Relationship between fat-to-fat-free mass ratio and decrements in leg strength after downhill running

R. C. HICKNER, P. M. MEHTA, D. DYCK, P. DEVITA, J. A. HOUMARD, T. KOVES, AND P. BYRD
Human Performance Laboratory, Department of Exercise and Sports Science, East Carolina University, Greenville, North Carolina 27858

Received 29 August 2000; accepted in final form 17 November 2000

The purpose of this study was to determine whether greater body fat mass (FM) relative to lean mass would result in more severe muscle damage and greater decrements in leg strength after downhill running. The relationship between the FM-to-fat-free mass ratio (FM/FFM) and the strength decline resulting from downhill running (−11% grade) was investigated in 24 male runners [age 23.4 ± 0.7 (SE) yr]. The runners were divided into two groups on the basis of FM/FFM: low fat (FM/FFM = 0.100 ± 0.005, body mass = 68.4 ± 1.3 kg) and normal fat (FM/FFM = 0.233 ± 0.020, body mass = 76.5 ± 3.3 kg, P < 0.05). Leg strength was reduced less in the low-fat (−0.7 ± 1.3%) than in the normal-fat individuals (−10.3 ± 1.5%) 48 h after, compared with before, downhill running (P < 0.01). Multiple linear regression analysis revealed that the decline in strength could be predicted best by FM/FFM (r² = 0.44, P < 0.05) and FM-to-thigh lean tissue cross-sectional area ratio (r² = 0.53, P < 0.05), with no additional variables enhancing the prediction equation.

There were no differences in muscle glycogen, creatine phosphate, ATP, or total creatine 48 h after, compared with before, downhill running; however, the change in muscle pH and creatine phosphate, ATP, or total creatine 48 h after, compared with before, downhill running was associated with a higher FM/FFM (r = −0.56, P < 0.05). These data suggest that FM/FFM is a major determinant of losses in muscle strength after downhill running.

The performance of novel exercise tasks, particularly those involving eccentric contractions, typically produces delayed-onset muscle soreness and muscle damage (6, 15, 24). Although muscle soreness, muscle damage, and muscle weakness are common consequences of eccentric contractions, the extent of these responses varies widely between individuals (15). Part of this variation may be due to prior exposure, in that prior performance of eccentric contractions can decrease the development of soreness and minimizes the loss in muscle strength after a bout of similar eccentric exercise (6). Thus training status, which is reflected in maximal aerobic capacity [maximal O₂ consumption (V̇O₂ max)] and miles run per week in runners, may influence changes in strength after eccentric exercise. The development of muscle stress beyond that which the muscles and tendons can accommodate has been a common hypothesis for the cause of soft tissue damage resulting from eccentric muscle contraction (8, 17). Inherent in this hypothesis is that all factors that increase muscle strain would increase muscle damage.

Increases in vertical impulse, loading rate, braking forces, and ground reaction forces have been shown to increase muscle strain and to positively correlate with body mass index (23). Excess body fat in the absence of a concomitant increase in cross-sectional area of nonweight-bearing muscles would likely increase the mechanical load on the muscle. The increased adipose mass would be expected to place additional mechanical and metabolic strain on the muscle, possibly resulting in an exacerbation of exercise-induced muscle damage during bouts of unfamiliar eccentric muscle contraction and a reduction in muscle strength in the lower extremities. If this exercise-induced muscle damage results in reduced muscle strength, functional limitations after bouts of eccentric exercise may be more prevalent in individuals with a high fat mass-to-fat-free mass ratio (FM/FFM).

The purpose of this study was to determine whether the added mechanical load of body fat would result in greater decrements in leg strength after downhill running in nonobese men. Muscle metabolite data were also obtained using the muscle biopsy procedure to determine whether reductions in muscle high-energy phosphates or muscle glycogen are related to a reduction in strength after eccentric exercise, as has been suggested previously (3, 28). A new paradigm for studies of loading is put forth, in that FM/FFM, rather than the absolute mass of the individual, is the most relevant parameter to be considered when the mechanical and physiological consequences of loading during weight-bearing activities are investigated.

Address for reprint requests and other correspondence: R. C. Hickner, 371 Ward Sports Medicine Bldg., Human Performance Laboratory, East Carolina University, Greenville, NC 27858 (E-mail: Hicknerr@mail.ecu.edu).

The costs of publication of this article were defrayed in part by the payment of page charges. The article must therefore be hereby marked “advertisement” in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.
METHODS

Subjects. Subjects participating in the study were 24 non-obese, healthy recreational or competitive runners. The runners were divided into two groups on the basis of FM/FFM: low fat (LF, FM/FFM < 0.14) and normal fat (NF, FM/FFM ≥ 0.14). Subjects participated in the study after giving informed consent according to the East Carolina University Policy and Review Committee on Human Research.

Protocol. The relationship between body composition and strength decline was investigated before and after downhill running in 24 male runners (age 23.4 ± 0.7 yr, body fat 13.8 ± 1.2%). Subjects reported to the laboratory 4 h after a meal at ~1200. A resting blood sample was drawn from an antecubital vein. Subjects then ran at 60% VO₂ max relative to body mass, or 8.9–11.6 km/h, downhill (~11% grade) on a motorized treadmill for 30 min. Blood samples were drawn at 0, 24, and 48 h after downhill running for determination of creatine kinase (CK). Muscle biopsies were taken from the vastus lateralis of the quadriiceps femoris muscle group at rest before and after 48 h after the downhill run for determination of muscle glycogen, ATP, creatine phosphate (CP), and free creatine (Cr). After assessment of muscle soreness, muscle strength of the right leg was tested in each subject on an isokinetic dynamometer (Kin-Com, Chattecx, Chattanooga, TN) before and 48 h after the downhill run. Subjects were asked not to ingest medication or undergo massage, icing, or other procedures that may alter muscle damage or perceptions of muscle soreness. Subjects were also asked not to perform structured exercise or to perform novel physical activity in the 48 h between the first and second testing sessions. Subjects completed a questionnaire to determine their average weekly running distance over the 2 mo before the investigation. Subjects were aware that the effect of downhill running on muscle soreness was being investigated but were not aware that data would be analyzed on the basis of two groups of subjects, i.e., those who were low fat and those who were not.

Body composition and anthropometric determinations. Residual volume was determined by the O₂ dilution method, as described by Wilmore (32). Body density was determined by hydrostatic weighing, with percent body fat calculated using residual volume and body density calculated using the equations of Brozek et al. (5). Circumferences of the waist (umbilicus) and the hip (greater trochanter) were determined for calculation of waist-to-hip ratio. Circumferences were measured at the end of a normal expiration with the subject in a standing position. Circumference and skinfold thickness at midthigh were also measured and used to calculate total lean tissue cross-sectional area (both thighs) at midthigh with the assumption that the thighs were cylinders with lean tissue area = π × radius². The radius of the lean tissue area was calculated from total thigh radius – one-half skinfold thickness at midthigh.

\[ \text{VO}_{2\ max} = \frac{\text{VO}_{2\ max} \times \text{VO}_{2\ max}}{7 \text{ days before downhill running for calculation of the relative intensity of downhill running (60% VO}_{2\ max}.\) \] After a 5-min warm-up at a self-selected pace, subjects ran at 7, 8, and 9 miles/h for 3 min per exercise intensity. Subjects continued at 9 miles/h treadmill speed for the remainder of the test, which consisted of increasing treadmill grade by 2% every 2 min. Respiratory gases were analyzed continuously and averaged over 20-s intervals using a metabolic measurement cart (model 2900, Sensormedics, Anaheim, CA). The subjects exercised to voluntary exhaustion, with achievement of VO₂ max determined by attainment of two of the following criteria: 1) plateau in O₂ consumption with increased exercise intensity, 2) respiratory exchange ratio >1.1, and 3) heart rate greater than age-predicted maximal heart rate.

Isokinetic strength testing. Isokinetic eccentric and concentric strength of the leg was tested at 1.0 and 3.1 rad/s on an isokinetic dynamometer. Subjects were seated on the dynamometer with straps placed around the waist and crossed over the shoulders and chest to minimize extraneous upper body movements. Subjects were instructed to fold their arms over their chest to minimize upper body contributions to force production. Subjects were familiarized with the strength tests on a previous visit to the laboratory, during which time they performed each of the tests. On the strength testing day, subjects performed 5 min of cycle ergometry exercise at ~40% VO₂ max for warm-up exercise. Gravity correction of the dynamometer was performed to account for the weight of the leg. Leg strength was then tested during concentric knee extension and flexion exercise. Leg strength was determined over 1.4 rad of motion at 1.0 and 3.1 rad/s, as well as during eccentric knee extension and flexion exercise at −1.0 and −3.1 rad/s. Total leg strength was calculated as the mean force production over all tests. Day-to-day variability of the isokinetic strength tests has been determined in this laboratory, in a group of individuals similar to those in the present study, to be 3–5% for the tests and protocols employed.

Blood sampling and analyses. Blood was drawn between 0900 and 1100 from an antecubital vein of subjects in a standing position 4 h after their most recent meal. Blood was also collected from subjects immediately after exercise, as well as at 24 and 48 h after the downhill run. Blood (10 ml) was collected in an untreated tube. For the samples obtained before and at the end of exercise, 0.5 ml of whole blood was pipetted into 1.0 ml of 3 N perchloric acid, thoroughly mixed, and centrifuged at 3,000 g. The supernatant was pipetted into a polyethylene storage vial for later analysis of blood lactate. The remaining whole blood was allowed to clot for 20 min and centrifuged at 3,000 g. The supernatant was pipetted into a polyethylene storage vial for later analysis of serum CK (samples before exercise, as well as 24 and 48 h after exercise) using a diagnostic kit from Sigma Chemical (St. Louis, MO).

Muscle biopsy. Muscle biopsies (~100 mg) were obtained percutaneously under local anesthesia (2–3 ml of 1% lidocaine) from the vastus lateralis of the quadriceps femoris muscle group at rest before and 48 h after the downhill run. The muscle sample was immediately (~<2 s) frozen in liquid nitrogen and stored under liquid nitrogen until subsequently lyophilized overnight. Samples were then dissected free of blood and connective tissue and partitioned for analysis of ATP, CP, Cr, and glycogen concentration using spectrophotometric methods as previously described (16).

Muscle soreness. Muscle soreness was determined by the same technician in all subjects immediately before and after 48 h after downhill running. Muscle soreness was indicated by the subjects on a digital scale from 0 to 10, with 0 indicating no soreness and 10 indicating extremely painful soreness. The technician applied enough force over the belly of the muscle with the thumb to initiate blanching under the thumbnail. The subject, on palpation, verbally expressed ratings of soreness from 0 to 10. This procedure was conducted to determine soreness of the quadriceps femoris muscle group, hamstring muscle group, and gastrocnemius and tibialis anterior muscles.

Statistics. Multiple linear regression analysis was performed to determine the relationship between FM/FFM, changes in soreness, body mass, VO₂ max, weekly running distance, and the change in strength after downhill running. Potential differences between groups were determined using
two-way (group \times time) repeated-measures ANOVA with Student-Newman-Keuls post hoc analysis. All statistical analyses were performed using SigmaStat software (Jandel Scientific, La Jolla, CA).

**RESULTS**

*Subject characteristics and weekly running distance.* Subject characteristics (age, height, weight, body composition, waist-to-hip ratio, and aerobic capacity per kilogram FFM) are presented in Table 1. Subjects were assigned to two groups [low fat (LF) and normal fat (NF)] on the basis of FM/FFM values, which were matched for age, FFM, and \( V_{\text{O}_2\text{max}} \) per kilogram of FFM. Body mass, FM, percent body fat, and FM/FFM were lower in the LF than in the NF group \((P < 0.05)\). LF and NF groups were not different \([P = \text{not significant (NS)}]\) with respect to FFM, body mass, or FM per square centimeter of midthigh lean tissue area. LF and NF groups were also not different \((P = \text{NS})\) with respect to aerobic capacity in absolute terms or in relation to FFM or midthigh lean tissue cross-sectional area.

**Leg strength.** Leg strength data are presented in Figs. 1–3. The only difference in leg strength between groups before downhill running was a higher 1.0 rad/s concentric quadriceps strength in the NF than in the LF group \((P < 0.05)\). Hamstring strength was not significantly affected by downhill running as measured 48 h after the downhill run when data are expressed as absolute strength \((\text{Fig. 1})\) or as a percent decrease from before to after downhill running \((\text{Fig. 3})\). Concentric quadriceps strength at 1.0 rad/s was lower in the NF group 48 h after than before downhill running \((\text{Fig. 2}; P < 0.05)\). Eccentric quadriceps strength at 3.1 rad/s was lower in the NF group 48 h after than before downhill running \((\text{Fig. 2}; P < 0.05)\). The change in quadriceps strength from before to 48 h after downhill running was larger in the NF than in the LF group at 1.0 and 3.1 rad/s during concentric and eccentric testing \((\text{Fig. 3}; P < 0.05)\). When expressed as a mean of the individual percent declines in strength, mean leg strength (mean of all strength measures) was reduced \(-0.7 \pm 1.3\) and \(-10.3 \pm 1.5\%\) in the NF and LF groups, respectively, after downhill running \((P < 0.01)\). The decrement in strength after downhill running was positively correlated with FM/FFM \((r = 0.66, P < 0.001)\) and FM-midthigh lean tissue area ratio \((r = 0.73, P < 0.001; \text{Fig. 4})\). There were no correlations between mean leg strength changes and body mass or FFM.

Multiple linear regression analysis was performed to determine the relationship between the loss of leg strength and the following variables: weekly running distance, FM/FFM, body mass, \( V_{\text{O}_2\text{max}} \) and the change in mean muscle soreness from before to 48 h after a downhill run. The multiple regression analysis indicated that weekly running distance, \( V_{\text{O}_2\text{max}} \), body mass, and the change in mean muscle soreness from before to 48 h after a downhill run were not correlated with the decrement in strength. FM/FFM was the only significant predictor of the decrement in strength after downhill running, explaining 44% of the variance in

---

**Table 1. Subject characteristics and training history**

<table>
<thead>
<tr>
<th></th>
<th>LF</th>
<th>NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>23.4 ± 1.1</td>
<td>23.2 ± 1.0</td>
</tr>
<tr>
<td>Height, cm</td>
<td>177.8 ± 1.5</td>
<td>176.7 ± 1.8</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>21.7 ± 0.4</td>
<td>24.4 ± 0.8*</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>68.4 ± 1.3</td>
<td>76.5 ± 3.3*</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>9.0 ± 0.7</td>
<td>18.7 ± 0.3*</td>
</tr>
<tr>
<td>FM, kg</td>
<td>6.2 ± 0.5</td>
<td>14.4 ± 1.4*</td>
</tr>
<tr>
<td>FFM, kg</td>
<td>62.3 ± 1.4</td>
<td>62.1 ± 2.6</td>
</tr>
<tr>
<td>FM/FFM</td>
<td>0.100 ± 0.008</td>
<td>0.233 ± 0.020*</td>
</tr>
<tr>
<td>W/H</td>
<td>0.83 ± 0.02</td>
<td>0.85 ± 0.02</td>
</tr>
<tr>
<td>Midthigh lean area, cm²</td>
<td>384.0 ± 17.0</td>
<td>396.0 ± 16.8</td>
</tr>
<tr>
<td>Body mass/thigh lean area, g/cm²</td>
<td>181.1 ± 6.2</td>
<td>195.0 ± 8.4</td>
</tr>
<tr>
<td>FM/thigh lean area, g FFM/cm²</td>
<td>16.1 ± 1.2</td>
<td>36.8 ± 3.3*</td>
</tr>
<tr>
<td>Training volume, km/wk</td>
<td>34.9 ± 6.2</td>
<td>22.9 ± 4.4</td>
</tr>
<tr>
<td>( V_{\text{O}_2\text{max}} ), l/min</td>
<td>4.2 ± 0.1</td>
<td>4.2 ± 0.2</td>
</tr>
<tr>
<td>( V_{\text{O}_2\text{max}}/\text{kg FFM, mI/kg}^{-1}\cdot\text{min}^{-1} )</td>
<td>67.2 ± 2.0</td>
<td>67.1 ± 2.3</td>
</tr>
</tbody>
</table>

Values are means ± SE; \( n = 12 \) subjects in each group. LF, low-fat group; NF, normal-fat group; BMI, body mass index; \( V_{\text{O}_2\text{max}} \), maximal aerobic capacity; FM, total body fat mass; FFM, total body fat-free mass; W/H, waist-to-hip ratio; midthigh lean area, lean tissue cross-sectional area at midthigh (for both thighs). *Significantly different from LF \((P < 0.05)\).
mean leg strength decrement after downhill running. When FM/FFM was replaced by FM-to-thigh lean tissue cross-sectional area ratio in the multiple regression analysis, FM-to-thigh lean tissue area ratio explained 53% of the variance in mean leg strength decrement after downhill running.

**Muscle soreness.** Peak muscle soreness of the leg musculature (peak score registered in the quadriceps, hamstring, gastrocnemius, or anterior tibialis muscles) was increased to the same extent at 48 h after downhill running in the NF and LF groups (4.3 ± 0.8 and 4.2 ± 0.5 arbitrary units, respectively) compared with no soreness before the run (P < 0.05, 0 vs. 48 h). Mean muscle soreness of the leg musculature (mean of quadriceps, hamstrings, gastrocnemius, and anterior tibialis muscle soreness scores) was also increased significantly and similarly 48 h after downhill running in the NF and LF groups (2.7 ± 0.7 and 2.2 ± 0.5 arbitrary units, respectively). Quadriceps muscles were rated significantly more sore than all other muscles tested (P < 0.05).

**Serum CK and blood lactate.** Serum CK was 87.6 ± 9.5 and 62.1 ± 9.2 IU in the LF and NF groups, respectively, before downhill running (P = NS). Serum CK increased (P < 0.05) to 329.9 ± 50.0 and 333.2 ± 39.9 IU in the LF and NF groups, respectively, 24 h after downhill running (P = NS). Serum CK 48 h after the downhill run (213.8 ± 31.3 and 193.4 ± 36.4 in LF and NF groups, respectively, P = NS) was also increased relative to CK before the downhill run (P < 0.05). There was no relationship between the increase in serum CK and the increase in muscle soreness or the decrease in muscle strength after downhill running. Blood lactate was 1.6 ± 0.1 and 1.7 ± 0.2 mM in the LF and NF groups, respectively, before downhill running (P = NS). Blood lactate increased in the LF and NF groups to 6.1 and 6.7 mM, respectively, by the end of exercise.

**Muscle ATP, PCr, Cr, and glycogen.** There were no differences in muscle ATP, PCr, and Cr before, compared with 48 h after, downhill running. Muscle ATP was 27.5 ± 0.3 and 26.3 ± 0.4 mmol/kg dry wt in the LF and NF groups, respectively, before downhill running (P = NS) and was not different 48 h after, compared with before, downhill running in either group. Muscle PCr was 85.2 ± 1.8 and 85.2 ± 3.2 mmol/kg dry wt in the LF and NF groups, respec-
tively, before downhill running ($P = \text{NS}$) and was not different 48 h after, compared with before, downhill running in either group. Muscle Cr was $47.9 \pm 2.0$ and $52.0 \pm 3.2$ mmol/kg dry wt in the LF and NF groups, respectively, before downhill running ($P = \text{NS}$) and was not different 48 h after, compared with before, downhill running in either group. Data for muscle glycogen stores are presented in Fig. 5. There was an interaction (group × time, $P < 0.05$) for muscle glycogen, in that muscle glycogen increased slightly in the LF group but decreased in the NF group from before the downhill run to 48 h after the run. Muscle glycogen was lower 48 h after the downhill run in the NF group than in the LF group ($P < 0.05$). The change in muscle glycogen from before to 48 h after downhill running was correlated with FM/FFM ($r = -0.56$, $P < 0.05$). The change in muscle glycogen from before to 48 h after downhill running was correlated with body mass, FM, FM/FFM, and FM-to-thigh lean tissue area ratio ($r = -0.43, -0.58, -0.57,$ and $-0.58$, respectively, $P < 0.05$).

**DISCUSSION**

Data from the present study support the hypothesis that there is a direct relationship between body composition and strength decline after downhill running. There was a range of 15 kg of body fat between individuals in the present study: individuals with the highest percentage of body fat exhibited the greatest loss in muscle strength. FM/FFM may therefore be a determinant of losses in muscle strength. In the present study, leg strength was reduced an average of 10% in the group of individuals with the higher body fat content (the NF group) 48 h after downhill running, whereas individuals in the LF group suffered no significant loss of strength. FM/FFM accounted for $45\%$ of the reduction in strength after downhill running. The increased FM/FFM may thus place an increased load on the lower extremities during downhill running, potentially resulting in increased muscle damage as a result of this activity.

The data in the present study may have been influenced by the higher body mass in the NF group than in the LF group. However, the finding of a greater decrement in leg strength after downhill running in the NF group than in the LF group is further supported by data obtained when the subjects in this study were divided post hoc in a different manner, i.e., one group with high body mass but low FM/FFM and another with low body mass but high FM/FFM. It was possible to create these two groups using 16 of our 24 subjects (8 subjects/group), resulting in one group with 68.2 ± 2.2 kg body mass and 0.22 ± 0.02 FM/FFM and one group with 4.5 kg more body mass (72.7 ± 1.9 kg) yet a lower FM/FFM (0.12 ± 0.01, $P < 0.01$). The mean leg strength data are very similar to the data presented for the two original groups, in that there was a greater ($P < 0.01$) loss of mean leg strength after downhill running in the group with lower body mass and high FM/FFM ($-10.7 \pm 1.8\%$ mean leg strength change) than in the group with higher body mass and low FM/FFM ($-0.13 \pm 2.0\%$ mean leg strength change). This clearly demonstrates that body mass is not re-
lated to reductions in strength after downhill running. FM/FFM is the major determinant of strength loss 48 h after this downhill running protocol. Although 10% strength loss may not be noticeable in an individual when performing common activities on level ground, this extent of strength loss may affect performance of tasks such as climbing stairs and heavy lifting.

Past investigations have focused on muscle damage and soreness after the various modes of muscle activity, e.g., eccentric, concentric, and isometric contraction, and have suggested that muscle damage may result from the high muscle strain resulting from loading of the muscle during eccentric contractions (13, 24). The intensity of exercise may play the dominant role in determining the degree of muscle damage and muscle soreness (8, 26). Fitzgerald et al. (12) demonstrated that when forces generated during eccentric and concentric contractions were kept constant, there was no difference in muscle soreness between subjects performing eccentric contractions and those performing concentric contractions. Muscle soreness was, however, much greater after eccentric than after concentric contractions when subjects performed the contractions at maximal intensity: forces generated were higher during eccentric than during concentric contractions in this case. Numerous authors have reported ~20% reductions in muscle strength after isokinetic eccentric exercise of the knee extensors and flexors (3, 10, 29). On the contrary, there are very few data on loss of muscle strength after downhill running. Eston et al. (11) reported a reduction in concentric leg strength (peak torque) of approximately ~18% 2 days after downhill running (40 min at ~10% grade) in a group of 10 men unaccustomed to eccentric exercise. The greater reduction of strength in the study by Eston et al. than in the present study (~0.7% in the LF group and ~10% in the NF group) may be due to the longer running time (40 min) and higher exercise intensity (80% of maximal heart rate) than in the present study (30 min at 60% \( \text{VO}_2\text{max} \)). Differences could also be due in part to the subjects’ training status, inasmuch as subjects in the present study were recreational or competitive runners. The reduction in strength in the study by Eston et al. was in fact not as great (~7% reduction in peak torque) in subjects who were preconditioned to eccentric exercise with a prior bout of eccentric knee extension exercise.

The increased loss of strength in the subjects with greater FM/FFM was not due to an increase in body mass, inasmuch as there was no correlation between body mass or FFM and the decrease in muscle strength after the downhill run. Although increased mass itself places additional load on the lower extremities during weight-bearing activities, any increase in nonfat tissue is often in the form of muscle. This increased mass may assist in supporting the additional body mass. Increases in nonmuscle mass, however, are most often due to fat deposited in the upper body in men (20). Increases in FM due to overeating or inactivity easily outpace increases in lean mass. This FM is therefore an additional load that must be supported by muscle, bone, and connective tissue in the lower extremities. There is an increased prevalence of degenerative knee joint disorders in obese individuals, indicating that increased FM may place an increased load on the knee joints (27). Toda et al. (27) demonstrated that reductions in body fat, but not reductions in body weight, are related to symptomatic relief from osteoarthritis. Although metabolic factors may also play a role in the pathogenesis of osteoarthritis, these data provide additional support for the hypothesis that increased FM places additional load on the lower extremities. No investigations have been conducted to determine whether increased FM has a detrimental effect on muscle tissue. The results from the present study indicate that an increased load due to higher body fat during eccentric muscle contraction in weight-bearing activities results in increased acute (48-h) reductions in muscle strength. The weight an individual carries should therefore not be the main focus of investigations of loading on lower extremities during weight-bearing activities. The more relevant parameter to consider during these investigations is the ratio of FM to muscle mass. Although we have not used sophisticated techniques to measure thigh muscle mass or cross-sectional area, the present data indicate that it may be the ratio of total body FM to thigh lean tissue cross-sectional area that is most relevant. Results of the present study and those of Toda et al. support the use of this paradigm for investigations of loading on muscle and other supportive tissues during weight-bearing activities.

The greater loss of strength in the subjects with higher FM/FFM was also not due to a potential relationship between aerobic capacity and muscle damage. Numerous studies have demonstrated a protective effect of a single bout of novel eccentric muscle contraction on subsequent bouts of the same activity (6, 7, 14, 22). However, in the present study, multiple regression analysis revealed that aerobic capacity and weekly running mileage did not improve the prediction of decrements in leg strength, despite the wide range of \( \text{VO}_2\text{max} \) and weekly running mileage of the subjects. The training (preconditioning) effect therefore had little influence in the present study, probably because all the subjects were at least recreational runners and had already become partially accustomed to downhill running. There was also no relationship between the increase in serum CK at 24 and 48 h after downhill running and the increase in muscle soreness or the decrease in muscle strength after downhill running, although differences at time points other than those measured cannot be ruled out. Whether there was some other difference in muscle quality between the two groups, perhaps increased intramuscular fat content and a concomitant lower myofibrillar protein content per unit thigh cross-sectional area in the group with higher FM/FFM, requires further investigation.

Previous investigations have demonstrated a reduction in muscle high-energy phosphate stores after eccentric muscle contractions (3, 28). Reductions in CP could result in decrements in strength; however, there was no difference in muscle stores of high-energy phos-
phates 48 h after and before downhill running. The cause of the reduction in strength after eccentric muscle contraction is still under investigation and may not be directly related to the degree of histologically determined muscle damage (17, 18). The processes of excitation-contraction coupling, calcium release and reuptake, and mechanical trauma to the actin and myosin contractile elements have been proposed as partial causes of the reduction in strength (1, 2, 30). Recent animal studies suggest that reductions in strength after eccentric contractions are due to some defect before calcium release yet are not due to impairment of action potential conduction along the sarcolemma (30). The extent to which these processes are affected by eccentric exercise in humans, and in humans with a high FM-to-muscle mass ratio in particular, remains to be investigated.

Numerous investigators have reported a reduction in muscle glycogen after eccentric muscle contractions (9, 19, 25, 28, 31), suggesting that muscle damage results in delayed glycogen resynthesis. In the present study, there was no statistically significant reduction in muscle glycogen 48 h after, compared with before, downhill running. There was, however, a negative correlation between the change in muscle glycogen and both the FM/FFM and the ratio of FM to midthigh lean tissue cross-sectional area. This may indicate that muscle damage was greater in individuals with high FM/FFM, resulting in greater strength decrements in those individuals. This hypothesis is not supported by CK data, although this marker is not always well associated with muscle damage (18). The muscle glycogen data must also be interpreted with caution, inasmuch as diet was not controlled in this study.

Further investigation is needed to determine why 1 kg of fat is not the same as 1 kg of lean mass in relation to strength decrements after downhill running. The influence of some factor associated with adipose tissue other than the mass of adipose tissue itself in causing the decrease in muscle strength after eccentric exercise cannot be ruled out. Adipose tissue has been shown to be a significant paracrine organ, secreting leptin, interleukins, and tumor necrosis factor-α (4, 21). These cytokines have been reported to be increased in overweight individuals and related to the degree of insulin resistance (4); furthermore, it has previously been demonstrated that downhill running results in insulin resistance (19). It is therefore possible that a cytokine or some other unknown factor released from fat contributes to not only insulin resistance, but also the loss of muscle strength after eccentric exercise. Individuals with higher FM/FFM may have a correspondingly greater release of this factor during or after downhill running.

It can be concluded that increased body FM relative to FFM is associated with a greater loss of leg strength 48 h after a bout of downhill running in young, nonobese male runners. Individuals with excess body fat may therefore be at greater risk of developing muscle weakness, and potentially muscle injury, after eccentric weight-bearing activities. Individuals with excess body fat should therefore avoid exercise-training programs with a high weight-bearing, eccentric component. This study also underscores the importance of considering body composition, rather than body mass, in studies of loading and the physiological consequences of loading during weight-bearing activities.

We acknowledge the excellent technical assistance of Josh Van Epps and Tanya Pehleman.

This study was supported by a grant from Experimental and Applied Sciences (Golden, CO).

REFERENCES


