of the multifidus muscle, which decreased at the L4 vertebral level ipsilateral to the disc lesion, but not elsewhere. Histologic examination revealed enlargement of adipocytes and clustering of myofibers. These changes may be important as a longitudinal study in human subjects has shown that atrophy of the multifidus muscle appears to be long-lasting, does not recover spontaneously in subjects with LBP even after full resumption of normal pain-
free activity and resolution of painful symptoms,3 and is associated with higher long-term recurrence rates of LBP.43 In addition, the finding of rapid and preferential atrophy of the multifidus muscle may be relevant for those who are required to stay in bed for periods of time due to a variety of medical conditions. Patients who are subjected to bed rest may experience compromised function of the multifidus muscle, even in the absence of LBP and pathology. Rapid change in LP musculature in response to bed rest may also provide part of the explanation for the harmful effects of bed rest on LBP sufferers.2

The results from the recovery period of the bed rest study are surprising. A rapid reversal of the changes seen in the multifidus muscle during bed rest occurs, with significant increase in CSA of the multifidus muscle occurring between the last scanning day in bed rest (BR56) and the first scanning session on reambulation, 4 days later (R + 4). Given the large body of human research showing atrophy in the extensor systems of both the lumbar spine11,38–40 and legs10,11,39,40,44–49 during bed rest and spaceflight, and that muscle hypertrophy requires longer than 4 days,50,51 other mechanisms must have been responsible for this rapid change in multifidus CSA. As imaging in the recovery period was not preceded by a period of recumbency, we suggest that changes in intramuscular fluid volumes may have caused this rapid change in multifidus CSA. Past studies have shown that body fluid shifts and/or postambulation fiber and connective tissue damage of atrophied muscle on reloading (with subsequent swelling)52 can result in significant muscle CSA changes on reambulation, masking muscle atrophy.39,40,52–54 Body fluid shifts typically establish within 2 hours of recumbency,53 but their influence on LP muscle size is unknown. This may therefore have masked the true degree of multifidus muscle atrophy still present after bed rest. Further bed rest studies, which control for fluid shifts and include MRI measurements of muscle water content in their protocol, are necessary to resolve these issues.

The finding of increased CSA of the abdominal and psoas muscles during bed rest was unexpected. EMG studies of the same subjects show the development of psoas muscles during bed rest that studies of the same subjects show the development of psoas muscles during bed rest was unexpected. EMG resolve these issues.

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The finding of increased CSA of the abdominal and psoas muscles during bed rest was unexpected. EMG studies of the same subjects show the development of superficial LP muscle overactivity during bed rest that persists up to 1 year afterwards.55 These MRI findings could reflect increases in muscle tone, with increases in CSA at central muscle regions. Alternatively, the increases in CSA could relate to the trunk being maintained in a flexed position and may reflect muscle shortening. Body fluid shifts are unlikely to be involved due to the rapid (2-hour) time course of the establishment of body fluid volume distribution on changes in posture.53 The CSA of the psoas muscles was still larger 28 days following the bed rest period. LeBlanc et al11 also found that the psoas muscle did not atrophy in a longer bed rest study of 17 weeks’ duration. These findings highlight the variability of response of different muscles with different functions to bed rest.

There are some of the limitations of this study. The main limitation is the small subject sample size, which is common to all bed rest studies due to their complex nature and expense. Despite the small sample size, significant changes were seen in muscles of the LP region. The trend toward a decreased CSA of the lumbar erector spinae muscles observed during the bed rest period would most likely have reached statistical significance with greater subject numbers. In addition, to assess the extensor muscles more thoroughly, future researchers could consider investigating the effects of bed rest on the thoracic components of the erector spinae muscles. Also, muscle biopsies, while invasive, would also provide additional insight into the effects of bed rest on the histologic properties of different muscles of the LP region. Finally, researchers conducting bed rest studies in the future may wish to devise a suitable strategy to control for fluid shift in the recovery period.

### Conclusion

The main finding of the current study is that bed rest leads to preferential atrophy of the multifidus muscle. Increases in CSA are also seen in the flexor musculature, some of which persist for some time after bed rest. Some of these changes resemble those seen in LBP. This could in part explain the negative effects of bed rest on LBP sufferers.

### Key Points

- Bed rest leads to preferential atrophy of the multifidus muscle and increased cross-sectional area of the abdominal flexor musculature.
- Changes in the cross-sectional area of the psoas muscle persisted after the period of bed rest, although the true pattern of recovery in the other musculature, including multifidus, may have been masked by body fluid shifts.
- The lumbopelvic muscle adaptations due to bed rest bear similarities to those that occur in low back pain.
- These findings suggest that prescription of bed rest may be detrimental for low back health.

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