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L. Wielopolski, L. M. Ramirez, A. M. Spungen, S. Swaby, P. Asselin and W. A. Bauman
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Factors influencing body composition in persons with spinal cord injury: a cross-sectional study


Factors influencing body composition in persons with spinal cord injury: a cross-sectional study. J Appl Physiol 95: 2398–2407, 2003. First published August 8, 2003; 10.1152/japplphysiol.00729.2002.—To determine the body composition differences across age, 133 men with chronic spinal cord injury (SCI) (66 with tetraplegia, 67 with paraplegia) were compared with an age-, height-, and ethnicity-matched able-bodied male reference population (n = 100) using two different dual-energy X-ray absorptiometry densitometers. The effects of duration of injury, level, and completeness of lesion were analyzed in the SCI population. Independent of age, total body and regional lean mass were lower and fat mass was higher in persons with SCI compared with controls. The SCI group was 13% (means ± SE) fatter per unit of body mass index (kg/m²) compared with the control group (P < 0.0001). Advancing age was strongly associated with less lean mass and greater adiposity in those with SCI, whereas it was mildly related in the controls. Total body and regional arm and trunk, but not leg, lean tissues were lower in subjects with SCI, across all ages, than in the controls. In summary, persons with SCI were fatter for any body mass index and demonstrated significantly less lean and more adipose tissues for any given age compared with controls.

fat tissue mass; lean tissue mass; percent fat; tetraplegia; paraplegia; aging; dual-energy X-ray absorptiometry

OVER THE PAST SEVERAL decades, the longevity of individuals with spinal cord injury (SCI) has improved but remains slightly less than that of the able-bodied population (34). Many age-associated disorders, such as carbohydrate intolerance, insulin resistance (5, 6, 19, 20, 29), lipid abnormalities (5, 8, 11, 30), and heart disease (3, 4, 32), occur prematurely and at a higher prevalence in the population with SCI. Some of these age-associated disorders may be related to adverse changes in body composition that result from immobilization and skeletal muscle denervation from SCI.

Body composition markedly deteriorates during the first 6 mo after SCI (1, 15–17, 37, 44): total body lean tissue mass decreases as much as 9.5% by 6 mo postinjury (1), whereas leg lean tissue mass decreased 15.1% by 1 yr postinjury (44). Because baseline measurements within the first 2–4 wk after SCI have not been possible, the true magnitude of lean tissue loss and fat tissue gain during the first year of injury remains unmeasured. Longitudinal body composition studies in persons with SCI are few, missing time points, and small in numbers (44). Several investigators have used cross-sectional designs with relatively small sample sizes to compare body composition changes and/or differences in chronic SCI with control subjects (12, 27, 35, 41).

In a study comparing monozygotic twins discordant for paraplegia, the paralyzed twins had significantly more total body fat mass and percent fat and less lean than their able-bodied cotwins (42). Intrapair difference scores between the twins with and without SCI revealed that lean tissue loss in the legs progressed well into the chronic phase, and this loss was directly related to duration of injury (DOI) (42). Other body composition studies in those with SCI have found a decrease in body cell mass (BCM), reductions in intracellular potassium, and reductions in total body and intracellular water (14, 18, 36, 40). The effects of SCI on bone are well documented. The predominant finding is a large loss of bone during the first year of injury due to disuse osteoporosis (2, 9, 10, 22), predisposing to an increased prevalence of fractures (2, 25, 31). In the monozygotic twin model, bone in the legs of the SCI twins was significantly lower and continued to be lost at a rate significantly greater than that of the non-SCI cotwins. The rate of bone loss correlated with duration of paralysis, progressing over decades, well after the first year of injury (7).

Compared with an able-bodied reference population, the primary hypotheses were as follows: 1) total body...
and regional lean tissue mass and percent would be significantly lower in persons with SCI; and 2) fat mass and percent would be higher. Within those with SCI, secondary hypotheses were as follows: 1) completeness of lesion, level of lesion, age, and DOI would be significantly related to differences in lean and fat tissue; and 2) reductions in lean tissue would be related to reductions in bone mineral content (BMC). We compared total body and regional body composition values of lean, fat, and bone tissue in a large cohort of persons with SCI with an able-bodied reference population. Total body and regional measurements were obtained. Correlations between lean tissue and bone were determined, and the contributions of age, DOI, and level and completeness of lesion were evaluated.

METHODS

Subjects. One-hundred and thirty-three male subjects with SCI (66 with tetraplegia and 67 with paraplegia) were studied at the Rancho Los Amigos National Rehabilitation Center, Downey, CA. One hundred male control subjects were selected from the Body Composition Unit data banks of St. Luke's-Roosevelt Hospital, New York, NY, matching for age (±10 yr), height (±5 cm), and ethnicity (Caucasian, African American, or Latino). Institutional Review Board approval was obtained for standard clinical practice for comprehensive assessment as part of the Rehabilitation Research and Training Center on Aging with Spinal Cord Injury, and consent was waived for the subjects with SCI. Institutional Review Board approval and informed consent were obtained in the control subjects, who were tested as part of the Rosetta Body Composition Research Project at the Body Composition Unit, St. Luke's-Roosevelt Hospital. The control subjects were, on average, 4 and 7 yr older than subjects in the subgroups with tetraplegia and paraplegia, respectively (Table 1). In the control group, height and weight were measured in the standing position; weight was measured on a wheelchair scale with the subject in the wheelchair. Once the subject was placed on the densitometer, the wheelchair was weighed by itself and subtracted from the total weight. On average, the subgroup with tetraplegia was significantly taller than controls (Table 1). Individual body size differences within and across the groups were normalized by reporting percent lean or percent fat tissue for each region and total body. Percent fat or lean tissue calculations excluded bone tissue. The absolute fat and lean tissue values in kilograms and BMC in grams were also reported. Subjects with SCI who had no volitional control of the muscles below the sacral area were defined as having a motor-complete injury. Overall, the subjects with SCI were wheelchair dependent, and none were able to ambulate or bear weight with their legs.

Body composition measurements. Dual energy X-ray absorptiometry (DXA) was used to study subjects with SCI and controls for estimates of regional and total body BMC (g), lean and fat tissue mass (kg), and percent. All subjects with SCI were studied on a Hologic QDR-2000. Control subjects were studied on a Lunar Expert. Two male able-bodied subjects were studied on both instruments (<3 wk apart) as test subjects for identification of densitometer variation between the instruments. The coefficients of variation and percent differences between the measurements performed on the Hologic and Lunar densitometers are reported (Table 2). For all subjects, calculations for total body tissue and percents thereof excluded the head and used the total tissue estimated from the densitometers, not measured body weight.

Research design and statistics. A cross-sectional comparative study design was employed. Analysis of variance comparative statistics with Scheffe's post hoc analyses were used to determine significant differences between the SCI and the three ethnic groups for BMC, lean and fat tissue mass, and percent. Comparative results for the continuous variables are reported as means ± SE. A χ2 analysis was used to determine the differences between older (>40 yr) and younger (<40 yr) subjects for the body composition variables. Multiple-regression analyses were used to determine the associations of DOI, controlling for the effect of age, on the body composition variables. Analysis of covariance was used to determine the relationship of age with the various body composition parameters in tetraplegia, paraplegia, and control groups.

RESULTS

Subject demographics. The characteristics of the study groups are reported (Table 1). The study groups had average ages ranging from 37 to 44 yr. Although age was statistically older in controls vs. those with paraplegia, the distribution of age across all three groups was proportional. The controls were significantly older than either the complete or incomplete SCI subgroups. Age, height, weight, and DOI were not significantly different between the complete or incomplete subgroups for SCI. The proportion of Caucasians,

<table>
<thead>
<tr>
<th>Table 1. Characteristics of the subjects</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Tetra</td>
</tr>
<tr>
<td>Count (n)</td>
</tr>
<tr>
<td>Age, yr</td>
</tr>
<tr>
<td>Height, m</td>
</tr>
<tr>
<td>Weight, kg</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
</tr>
<tr>
<td>Duration of injury, yr</td>
</tr>
<tr>
<td>Motor complete (n)</td>
</tr>
<tr>
<td>Caucasian (n)</td>
</tr>
<tr>
<td>African American (n)</td>
</tr>
<tr>
<td>Latino (n)</td>
</tr>
</tbody>
</table>

Values are means ± SE; n, no. of subjects. Tetra, tetraplegia; Para, paraplegia; BMI, body mass index; n/a, not applicable. Significant difference: aP < 0.0001, Tetra vs. control; bP < 0.0005, Para vs. control; cP < 0.001, complete and incomplete vs. control; dP < 0.01, complete vs. incomplete; eP = 0.001, complete vs. control.

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African Americans, and Latinos across the three groups was distributed evenly. There were no significant age differences for the ethnic subgroups. DOI was significantly greater in whites compared with African Americans or Latinos (18 ± 8, 15 ± 9, and 10 ± 8 yr, respectively, P < 0.0001; data not shown in Table 1).

Differences in body composition for ethnic background were tested in all subjects as one large group (N = 233) and separately in the subgroups of tetraplegia (n = 66), paraplegia (n = 67), or control (n = 100). There were no significant ethnicity differences for the total group or within the three study groups for total or regional BMC, lean or fat tissue mass, or percent.

**Tetraplegia vs. paraplegia vs. control.** As expected, large body composition differences were found between SCI and control subjects. Overall, lean tissue, both by absolute kilogram and percent, was lower, whereas fat was higher in the total body and in most regional sites, in those with SCI (Fig. 1 and Table 3). Fat tissue mass and percent fat were greater throughout in both groups with SCI. Total body fat was 10% greater in the group with tetraplegia and 12% greater in the group with paraplegia than in the control group. Additionally, percent fat in the arms was 8% greater in those with tetraplegia than in paraplegia (Table 3, Fig. 1B).

Lean tissue mass and percent lean were significantly lower in the leg, trunk, and total body in both SCI groups compared with controls. Arm lean was significantly lower in those with tetraplegia than in either the paraplegia or control groups. However, a surprising finding in those with paraplegia was that percent lean (but not absolute lean) in the arms was significantly lower than the controls (Table 3, Fig. 1A). This could be explained by the higher amount of absolute fat mass in the arms in those with paraplegia compared with controls (32.17 ± 2.04 vs. 16.25 ± 1.38 kg, P < 0.0001; Table 3).

Body mass index (BMI), which is often used as a surrogate measure of adiposity, but does not distinguish between the individual components of weight, was not statistically different among the groups, although, as previously reported (35), fat mass and percent were significantly higher in the group with SCI compared with controls (Tables 1 and 3). In both groups, the correlation of BMI with total body percent fat was statistically significant (SCI: R = 0.60, P < 0.0001 and controls: R = 0.81, P < 0.0001). By analysis of covariance, it was demonstrated that the SCI group had significantly more total body fat at any kilogram per meter squared of BMI than the control group. This analysis resulted in an average of 13 kg/m² (95% confidence interval, 10.6–15.6) additional BMI.

The subgroup with tetraplegia had significantly lower arm BMC compared with those with paraplegia and controls (Table 3). BMC in the leg, trunk, and total body was not significantly different between the subgroups with tetraplegia and paraplegia. BMC was significantly lower in both SCI groups compared with controls in the legs, trunk, and total body. Leg lean tissue mass was positively related to leg BMC in the tetraplegia, paraplegia, and control groups (R = 0.55, P < 0.0001; R = 0.53, P < 0.0001, and R = 0.86, P < 0.0001, respectively). Arm BMC and arm lean tissue were significantly less in the...
group with tetraplegia compared with the paraplegia and control groups (Table 3). Arm BMC and arm lean tissue were significantly related within all three groups, without significant differences among the groups for this relationship (Fig. 3).

**Motor-complete vs. motor-incomplete spinal lesions.** Within the paraplegia and tetraplegia groups, those with complete injury generally had significantly lower regional and total body lean tissue mass and higher absolute fat mass compared with those in the incomplete injury subgroup. However, most of these differences failed to remain significant after correcting for body size by using percent fat and percent lean tissue. For either subgroup with tetraplegia or paraplegia, subjects with motor-complete injury had significantly lower BMC in the legs and total body than those in the incomplete group (Table 4). In the group with paraplegia, leg percent fat was 6 ± 2% greater in those with complete injury compared with those in the incomplete subgroup (P < 0.05) (Table 4). Therefore, the SCI group as a whole was stratified by complete and incomplete motor lesions and compared with the control group for differences in percent lean and fat (Fig. 4). No other variables for percent lean and fat were statistically significant for differences between those with complete vs. incomplete lesions (Table 4).

Both SCI subgroups (complete and incomplete) and the control group had significantly different total body BMC (1,431 ± 39, 1,756 ± 76, and 3,030 ± 44 g, respectively; P < 0.0001). A moderate-to-strong correlation was found between leg BMC and leg lean tissue mass in the control and incomplete SCI groups; whereas this relationship was weak in the complete SCI group (Fig. 5). Although absolute values were lower for the leg BMC-to-lean tissue mass ratio, subjects with incomplete motor SCI were not statistically different for the slope of the relationship from control.

In contrast, subjects with complete motor SCI had, on average, a 13 ± 1% increase in percent fat for any given BMI compared with the control subjects.
Body composition associations with age and DOI. In the control group, age was not significantly related to the body composition variables, with the exception of trunk percent lean tissue, which demonstrated a significant, albeit mild, relationship with age ($R = 0.20$, $P < 0.05$). No other significant age effects were found in controls. In the groups with paraplegia and tetraplegia, almost all percent lean tissue regional and total body values demonstrated significantly lower values with increasing age (Fig. 6). In the arms, trunk, and total body (but not the legs), the subjects with either tetraplegia or paraplegia demonstrated significant declines in percent lean tissue with age at a greater rate than those in the control group (Fig. 6). Total body percent lean tissue decreased per decade by 3.0% in the control group; age was not significant. Comparisons between the tetraplegia and paraplegia groups stratified by age (<40 yr, ≥40 yr) for total

Table 4. Regional and total body composition results for motor-complete and -incomplete SCI

<table>
<thead>
<tr>
<th></th>
<th>Complete</th>
<th>Incomplete</th>
<th>$P$ value</th>
<th>Complete</th>
<th>Incomplete</th>
<th>$P$ value</th>
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<tr>
<td>Count $(n)$</td>
<td>44</td>
<td>21</td>
<td></td>
<td>49</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Lean, g</td>
<td>4.58 ± 0.02</td>
<td>5.73 ± 0.04</td>
<td>&lt;0.005</td>
<td>7.28 ± 0.02</td>
<td>7.28 ± 0.04</td>
<td>NS</td>
</tr>
<tr>
<td>Lean, %</td>
<td>60 ± 2</td>
<td>59 ± 2</td>
<td>NS</td>
<td>67 ± 1</td>
<td>70 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, g</td>
<td>2.93 ± 0.02</td>
<td>3.64 ± 0.04</td>
<td>NS</td>
<td>3.35 ± 0.02</td>
<td>2.86 ± 0.04</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, %</td>
<td>36 ± 2</td>
<td>37 ± 2</td>
<td>NS</td>
<td>29 ± 1</td>
<td>26 ± 3</td>
<td>NS</td>
</tr>
<tr>
<td>BMC, g</td>
<td>302 ± 13</td>
<td>390 ± 24</td>
<td>&lt;0.001</td>
<td>439 ± 10</td>
<td>430 ± 20</td>
<td>NS</td>
</tr>
<tr>
<td>Lean, g</td>
<td>11.51 ± 0.04</td>
<td>14.03 ± 0.07</td>
<td>&lt;0.005</td>
<td>11.18 ± 0.04</td>
<td>13.08 ± 0.07</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Lean, %</td>
<td>59 ± 1</td>
<td>59 ± 1</td>
<td>NS</td>
<td>56 ± 1</td>
<td>62 ± 3</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, g</td>
<td>7.77 ± 0.04</td>
<td>9.26 ± 0.07</td>
<td>NS</td>
<td>8.48 ± 0.05</td>
<td>7.70 ± 0.90</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, %</td>
<td>39 ± 1</td>
<td>38 ± 1</td>
<td>NS</td>
<td>41 ± 1</td>
<td>35 ± 3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>BMC, g</td>
<td>469 ± 29</td>
<td>748 ± 62</td>
<td>&lt;0.001</td>
<td>544 ± 29</td>
<td>777 ± 54</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Lean, g</td>
<td>24.48 ± 0.06</td>
<td>26.10 ± 1.34</td>
<td>NS</td>
<td>26.10 ± 0.05</td>
<td>29.10 ± 1.00</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Lean, %</td>
<td>68 ± 2</td>
<td>67 ± 2</td>
<td>NS</td>
<td>68 ± 1</td>
<td>73 ± 3</td>
<td>NS</td>
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<tr>
<td>Fat, g</td>
<td>12.56 ± 1.05</td>
<td>13.24 ± 1.50</td>
<td>NS</td>
<td>12.83 ± 1.00</td>
<td>11.14 ± 1.71</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, %</td>
<td>31 ± 2</td>
<td>32 ± 2</td>
<td>NS</td>
<td>31 ± 1</td>
<td>25 ± 3</td>
<td>NS</td>
</tr>
<tr>
<td>BMC, g</td>
<td>522 ± 23</td>
<td>576 ± 38</td>
<td>NS</td>
<td>563 ± 19</td>
<td>598 ± 36</td>
<td>NS</td>
</tr>
<tr>
<td>Lean, g</td>
<td>40.57 ± 1.04</td>
<td>45.86 ± 2.03</td>
<td>&lt;0.05</td>
<td>44.60 ± 0.96</td>
<td>49.36 ± 1.75</td>
<td>&lt;0.05</td>
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<tr>
<td>Lean, %</td>
<td>64 ± 2</td>
<td>63 ± 2</td>
<td>NS</td>
<td>64 ± 1</td>
<td>69 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, g</td>
<td>23.26 ± 1.61</td>
<td>26.13 ± 2.41</td>
<td>NS</td>
<td>24.65 ± 1.63</td>
<td>21.70 ± 2.90</td>
<td>NS</td>
</tr>
<tr>
<td>Fat, %</td>
<td>34 ± 2</td>
<td>35 ± 2</td>
<td>NS</td>
<td>33 ± 1</td>
<td>28 ± 3</td>
<td>NS</td>
</tr>
<tr>
<td>BMC, g</td>
<td>1,304 ± 56</td>
<td>1,715 ± 118</td>
<td>&lt;0.001</td>
<td>1,545 ± 49</td>
<td>1,804 ± 92</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Values are means ± SE. NS, not significant.
Between the tetraplegia and paraplegia groups, fat (% and g) and lean (% and g) were not different, controlling for DOI. Therefore, the groups were analyzed together as one SCI group. DOI was inversely related to percent lean tissue in the arms ($R = 0.33$, $P < 0.0001$), trunk ($R = 0.32$, $P = 0.0002$), and total body ($R = 0.28$, $P = 0.0001$), but not in the legs. A direct relationship was demonstrated between DOI and percent fat in the arms ($R = 0.37$, $P = 0.003$), trunk ($R = 0.32$, $P = 0.0002$), and total body ($R = 0.28$, $P = 0.0002$), but not in the legs. Additional lean tissue decline trends were noted for DOI over and above those attributable to age, albeit nonsignificant, in the arms, trunk, and total body. As such, the percent lean tissue loss per decade associated with DOI, controlling for age, in the arms was $2.0 \pm 1.4\%$ (partial $r = -0.12$, $P = 0.17$), in the trunk, $1.8 \pm 1.4\%$ (partial $r = -0.11$, $P = 0.20$), and total body, $1.4 \pm 1.2\%$ (partial $r = -0.10$, $P = 0.28$). No such age and DOI trends were noted for the legs.

Measurement of body composition on the Hologic and Lunar densitometers was performed in two able-bodied male subjects (Table 2). The average percent difference within the subjects was calculated (Table 6). The percent difference of subjects with tetraplegia or paraplegia from control subjects was calculated and compared with the average within-subject differences between the two densitometers (Table 6).

DISCUSSION

Lean tissue mass and percent for total body, leg, trunk, and BMC were significantly less in both the tetraplegia and paraplegia groups than in the controls.
In the arms, only the group with tetraplegia had significantly lower lean tissue mass and percent than the controls, whereas fat tissue mass and percent were greater in both subgroups of SCI compared with the controls for all regions and total body. In addition to the expected differences of less lean, more fat, and less bone in the group with paralysis, the results suggest that the chronic phase of SCI may result in an exponential loss of skeletal muscle and an increase in fat with aging relative to the general population.

**Lean, fat, and BMI in SCI.** No significant differences were found for level of lesion (tetraplegia, paraplegia) or completeness of lesion (incomplete, complete motor lesions) on total body lean or fat percent. By a multiple isotope dilution method, in five normally nourished subjects with tetraplegia, with an average age of 28 yr and DOI of 5 yr, body fat was 24.1%, with BCM being lower by 34% from a predicted value of 41% (24). In 37 subjects with SCI studied by radioisotopic dilution methodology, percent fat mass in subjects with low paraplegia was comparable to that in able-bodied controls at 20%, but all other subjects with higher levels of SCI had total body percent fat that ranged from 30 to 36% (36). Reduction in BCM was correlated with the severity of the neurological defect (36).

Overall, subjects with SCI had >5 kg more fat mass, with total body fat percent higher by 50% (22–33% of total weight) more than controls. As in the general population, BMI and adiposity were correlated in SCI, except that the line was shifted to the left (Fig. 2), indicating that total body fat mass and percent were significantly greater at any given unit of BMI in persons with SCI than in controls. This finding of more fat per unit BMI was also reported in the study of monzygotic twins: one with SCI compared with a non-SCI cotwin (42). Other investigators have demonstrated similar findings. In a small study of five subjects with chronic paraplegia (average age 33 yr), by DXA, persons with SCI had >11 kg more fat mass compared with able-bodied controls (25). BMI was not significantly different between the paraplegia and control groups (24.8 vs. 24.1 kg/m²) (28). Adjustments in classifications of normal, overweight, obese, and morbid obesity by BMI are needed for persons with SCI.

**Age and DOI effects on body composition.** The association of age and DOI with total body and the specific regions for lean tissue mass and percent, fat tissue mass and percent, and BMC were examined. The control subjects were marginally older, on average, than the subjects with SCI. A significant age effect on body composition was not found in this relatively young control population (mean age of 44 yr). In contrast, advancing age and DOI were correlated with less lean tissue percent and more adiposity in those with SCI for any age, with percent lean tissue reductions across age in the arms and trunk accounting for most of the differences. The subjects with SCI had less total body percent lean and greater percent fat at younger ages than the corresponding younger aged control group, a finding that persists with advancing age, confirming...
percent lean (†P < 0.0001) than those in the comparable group with SCI. In the SCI group, those in the younger age category had significantly more percent lean (‡P < 0.0001) than those in the comparable group with SCI. In the SCI group, those in the younger age category had significantly more percent lean (‡P < 0.0001) and less percent fat (†P < 0.0001) than those in the older age category (≥40 yr), whereas no such body composition changes with age were found in the control group. Values are means ± SE.

Premature adverse changes in body composition. Comparing the younger and older groups for those with SCI, the group <40 yr old had significantly more lean and less fat mass in all regions. However, in the able-bodied control group, only the body composition measures in the trunk demonstrated adverse differences between the younger and older age groups.

DOI was also strongly associated with loss of lean tissue in the SCI group, but this association was less than that for advancing age. Multiple regression analysis, controlling for age, did not result in an additional significant effect of DOI. In contrast, a strong effect of DOI was demonstrated in the legs and total body of monozygotic twins with chronic paraplegia compared with their able-bodied cotwins. A continued loss of lean tissue over time from injury was reported: the longer the DOI, the greater the depletion of leg and total body lean tissue (42). It should be appreciated that the power of a monozygotic twin design controls for differences in age and genetic factors, providing the strongest possible proof of a SCI-specific effect.

Relationship of bone with lean tissue. The effects of acute immobilization on the skeleton have been reported extensively. Any condition that results in immobility, or a reduction of the forces of gravity, has resulted in rapid loss of bone (7, 23, 24, 28, 38). The rate of lower extremity fractures is greater in those with SCI than in ambulatory persons. A relationship between bone mineral density (BMD) and knee fractures has been noted, with lower BMD found in those with SCI and fractures (23). In this report, leg and trunk BMC were similar with high and low cord lesions. Presumably due to disuse paralysis, only arm BMC was less in subjects with tetraplegia compared with those with paraplegia. Subjects with paraplegia and controls had similar arm BMC. Complete motor paralysis is associated with greater bone loss in the denervated extremities than in those with incomplete lesions. As previously demonstrated in incomplete SCI of the Brown-Sequard type, the mean BMD of the more paretic knee was lower than that of the stronger knee (22). Level of lesion has also been shown to effect bone loss: subjects with tetraplegia had lower BMD than those with paraplegia (24).

In this report, a direct association was found between leg lean tissue and bone in controls and those with SCI. A strong linear relationship was found between lean tissue and BMC in the legs, both in subjects with incomplete lesions and in able-bodied controls. In subjects with complete SCI, a much weaker relationship was noted between these variables, as might have been expected in the absence of function and gravity-bearing activity (10, 39, 44). Of note, those with complete lesions had less bone preserved per unit of muscle tissue compared with incomplete lesions. This raises the possibility that, below a certain threshold of coordinated muscle activity, bone mass will be less well preserved in SCI patients.

Table 6. Comparisons between the Hologic and Lunar instruments in the two-test subjects and percent differences between the groups with SCI and control

<table>
<thead>
<tr>
<th>%Diff H vs. L</th>
<th>Tetra %Diff From Control</th>
<th>Para %Diff From Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean, kg</td>
<td>3.7</td>
<td>31.1</td>
</tr>
<tr>
<td>Fat, kg</td>
<td>-42.8</td>
<td>-93.9</td>
</tr>
<tr>
<td>BMC, g</td>
<td>7.4</td>
<td>25.2</td>
</tr>
<tr>
<td>Leg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean, kg</td>
<td>13.1</td>
<td>39.0</td>
</tr>
<tr>
<td>Fat, kg</td>
<td>-24.9</td>
<td>-39.4</td>
</tr>
<tr>
<td>BMC, g</td>
<td>10.2</td>
<td>53.6</td>
</tr>
<tr>
<td>Trunk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean, kg</td>
<td>-7</td>
<td>9.1</td>
</tr>
<tr>
<td>Fat, kg</td>
<td>9.8</td>
<td>-23.5</td>
</tr>
<tr>
<td>BMC, g</td>
<td>15.2</td>
<td>39.0</td>
</tr>
<tr>
<td>Total body</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean, kg</td>
<td>8.2</td>
<td>27.8</td>
</tr>
<tr>
<td>Fat, kg</td>
<td>1.4</td>
<td>-28.7</td>
</tr>
<tr>
<td>BMC, g</td>
<td>20.1</td>
<td>52.6</td>
</tr>
</tbody>
</table>

%Diff H vs. L, average percent difference, within subjects, between H and L in the 2-test subjects; Tetra %Diff or Para %Diff from Control, average percent difference between Tetra or Para (measured on H) from control (measured on L).
maintained. Bauman et al. (7) have reported, by intrapair difference scores, a continued loss of bone in the legs of monozygotic twins with chronic paraplegia compared with their able-bodied cotwins, and DOI was found to be directly associated with residual leg BMC, whereas age was not. A strong relationship was demonstrable between lean tissue and BMC in the arms, a non-weight-bearing bone, regardless of level or completeness of lesion (42). In all three groups, arm BMC and arm lean tissue were strongly related in this study as well, further supporting the initial finding in the monozygotic twin study (42). A positive correlation was found between leg lean tissue and bone in the non-SCI twins, but none was found in those with SCI (42). It is well appreciated that a strong association exists between muscle strength and BMC or density in the able-bodied population (13, 21, 26, 39).

Limitations. In the study herein, arm fat (kg and %) was found to be significantly higher in the SCI group compared with controls. This finding is not consistent with previous results from the monozygotic twin model (42). No differences in arm fat were found between the twins. Although it should be appreciated that the twins with SCI had paraplegia and were a very active group, more likely variation between the two densitometers explains some of the large arm fat tissue differences. Two different pinhole source densitometers were used for this study: the subjects with SCI were imaged on a Lunar QDR 2000 Plus, whereas the able-bodied controls were studied on a Lunar Expert. In an attempt to identify variation between the two instruments, two able-bodied male subjects were imaged on both machines. In these two test subjects, the average percent differences between the densitometers were greatest for arm (~43%) and leg (~25%) fat tissue. In both regions, the Hologic overestimated fat tissue compared with the Lunar densitometer. This finding is consistent with the findings of other investigators (33, 43). In subjects with SCI, average arm fat was ~96% greater and leg fat was ~40% greater than in control subjects (Table 6). The large differences between SCI and control subjects are likely due to a combination of using different densitometers and a true difference in arm and leg fat between the SCI and control groups.

DXA is a physical method that measures the different attenuations of fat and fat-free mass, being independent of traditional assumptions for body composition determination. The accuracy of DXA for application in persons who are markedly obese has yet to be validated. Persons with SCI may be more obese than is apparent from either body weight or BMI, but they do not have a markedly higher absolute fat mass, nor are they morbidly obese. However, acquisition of data and processing of that information by different software packages may also influence the results (39, 43).

In summary, lean tissue was lower and fat tissue was higher in most regions in the SCI group compared with controls. Comparisons within SCI for level of lesion revealed lower lean tissue and more fat percent in the arms and total body in persons with tetraplegia compared with paraplegia. In both the tetraplegia and paraplegia subgroups, persons with incomplete lesions showed greater sparing of absolute lean and bone tissues. BMC in the paralyzed regions was significantly lower in those with SCI compared with controls. Individuals with tetraplegia had lower BMC in the arms than those with paraplegia or controls. Leg lean tissue was positively related to leg BMC in both groups with SCI and in controls; however, in those with complete motor lesion, there was markedly less bone per unit of lean tissue. Persons with SCI have adverse body composition changes, similar to those seen with aging, but these changes appear to occur prematurely and may be accelerated. These soft tissue body composition changes may negatively impact carbohydrate and lipid metabolism, which may increase risk for macrovascular disease. Strategies for innovative interventions aimed at reducing the relative decrease in lean tissue and increase in adiposity in immobilized populations should be considered.

DISCLOSURES

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REFERENCES

11. Brenes G, Dearwater S, Shapera R, LaPorte RE, and Collins E. High density lipoprotein cholesterol concentrations in


