Resistance Training Reduces Fasted- and Fed-State Leucine Turnover and Increases Dietary Nitrogen Retention in Previously Untrained Young Men

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Abstract

We aimed to determine the impact of intense resistance training, designed to increase lean body mass (LBM), on both fasted and fed whole body protein kinetics in untrained young men. Twelve healthy males (22 ± 2 y of age; BMI, 24.3 ± 2.4 kg/m²) participated in a 12-wk (5-d/wk) resistance training program. Before and after training, a primed constant infusion of [1-13C]leucine was used to measure whole body leucine turnover, protein breakdown, and nonoxidative leucine disposal in the fasted and fed states. Participants were studied during 5-d controlled diet periods that provided a moderate protein intake [1.4 g/(kg body wt · d)]. We estimated protein turnover and nitrogen balance. Training increased LBM (61.6 ± 6.9 vs. 64.8 ± 6.7 kg, P < 0.05). After training, whole body leucine turnover was reduced (P < 0.01) in both fasted (167 ± 18 vs. 152 ± 17) and fed (197 ± 23 vs. 178 ± 21) states [all values μmol/(kg LBM · h)]. Training-induced decreases (P < 0.01) in protein breakdown occurred in the fasted (165 ± 18 vs. 144 ± 17) and fed (111 ± 23 vs. 93 ± 20) states. Following training, nonoxidative leucine disposal was similarly reduced (P < 0.01) in the fasted (144 ± 18 vs. 126 ± 18) and fed (151 ± 20 vs. 133 ± 19) states. Nitrogen balance was more positive after training (13.7 ± 8.1 vs. 33.4 ± 12.5 g/(kg LBM · d), P < 0.01) indicating an increased retention of dietary nitrogen. Intense resistance training alters whole body protein kinetics in novice weightlifters regardless of feeding status. The increase in nitrogen balance after training demonstrates a more efficient utilization of dietary nitrogen, suggesting that protein requirements for novice weightlifters are not elevated. J. Nutr. 137: 985–991, 2007.

Introduction

Body proteins are continuously synthesized and degraded, providing a mechanism for the maintenance of optimally functioning proteins. It is well established that acute resistance exercise increases muscle protein turnover, with the balance favoring the synthesis of new proteins (1,2), setting the stage for muscle fiber hypertrophy and an increase in lean body mass (LBM)3. However, it is less clear how resistance training (i.e., multiple acute bouts of resistance exercise) would affect the rates of whole body protein synthesis and breakdown during a period of muscle growth (3–8).

Studies investigating the impact of resistance training on protein kinetics yield conflicting results. Some studies suggest that resistance training increases whole body protein turnover (3,4,9), whereas others report that protein kinetics are either unaltered (5,6) or actually reduced after training (7,8). In addition, the majority of studies have only investigated protein metabolism in either the fed or fasted states, but not both (3–5,9). Muscle protein mass is regulated acutely (hour-to-hour) by feeding (10,11). Hence, when one considers that individuals spend time in both the postabsorptive (i.e., fasted) and postprandial (i.e., fed) states, measuring protein kinetics in only one of these conditions would only provide partial information regarding the effects of resistance training on overall protein metabolism. We recently demonstrated that whole body protein synthesis and protein breakdown, when measured over a 24-h period, are significantly reduced after 12 wk of resistance training in young males (8). Whereas these data provide an aggregate daily response in free-living individuals, they do little to delineate possible training-induced changes in fasted and/or fed state protein kinetics. Therefore, to obtain a comprehensive picture of whole body protein kinetics, it is necessary to determine whether resistance training differentially affects protein metabolism in the fasted and fed states.

Whole body nitrogen balance has traditionally been used to estimate protein requirements in a variety of different populations (3,6,9,12,13). Cross-sectional studies suggest that resistance-trained individuals require 12–100% greater protein intakes than untrained individuals. However, the majority of studies have only investigated protein metabolism in either the fed or fasted states, but not both (3–5,9). Muscle protein mass is regulated acutely (hour-to-hour) by feeding (10,11). Hence, when one considers that individuals spend time in both the postabsorptive (i.e., fasted) and postprandial (i.e., fed) states, measuring protein kinetics in only one of these conditions would only provide partial information regarding the effects of resistance training on overall protein metabolism. We recently demonstrated that whole body protein synthesis and protein breakdown, when measured over a 24-h period, are significantly reduced after 12 wk of resistance training in young males (8). Whereas these data provide an aggregate daily response in free-living individuals, they do little to delineate possible training-induced changes in fasted and/or fed state protein kinetics. Therefore, to obtain a comprehensive picture of whole body protein kinetics, it is necessary to determine whether resistance training differentially affects protein metabolism in the fasted and fed states.

Whole body nitrogen balance has traditionally been used to estimate protein requirements in a variety of different populations (3,6,9,12,13). Cross-sectional studies suggest that resistance-trained individuals require 12–100% greater protein intakes than
their sedentary counterparts to maintain whole body nitrogen balance (3,12). Furthermore, initiation of an intense resistance training program may increase protein requirements by ~200% in novice weightlifters (13). Notwithstanding, longitudinal studies report that resistance training actually improves whole body nitrogen retention at a given protein intake, suggesting that resistance training may reduce protein requirements due to more efficient protein remodelling (6,7,9). Consistent with the anabolic nature of resistance exercise (1,2), we propose that resistance training would promote a greater retention of dietary nitrogen thereby decreasing the likelihood of an increased need for dietary protein.

The purpose of this study was to determine how resistance training alters whole body postabsorptive and postprandial leucine metabolism. Leucine is an essential amino acid that is primarily metabolized within lean tissues of the body (14). Muscle tissue, the primary tissue impacted by resistance training, is enriched in branched chain amino acids such as leucine and is also the major site of leucine oxidation. Therefore, changes in whole body leucine metabolism can provide information on the kinetics of lean tissue protein metabolism and possibly provide insight into the role muscle protein kinetics play in whole body protein turnover after an intense resistance training program. We also aimed to determine whether the need for dietary protein is elevated above a moderate [1.4 g/(kg body wt \( \cdot \) d)] level in untrained novice weightlifters completing a whole body resistance training program. Consistent with the anabolic nature of resistance exercise (1,2), we proposed that resistance training would promote a greater retention of dietary nitrogen.

Subjects and Methods

Subjects. Twelve healthy recreationally active young males (aged \( \geq 22 \pm 2 \) y; BMI, 24.3 \( \pm \) 2.4 kg/m\(^2\)) were recruited to participate in a 12-wk whole body resistance training program. Participants were informed about the experimental procedures, as well as the purpose of the study and potential risks, prior to providing written consent. Participants also completed a routine medical screening questionnaire and, based on their responses, were all deemed healthy. Participants were recreationally active (1–3 h/wk of physical activity) but had not engaged in any resistance exercise for at least 6 mo prior to the start of the study. Participants were instructed to maintain any habitual activity outside of the prescribed resistance exercise program for the duration of the study. The study conformed to all standards for the use of human subjects in research as outlined in the Helsinki declaration and was approved by the local Research Ethics Board of McMaster University and Hamilton Health Sciences.

Study design. Participants were studied before and after a 12-wk whole body routine resistance training program. Body composition was assessed before and 2 d after completion of the final training session using dual energy X-ray absorptiometry (DXA: Model QDR-4500A, Hologic) to determine changes in total body mass, fat-free mass, fat and bone-free mass, and body fat mass, as previously described (8). Participants were studied during 5-d controlled diet periods before training and during the final week of training to measure whole body nitrogen balance and leucine kinetics to determine training-induced changes in protein metabolism.

Resistance training program. The 12-wk whole body resistance training program involved 13 guided-motion resistance exercises divided over 3 different training days, as previously described (8). Briefly, training days were divided into legs (leg press, leg curl, leg extensions, and standing calf raises), pushing exercises (seated military press, bench press, vertical bench press, chest fly, and seated machine triceps extensions), and pulling (latsissimus pull-down, seated wide-grip row, seated narrow low row, and seated biceps curl) exercises. One repetition maximum (1 RM) was measured for each exercise before training and 2–4 d after the last training session to evaluate strength changes. Participants trained 5 d/wk at an initial intensity of ~70% of the pretraining 1 RM with a goal of 2 sets of 10–12 repetitions during the first 2 wk. In wk 3–12, exercise intensity was adjusted to ~80–85% 1 RM so that 3 sets of 6–10 repetitions were performed. All training sessions were supervised by a study investigator to ensure proper technique and exercise intensity adherence. Compliance with the training program in terms of attendance was >95% for all participants.

Muscle biopsies. Muscle biopsies of the vastus lateralis were obtained from each participant using a Bergstrom needle (modified for suction) under local anesthesia (2% lidocaine). Single biopsies were taken from a randomly selected thigh before training and the contralateral thigh 2–4 d after the final training session to confirm that changes in muscle strength and lean body mass were accompanied by increases in muscle fiber area indicative of hypertrophy. Upon excision, muscle biopsies were dissected free of visible fat and connective tissue and embedded in optimal cutting temperature gel (Tissue Tech, Sakura Finetechical), frozen in isopentane cooled by liquid N\(_2\) and stored at ~80°C. Histochemical analysis of muscle fibers was performed through myosin ATPase staining (15).

Diet. Participants were required to complete 3-d diet records prior to the start of the study and, at 6 wk and 11 wk of training, to provide an estimate of habitual macronutrient consumption (analyzed using Nutritionist V, First Data Bank). Participants were provided with reference lists to estimate portion sizes and were instructed to record all food and drink consumed in a diet log during a 3-d period (i.e., 2 weekdays and 1 weekend). Dietary controls were in place for 5 d before and during the final week of training to investigate whole body protein metabolism. Total energy needs were estimated according to the Harris-Benedict equation and were adjusted using a “light” activity factor (1.4) for pretraining and a “moderate” activity factor (1.6) for post-training. Food for each day was prepackaged and participants were instructed to check off each food item from a list as they consumed it. Relative protein intake was kept constant at a moderate level of 1.4 g/(kg body wt \( \cdot \) d) according to previous literature (3). Carbohydrate and fat contents of the controlled diets were adjusted during the final week of training to compensate for the increased energy requirement of the training sessions. Portions of 3 different representative test diets were lyophilized to verify nitrogen and energy content by Kjeldahl technique and bomb calorimetry, respectively. All controlled diets were corrected for nitrogen and energy content based on values obtained from these 3 representative diets. Body mass was monitored over the course of the controlled diet to ensure participants were in energy balance.

Nitrogen balance. Participants collected urine on d 4 and 5 of the controlled diet period for determination of 24-h nitrogen excretion. Urine collection was performed on the same day as the \([1-\text{C}]\)leucine infusion, both pre- and post-training, to provide concurrent measures of whole body nitrogen balance and leucine metabolism. Urine was also collected on the last training day during the post-training controlled diet period. Urinary nitrogen content was determined using the micro-Kjeldahl technique. Total nitrogen intake and urinary nitrogen excretion were used to calculate modified nitrogen balance (N\(_{\text{Balance}}\) = N\(_{\text{intake}}\) – N\(_{\text{urine}}\)). In addition, standard fecal, sweat, and miscellaneous nitrogen losses for sedentary and resistance trained athletes consuming a moderate protein diet were also used to estimate whole body nitrogen balance (3). Urinary urea and creatinine were analyzed by the Core Clinical Chemistry Laboratory at McMaster University, as previously described (8).

Infusion protocol. Whole body protein metabolism was measured on d 5 of the controlled diet period both pre- and post-training. Participants reported to the laboratory in the morning after an overnight fast and rested comfortably for 10 min. A baseline breath sample was collected in a 100-L Douglas Bag prior being injected into a 10-mL evacuated tube for determination of background breath\(\frac{1}{2}\)CO\(_2\)\(\cdot\)CO\(_2\) ratio by gas chromatography combustion-isotope ratio MS (BreathMat Plus, Finnigan MAT GmbH). Catheters were inserted in the medial vein of both arms; one for catheters, as previously described (8).
Bone mineral content, Body fat, and their interactions and main effects. For all analyses, differences were considered to determine differences between means for all significant (pre vs. post) and day (1 vs. 2) as factors. A Tukey post-hoc test was performed to determine differences in leucine metabolism, data were analyzed using a 2-pool steady state model with plasma \(^{13}C\)KIC and breath CO\(_2\) enrichments were stable during the infusion protocols with CV of <4% (range: 0.5–10%) and <6% (range: 0.3–14%), respectively. Training altered fasted whole body leucine kinetics through a ~9% depression in turnover that was the result of decreases in the rates of leucine breakdown and nonoxidative leucine disposal (NOLD), an estimate of protein synthesis (P < 0.01; Fig. 1). Feeding increased the rates of both leucine turnover and oxidation and decreased the rate of leucine breakdown, which resulted in an improvement in whole body leucine balance (P < 0.01). NOLD tended to be greater in the fed state (P = 0.066). There was a similar reduction (~9%) in fed state leucine turnover after training that was reflective of decreases in leucine breakdown and NOLD (P < 0.01).

Urine. Urinary nitrogen excretion decreased during the last week of training which resulted in a more positive (P < 0.01) modified (urine only) nitrogen balance (NBAL) post-training [53.6 ± 8.6 vs. 95.2 ± 17.0 mg/(kg LBM · d)]. When fecal and miscellaneous nitrogen losses were estimated, NBAL was still significantly more positive (P < 0.01) after compared with before training [13.7 ± 8.1 vs. 33.4 ± 12.5 mg/(kg LBM · d)]. There was no day-to-day difference in either the modified or estimated NBAL (Table 4). Although urinary urea excretion decreased (P < 0.01) after training [3.0 ± 0.3 vs. 2.3 ± 0.4 mmol/(kg LBM · d)], its contribution to total nitrogen excretion was unaltered (82 ± 3 vs. 84 ± 4%). Consistent with an increase in muscle mass, urinary creatinine excretion increased (P < 0.05) from pre- to post-training (27.4 ± 3.5 vs. 28.3 ± 3.5 mmol · d\(^{-1}\)). Both urea and creatinine excretion remained constant during the 2-d urine collection period with mean interday CV being ~7 and ~6%, respectively.

**Discussion**

Our intense resistance training protocol (5 d/wk for 12 wk) was effective in inducing increases in muscle size, muscle strength,
and LBM. We found that 12 wk of high-intensity resistance training significantly reduced whole body postabsorptive and postprandial leucine turnover. Despite reductions in protein turnover, whole body nitrogen balance was more positive after training, suggesting that 12 wk of resistance exercise resulted in a greater net retention of dietary nitrogen.

Resistance training resulted in a significant increase in LBM, which is consistent with previous training programs of similar intensity and duration (5,21) and suggests that participants in the present study were in positive energy balance during the training program. In apparent contrast, habitual macronutrient and energy intake in the present study remained relatively constant throughout the training program (Table 2). Because resistance training would increase energy demands, these data could suggest that activity outside of the prescribed training program was reduced slightly to support training-induced accretion of lean mass. However, it is more likely that participants in the present study slightly underestimated habitual energy intake. Although participants were carefully instructed on how to record daily food intake, dietary assessment based on self-report typically results in an underestimation of actual energy intake (22). Therefore, our values for macronutrient and energy intake during the training period are likely to represent minimum estimates of the habitual consumption of the participants. Regardless, our measures of whole body leucine metabolism and nitrogen balance were performed while participants were consuming a diet that provided adequate (possibly surfeit) protein and energy and therefore provide an accurate estimate of whole body protein metabolism after a resistance training program.

In the present study, whole body postprandial leucine metabolism was measured by providing participants small aliquots of a liquid meal supplement to induce a mild state of hyperamino-acidemia and hyperinsulinemia to stimulate protein synthesis and inhibit protein degradation (11). This approach to establishing a postprandial state has been used previously to measure fed-state leucine kinetics and was shown to provide reasonable estimates of 24-h leucine oxidation (3,5,6,9,23). Although this constant feeding is effective at maintaining isotopic equilibrium for the accurate evaluation of steady state leucine kinetics, some studies suggest this model underestimates the anabolic effect of feeding. Compared with constant feeding, dietary leucine consumed at, or in excess of, the daily requirement in physiologically discrete meals results in a significantly greater 24-h leucine balance (24,25). However, the positive leucine balance in these studies suggest that individuals were gaining lean body mass, which was likely not the case (24,25). Therefore, whereas constant feeding may underestimate leucine kinetics, it is also possible that feeding

### Table 2

<table>
<thead>
<tr>
<th>Diet</th>
<th>Time</th>
<th>Energy (MJ/d)</th>
<th>Energy (kJ/kg·d)</th>
<th>Protein (g/kg·d)</th>
<th>Protein CHO (g/d)</th>
<th>Fat (g/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled</td>
<td>Pre</td>
<td>12.8 ± 1.8</td>
<td>161 ± 12</td>
<td>1.39 ± 0.04</td>
<td>109 ± 11</td>
<td>435 ± 65</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>13.3 ± 1.5*</td>
<td>166 ± 12</td>
<td>1.39 ± 0.04</td>
<td>111 ± 14</td>
<td>480 ± 53*</td>
</tr>
<tr>
<td>Habitual</td>
<td>Pre</td>
<td>12.4 ± 3.8</td>
<td>160 ± 57</td>
<td>1.48 ± 0.42</td>
<td>116 ± 29</td>
<td>372 ± 116</td>
</tr>
<tr>
<td></td>
<td>6 Wk</td>
<td>12.1 ± 3.1</td>
<td>154 ± 45</td>
<td>1.59 ± 0.39</td>
<td>125 ± 29</td>
<td>375 ± 118</td>
</tr>
<tr>
<td></td>
<td>11 Wk</td>
<td>12.9 ± 2.6</td>
<td>159 ± 32</td>
<td>1.48 ± 0.34</td>
<td>118 ± 19</td>
<td>437 ± 129</td>
</tr>
</tbody>
</table>

1 Values are means ± SD, n = 12. *Different from pre controlled diet period, P < 0.05.
2 Macronutrient intake is expressed relative to weekly body weight measurements (pre = 79.0 ± 9.4 kg; 6 wk = 79.3 ± 10.2 kg; 11 wk = 80.2 ± 10.2 kg).
3 Carbohydrate.

### Table 3

<table>
<thead>
<tr>
<th>BCAA, μmol/L</th>
<th>Pre</th>
<th>Fasted</th>
<th>Fed</th>
<th>Post</th>
<th>Fasted</th>
<th>Fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEAA, μmol/L</td>
<td>1462 ± 201</td>
<td>1637 ± 234</td>
<td>1623 ± 120</td>
<td>1786 ± 134</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAA, μmol/L</td>
<td>764 ± 151</td>
<td>891 ± 201</td>
<td>840 ± 67</td>
<td>938 ± 99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCAA, μmol/L</td>
<td>288 ± 71</td>
<td>355 ± 96</td>
<td>314 ± 39</td>
<td>359 ± 47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leucine, μmol/L</td>
<td>104 ± 24</td>
<td>126 ± 31</td>
<td>107 ± 13</td>
<td>122 ± 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose, mmol/L</td>
<td>4.1 ± 0.6</td>
<td>4.5 ± 0.8</td>
<td>4.4 ± 0.6</td>
<td>5.0 ± 0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulin, pmol/L</td>
<td>13.7 ± 6.9</td>
<td>20.6 ± 92.2</td>
<td>14.4 ± 5.1</td>
<td>146.9 ± 64.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Values are means ± SD, n = 11. Condition (fed vs. fasted) was significant for all variables, P < 0.05. Time (pre vs. post) did not affect any variable.
2 Nonessential amino acids (sum of Ala, Arg, Asn, Asp, Gin, Glu, Gly, Pro, Ser, Tyr; note Cys not measured).
3 Essential amino acids (sum of His, Ile, Leu, Lys, Met, Phe, Thr, Val; note Trp not measured).
4 Branched chain amino acids (sum of Ile, Leu, Val).
physiologically discrete meals may overestimate whole body leucine metabolism in the fed state. Here we present leucine kinetics during constant feeding of a complete liquid meal supplement to provide a minimum estimate of whole body postprandial leucine metabolism.

Our study is, to our knowledge, the first to measure whole body protein metabolism in both the fasted and fed states in healthy young men after a period of intense resistance training. We demonstrate that both postabsorptive and postprandial protein turnover are similarly reduced after resistance training in young men and are the result of decreases in whole body protein breakdown and protein synthesis. These data are at odds with some (4–6,9) but not all longitudinal studies (7,8). Fasted and fed state whole body leucine metabolism has been previously reported to be either unchanged or slightly elevated after resistance training (4–6,9), suggesting that training may chronically increase the synthesis and breakdown of lean tissue. However, previous studies investigating the impact of resistance training on protein metabolism have either used elderly populations, in which there was no training-induced changes in muscle mass, or a comparatively lower training volume (3 d/wk) (4,6,9). The altered protein kinetics demonstrated after training in the present study may be specific to the more intense nature of the resistance exercise-induced accretion of lean mass, or a comparatively lower training volume (3 d/wk) (4,6,9).

We demonstrate that both postabsorptive and postprandial leucine metabolism in the fed state. Here we present leucine kinetics during constant feeding of a complete liquid meal supplement to provide a minimum estimate of whole body postprandial leucine metabolism.

Considering that nonurinary nitrogen losses are similar between sedentary and resistence trained individuals (3). Both methods of estimating whole body nitrogen balance yield slightly positive results in the untrained state (Table 4). However, without a consideration of obligatory nitrogen losses through routes other than urine results in an overestimation of the true nitrogen balance. In the present study, nitrogen excretion was measured in the urine and was also estimated from typical miscellaneous nitrogen losses in sedentary and resistance trained individuals (3). Both methods of estimating whole body nitrogen balance yield slightly positive results in the untrained state (Table 4). However, it is unlikely that participants consuming a diet with a moderate protein and adequate, but not excessive, energy intake were accruing significant lean body mass before training, which suggests that our values represent a slight overestimate of the true nitrogen balance. Nonetheless, a significantly more positive nitrogen balance during the final week of training in the present study is consistent with a resistance exercise-induced accretion of lean mass. Considering that nonurinary nitrogen losses are similar between sedentary and strength athletes consuming a diet with a moderate protein and (8). Regardless, we observed that 12 wk of intense resistance training in novice weightlifters resulted in a reduction in the rates of whole body protein turnover regardless of feeding status.

A post-training reduction in whole body leucine metabolism at a time when muscle protein kinetics are either unaltered (4) or slightly elevated is intriguing (5,26,27). However, resistance exercise is a potent anabolic stimulus that increases the intracellular reutilization of amino acids from protein breakdown in both the fasted and fed states (1,2,28–30). The net result would be that amino acid release from the intramuscular free pool would be reduced with resistance exercise. Because the reciprocal pool model for assessing leucine turnover directly measures the rate of appearance of the ketoacid of leucine in the plasma, a reduction in whole body leucine metabolism could be the result of an exercise-induced decrease in intramuscular amino acid release. Insofar as leucine oxidation is concerned, we observed no difference after training, which resulted in a similar reduction in nonoxidative leucine disposal after training. Therefore, it may be that the decrease in whole body leucine turnover in the present study was the result of a resistance exercise-induced increase in muscle protein synthesis (1,2,28–30), which would be measured, using the reciprocal pool model, as a decrease in amino acid release (i.e., flux) from muscle tissue.

A limitation of the current methodology used to measure leucine kinetics is its inability to detect tissue-specific changes in protein kinetics and the impact these changes may have on the measurement of whole body protein turnover. The increase in LBM and muscle fiber hypertrophy in the present study suggests that muscle became a site for a relatively greater use of amino acids for protein accretion. It is possible that, in response to the chronic anabolic stimulus of resistance training, leucine turnover was reduced slightly in central tissues not experiencing significant growth (e.g., splanchnic region) and directed more toward peripheral muscle tissues to support training-induced protein accretion. This could explain, in part, the decrease in fasted and fed whole body leucine turnover because muscle protein metabolism (~1.5%/d) is markedly lower than that of other lean tissues such as the splanchnic region (~12%/d) or kidneys (~38%/d) (14,31,32). Therefore, the possibility of training-induced changes in nonmuscle tissue protein metabolism deserves further study.

Urinary nitrogen excretion contributes 80–85% to total nitrogen excretion and provides a reasonable estimate of whole body nitrogen balance (3,33); however, without a consideration of obligatory nitrogen losses through routes other than urine results in an overestimation of the true nitrogen balance. In the present study, nitrogen excretion was measured in the urine and was also estimated from typical miscellaneous nitrogen losses in sedentary and resistance trained individuals (3). Both methods of estimating whole body nitrogen balance yield slightly positive results in the untrained state (Table 4). However, it is unlikely that participants consuming a diet with a moderate protein and adequate, but not excessive, energy intake were accruing significant lean body mass before training, which suggests that our values represent a slight overestimate of the true nitrogen balance. Nonetheless, a significantly more positive nitrogen balance during the final week of training in the present study is consistent with a resistance exercise-induced accretion of lean mass. Considering that nonurinary nitrogen losses are similar between sedentary and strength athletes consuming a moderate [1.4 g/(kg body wt · d)] protein diet (3), our interpretation of a greater nitrogen balance after resistance training is, although an overestimate, still valid.

Consistent with previous training studies, urinary nitrogen balance was significantly more positive after 12 wk of resistance training.
training, which suggests that there is a greater net retention of dietary nitrogen in the trained state (6–9). In the present study, nitrogen balance was measured during a period in which participants were still training to provide an estimate of how daily protein utilization is influenced by chronic resistance exercise. Considering that participants were still exercising, the greater nitrogen balance during d 1 of the urine collection was likely influenced by the acute interactive and additive effects of feeding and resistance exercise (2). However, urinary nitrogen balance was not significantly reduced the day after the last training session (Table 3), which demonstrated that resistance exercise improves the retention of dietary nitrogen for up to 48 h. Taking into account that relatively intense resistance training programs typically allot no more than ~2 d of recovery time between training sessions, whole body protein balance would consistently be more positive during, compared with before, training. Therefore, consistent with the anabolic nature of resistance exercise, we interpret these and previous results as a reflection of a chronic response to resistance training that favors the net retention of dietary nitrogen (8).

In the present study, the greater nitrogen retention after 12 wk of training, and at a time when participants were still exercising, suggests that resistance exercise per se does not appear to increase dietary protein needs in previously untrained young males, which would have been evident as a lower nitrogen balance. Although protein requirements may be slightly elevated (>1.35 g/[kg body wt · d]) during the early stages (≤4 wk) of resistance training (8,13), the present study demonstrates that by 12 wk of training a protein intake of 1.4 g/[kg body wt · d] is adequate for individuals to maintain a positive nitrogen balance. Although our data do not directly address the level of protein intake at which zero nitrogen balance would occur, the significantly more positive nitrogen balance after training demonstrates a more efficient utilization of dietary protein in the trained state. An enhanced dietary protein efficiency could suggest that protein intakes <1.4 g/[kg body wt · d] would be sufficient for novice weightlifters to benefit from routine resistance training with specific regard to favorable changes in body composition. Furthermore, findings from the present study cannot be directly extrapolated to more experienced weightlifters (>3 mo of training) who may have maximized lean mass gains. However, considering that changes in muscle strength and muscle size occur more rapidly in untrained compared with trained individuals, it is likely that protein requirements would be greatest during the early stages of a resistance training program (13,34). Therefore, we speculate that, because a protein intake of 1.4 g/[kg body wt · d] was adequate to maintain a positive nitrogen balance in novice weightlifters, dietary protein requirements would be below the habitual intake [typically ≥2 g/[kg body wt · d)] of many resistance trained individuals (10). Future studies should investigate protein requirements in response to resistance training programs of longer duration.

In summary, the present study demonstrates that 12 wk of intense resistance training decreases both fasted and fed whole body leucine turnover in previously untrained young men. The depression in whole body protein turnover was the result of similar reductions in protein breakdown and nonoxidative leucine disposal regardless of nutritional status. Despite decreases in whole body leucine kinetics, nitrogen balance was more positive after training when consuming a weight-maintaining diet providing a moderate [1.4 g/[kg body wt · d)] level of protein. The improvement in nitrogen balance after training suggests that protein requirements are not increased as a result of resistance training.

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Literature Cited


