Effects of liquid carbohydrate/essential amino acid ingestion on acute hormonal response during a single bout of resistance exercise in untrained men

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Abstract
Objective: The primary objective of this study was to investigate the influence of nutritive interventions on acute hormonal responses to a single bout of resistance exercise in untrained young men. Specifically, the aim was to determine whether the acute hormonal milieu conducive to enhancing skeletal muscle hypertrophic adaptation to resistance training could be created. The potential role of cortisol in inhibiting training-induced muscle growth is of particular interest, as is whether exercise-induced cortisol release can be attenuated by nutritive interventions.

Methods: After a 4-h fast, 32 subjects performed a single bout of resistance exercise (~60 min), during which they consumed a 6% carbohydrate (CHO) solution, a 6-g essential amino acid (EAA) mixture, a combined CHO + EAA supplement, or a placebo beverage. Blood samples were collected every 15 min throughout the exercise bout, immediately after exercise, and 15 and 30 min after exercise for analysis of total testosterone, cortisol, growth hormone, insulin, and glucose.

Results: No significant change in glucose or insulin was observed for placebo. CHO and CHO + EAA ingestion resulted in significantly (P < 0.001) increased glucose and insulin concentrations above baseline, whereas EAA resulted in significant postexercise increases (P < 0.05) in insulin only. Placebo exhibited a significant increase in cortisol within 30 min (P < 0.01), with a peak increase of 105% (P < 0.001) immediately after exercise, and cortisol remained 54% above baseline at 30 min after exercise (P < 0.05). Conversely, the treatment groups displayed no significant change in cortisol during the exercise bout, with CHO and CHO + EAA finishing 27% (P < 0.01) and 23% (P < 0.05), respectively, below baseline at 30 min after exercise. No between-group differences in exercise-induced growth hormone or testosterone concentrations after nutritive intervention were present.

Conclusion: These data indicate that CHO and/or EAA ingestion during a single bout of resistance exercise suppresses the exercise-induced cortisol response, in addition to stimulating insulin release. We conclude that the exercise-induced hormonal profile can be influenced by nutritive interventions toward a profile more favorable for anabolism. © 2006 Elsevier Inc. All rights reserved.

Keywords: Resistance exercise; Carbohydrate/essential amino acid supplementation; Acute hormonal response

Introduction

Biochemical (hormonal) responses play a central role in signaling the cellular remodeling process of myofibrillar proteins and are intimately involved with protein synthesis and degradation [1,2]. A multitude of hormones that exert anabolic effects such as testosterone, growth hormone, insulin, and insulin-like growth factor-I regulates protein synthesis [3–5], whereas catabolic hormones, principally cortisol, increase protein degradation [6] in an attempt to support glucose synthesis. This dynamic balance between anabolic and catabolic milieu will ultimately influence protein turnover [1] and result in a positive or negative muscle protein balance. One way to influence muscle protein balance after resistance exercise is by nutritive interventions...
Research indicates that carbohydrate (CHO) and/or essential amino acid (EAA) ingestion around the time of exercise modifies the acute biochemical events associated with resistance training, shifting the exercise-induced hormonal profile toward a profile more favorable for positive protein balance. Specifically, it is the response of insulin and cortisol that has received much attention because they are intimately involved in protein turnover.

An acute bout of resistance exercise performed in conjunction with liquid CHO ingestion during the exercise bout [10], 10 min before and after exercise [11], and 60 min after exercise [12,13] results in significantly increased insulin levels. Roy et al. [12] suggested that consumption of a CHO supplement after an acute bout of resistance exercise increases insulin concentrations, thereby enhancing muscle protein balance. This is most likely due to the inhibitory effect of insulin on muscle protein breakdown [14], although this effect may be entirely restricted to globular proteins because myofibrillar proteins are unaffected by systemic hyperinsulinemia [15]. Therefore, insulin’s mechanism of action on skeletal muscle is controversial [16,17].

In the absence of an increase in amino acid concentration, an increase in insulin has only a modest effect on muscle protein synthesis [18]. Therefore, supplying exogenous EAA during the exercise bout should allow expression of the stimulatory effect of insulin. Accordingly, Tipton et al. [19] showed that rates of protein synthesis and net protein balance are higher when amino acid availability is increased after an acute bout of resistance exercise than when subjects are fasted. As a result, amino acid supply to the muscle intracellular compartment through enhanced amino acid transport into muscle is suggested to be an important regulatory factor in determining the rate of muscle protein synthesis [20]. However, recent data presented by Bohe et al. [21] have indicated that protein synthesis is modulated by extracellular, not intracellular, amino acid availability.

Research has shown that different resistance exercise protocols result in an acute increase in cortisol [10,22,23]. However, Conley and Stone [24] suggest that excessive cortisol levels exhibited after a single bout of resistance exercise may elicit physiologic responses detrimental to the positive adaptations attributed to resistance training. Liquid CHO ingestion during the exercise bout is suggested [10] to increase the exogenous glucose load, resulting in inhibition of the glucose-regulatory response of cortisol. Further, addition of EAA (CHO + EAA) may augment this response by providing a potent stimulus, increasing extracellular amino acid availability and insulin release. Such an environment may provide greater potential for protein accretion and skeletal muscle growth, thus counteracting the stimulatory effect of cortisol on skeletal protein degradation.

The present investigation examined the influence of nutritive interventions (a 6% CHO solution, a 6-g EAA mixture, or a combined CHO + EAA beverage) on acute biochemical responses to a single bout of resistance exercise in untrained young men. Specifically, the objective of this investigation was to determine whether the acute hormonal milieu conducive to enhancing skeletal muscle hypertrophic adaptation to resistance training could be created by ingesting one of these interventions during the exercise bout. The potential role of cortisol in inhibiting training-induced muscle growth [10] is of particular interest, as is whether exercise-induced cortisol release can be attenuated by such nutritive interventions.

Materials and methods

Subjects

Thirty-two untrained young men (18 to 29 y old) volunteered to participate in this investigation. After a full explanation of all procedures and possible risks of the investigation, written informed consent was obtained before testing began. Subjects completed a health history questionnaire; all were apparently healthy and had no medical contraindications or history of any endocrine disorders that might influence their responsiveness to an acute bout of resistance exercise. No subject was taking any medication or nutritional supplementation; all were non-steroid users and non-smokers. Subjects were randomly allocated into one of four groups: CHO group (n = 8), EAA group (n = 8), combined CHO + EAA group (n = 8), or placebo (PLA) group (n = 8). All experimentation was approved by the ethics in human research committee of the university.

Experimental design

To examine the influence of nutritive interventions on acute hormonal responses to a single bout of heavy-resistance exercise in untrained young men, a randomized, double-blind, placebo-controlled design was used. Subjects reported to the Exercise and Sport Sciences Laboratory on three occasions separated by no more than 7 d. All sessions were performed between 3:00 and 5:00 pm to minimize the influence of diurnal variations on exercise performance and hormonal response [25], with times held constant for each subject. Subjects were required to refrain from all strenuous activity, alcohol use, caffeine, and sexual activity and were notified to maintain normal nocturnal sleep habits (i.e., approximately 8 h/night) throughout the experimental timeline.

During the initial laboratory session (day 1), descriptive data including height, weight, and body composition were recorded. Height was measured to the nearest 0.1 cm by using a stadiometer (Len Blayden, Lugarno, Australia) and weight was measured to the nearest 0.01 kg by using an electronic precision balance scale (HW-100KAI, GEC, Avery Ltd., Miranda, Australia). Body composition was determined by dual-energy x-ray absorptiometry with a total-body scanner (DPX-IQ, Prodigy, Lunar Corp., Madison,
Ingestion of 22.5-30.0 ml of nutritive combination (6% CHO EAA (Musashi, Notting Hill, Australia), a CHO (Gatorade, Quaker Oats Inc., Chicago, IL, USA), 6 g of EAA, or PLA (aspartame phenylalanine (0.93 g), threonine (0.88 g), and valine (0.70 g), which has been previously shown to enhance skeletal muscle anabolism [8].

**1-RM strength test**

Maximal strength was assessed for each of the eight selected exercises in the heavy-resistance protocol by completing a 1-RM test (i.e., the heaviest load that could be correctly performed once). Warm-up consisted of one set of 5 to 10 repetitions at 40% to 60% of perceived maximum. Subjects then rested for 1 min while performing light stretching. This was followed by three to five repetitions performed at 60% to 80% of perceived maximum. Thereafter, three to four subsequent attempts were made to determine the 1-RM strength, with the weight increased progressively until the subject failed at the given load. Three minutes of rest was allocated between lifts. By definition, 1-RM is the maximum amount of weight that can be lifted one time through a full range of motion by using good form at a tempo of 2:0:2 (2 s eccentric, 2 s concentric).

**Resistance exercise protocol**

The resistance exercise protocol (Table 1) used for this investigation was that used by Bird and Tarpenning [23]. The subject’s goal was to complete three sets of 8 to 10 repetitions at approximately 75% of that subject’s 1-RM. One minute of rest between each set and 2 min between each exercise were allowed for recovery. Machine exercises 1 to 5 were performed on Panatta Sports Fit 2000 Line weight machines (Panatta Sports, Aprio MC, Italy), and exercises 6 to 8 were performed with an Olympic-style barbell (York Barbell, York, PA, USA). The resistance exercise session lasted approximately 60 min, was preceded...
by a 10-min warm-up, and concluded with a 10-min warm-down period. Staff trained in the principles associated with resistance training supervised all sessions.

**Blood sampling and analysis**

After a 4-h fast, subjects reported to the laboratory and sat quietly for 15 min. A 20-gauge, 1.00-inch Teflon indwelling cannula (Saf-T-Intima, Becton Dickinson Inc., Sandy, UT, USA) was inserted into an antecubital forearm vein, after which subjects sat quietly for another 15-min period before blood collection to minimize hormonal fluctuations related to anticipatory responses [26]. Using a Vacutainer assembly and serum separator tubes (Monovette, Sarstedt, Numbrecht, Germany), 5-mL blood samples were drawn before exercise, every 15 min throughout the exercise bout, immediately after exercise (IP), and 15 min (P15) and 30 min (P30) after exercise. To assist keeping the line clear and prevent clotting, 1-mL of saline solution was injected into the cannula line between each blood draw. Blood samples were gently inverted five times and allowed to stand at room temperature for a minimum of 20 min. Samples were then centrifuged for 10 min at 3000 rpm, with the supernatant removed, placed into plastic storage containers, and frozen at −20°C until analysis.

Before analysis the serum was allowed to reach room temperature and then mixed gently by inversion. Glucose was determined by an enzymatic spectrophotometric method (Dimension Xpand, Dade Bearing Inc., Newark, DE, USA). Total testosterone and cortisol concentrations were determined by a competitive immunoassay technique using chemiluminescent technology (VITROS ECi, Ortho-Clinical Diagnostics Inc., Rochester, NY, USA) with detection limits lower than 0.03 nmol/L and lower than 3 nmol/L, respectively. Insulin and growth hormone concentrations were determined by a solid-phase, two-site chemiluminescent immunometric assay (Immulite 2000, Diagnostic Products Corp., Los Angeles, CA, USA), with detection limits of 2 μIU/mL and 0.026 mIU/L, respectively. To avoid inter-assay variations, all samples for each subject were assayed in the same assay run. Analyses of glucose, total testosterone, cortisol, insulin, and growth hormone showed intraassay coefficients of variation of 5.9%, 2.6%, 2.7%, 3.1%, and 7.2%, respectively. Serum hormone concentrations were not corrected for plasma volume shifts; thus, all statistical analyses were performed on hormone values based on actual measured circulating concentrations.

**Statistical analysis**

Descriptive data were generated for all variables and expressed as mean ± standard error of the mean. Analysis was performed with SPSS 11.5 (SPSS Inc., Chicago, IL, USA). Statistical analysis involved a two-way analysis of variance (group by time) with repeated measures. The source of significant differences was located using Tukey’s Honestly Significant Difference post hoc procedure. Significant interactions were analyzed by simple main effects. Statistical significance was set at \( P < 0.05 \).

**Results**

**Physical characteristics, 1-RM performance data, and daily dietary intake**

The physical characteristics, 1-RM performance data, and daily dietary data of the research subjects are listed in **Table 2**. The four groups did not significantly differ with respect to physical characteristics and 1-RM performance data. Thus, groups were matched for these variables. Nutritional analysis of daily dietary intake showed that diets were consistent across groups. The macronutrient composition of dietary intake was also similar across groups.

### Table 2

<table>
<thead>
<tr>
<th>Physical characteristics, 1-RM performance data, and daily intake of dietary energy and nutrients*</th>
<th>PLA group (n = 8)</th>
<th>CHO group (n = 8)</th>
<th>EAA group (n = 8)</th>
<th>CHO + EAA group (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Age (y)</td>
<td>20.3 ± 0.8</td>
<td>22.3 ± 1.2</td>
<td>21.3 ± 0.7</td>
<td>20.6 ± 0.5</td>
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<td>Height (cm)</td>
<td>182.6 ± 1.8</td>
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<td>181.2 ± 2.9</td>
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<td>Weight (kg)</td>
<td>80.4 ± 4.5</td>
<td>79.3 ± 4.4</td>
<td>79.7 ± 4.6</td>
<td>79.3 ± 3.9</td>
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<td>Fat mass (kg)</td>
<td>18.7 ± 3.2</td>
<td>12.7 ± 1.5</td>
<td>18.3 ± 3.2</td>
<td>13.8 ± 2.8</td>
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<td>Fat-free mass (kg)</td>
<td>58.3 ± 1.9</td>
<td>63.1 ± 3.2</td>
<td>58.1 ± 1.9</td>
<td>61.7 ± 2.9</td>
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<td><strong>1-RM performance data</strong></td>
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<td></td>
</tr>
<tr>
<td>45° leg press (kg)</td>
<td>141.9 ± 16.6</td>
<td>145.9 ± 7.8</td>
<td>138.8 ± 12.0</td>
<td>142.5 ± 16.4</td>
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<tr>
<td>Bench press (kg)</td>
<td>58.1 ± 6.7</td>
<td>67.8 ± 5.2</td>
<td>65.6 ± 3.1</td>
<td>63.1 ± 6.0</td>
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<tr>
<td><strong>Dietary intake</strong></td>
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<td></td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>2704.2 ± 196.4</td>
<td>2895.8 ± 225.6</td>
<td>2828.8 ± 220.9</td>
<td>2744.0 ± 253.1</td>
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<tr>
<td>Protein (g)</td>
<td>127.3 ± 13.0</td>
<td>113.6 ± 9.0</td>
<td>139.1 ± 11.8</td>
<td>113.9 ± 9.5</td>
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<tr>
<td>Carbohydrate (g)</td>
<td>299.7 ± 20.9</td>
<td>343.6 ± 22.9</td>
<td>298.1 ± 30.0</td>
<td>338.3 ± 33.8</td>
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<tr>
<td>Fat (g)</td>
<td>108.6 ± 8.7</td>
<td>113.0 ± 9.5</td>
<td>117.6 ± 10.0</td>
<td>100.3 ± 14.0</td>
</tr>
</tbody>
</table>

1-RM, one-repetition maximum; CHO, 6% carbohydrate solution; EAA, 6-g essential amino acid mixture; PLA, placebo

* Data are presented as mean ± standard error. No significant differences were found for any parameter.
addition, the effect of CHO/H11001, and CHO + EAA. (significantly higher glucose levels at 30 min, 45 min, IP, with that of PLA and EAA was pronounced, resulting in least P30 (4.4 μM), and remained significantly higher than the pre-exercise levels for at least P30 (4.2 μM), and remained significantly higher than the pre-exercise levels. Serum glucose levels of 31% and 40%, respectively, with all treatments (P < 0.05): aCHO from PLA; bCHO EAA from PLA; cCHO from EAA; dCHO + EAA from EAA. CHO, 6% carbohydrate solution; EAA, 6-g essential amino acid mixture; IP, immediately after exercise; P15, 15 min after exercise; P30, 30 min after exercise; PLA, placebo; Pre, before exercise.

**Figure 2**

**Serum glucose**

Figure 2 shows the serum glucose response during and after a single bout of resistance exercise. The PLA group showed no significant change in serum glucose concentrations to the exercise bout from the pre-exercise value (4.6 ± 0.1 mM) or up to P30 (4.2 ± 0.1 mM). The EAA group displayed a trend similar to that of the PLA group. Serum glucose remained statistically unchanged from the pre-exercise value (4.5 ± 0.1 mM) throughout the exercise bout and up to P30 (4.2 ± 0.2 mM).

Conversely, CHO and CHO + EAA ingestion during the exercise bout resulted in significantly increased (P < 0.05) serum glucose levels of 31% and 40%, respectively, with all time points significantly higher than pre-exercise levels. The increase in glucose for the CHO group occurred within 15 min of commencing the exercise bout, peaked IP (5.6 ± 0.2 mM), and remained significantly higher than the pre-exercise value of 4.3 ± 0.1 mM for at least P30 (5.1 ± 0.1 mM, P < 0.05). CHO ingestion also resulted in significantly higher glucose levels compared with PLA at IP, P15, and P30 and with EAA IP and P15 (P < 0.05). The response of the CHO + EAA group mirrored that of the CHO group. The CHO + EAA group displayed a significant increase in glucose within 15 min, peaked IP (6.1 ± 0.1 mM), and remained significantly higher than pre-exercise levels for at least P30 (4.4 ± 0.1 versus 5.5 ± 0.4 mM, P < 0.05). In addition, the effect of CHO + EAA ingestion compared with that of PLA and EAA was pronounced, resulting in significantly higher glucose levels at 30 min, 45 min, IP, P15, and P30 (P < 0.05).

**Exercise Recovery**

Serum insulin

Figure 3 shows the serum insulin response during and after a single bout of resistance exercise. The PLA group showed no significant change in serum insulin concentration to the exercise bout from the pre-exercise value (8.8 ± 1.2 μIU/mL), with a slight, but non-significant, increase up to P30 (8.1 ± 0.8 μIU/mL). The EAA group displayed significantly increases in insulin concentration relative to the pre-exercise value (8.3 ± 3.2 μIU/mL) and at P15 and P30 (17.8 ± 3.7 μIU/mL, P < 0.001; 14.0 ± 2.1 μIU/mL, P < 0.05, respectively).

In contrast, serum insulin concentrations for the CHO and CHO + EAA groups reflected changes in glucose concentrations. After the CHO intervention there was an appreciable increase in insulin concentration after commencement of the exercise bout relative to the pre-exercise value (7.9 ± 0.7 μIU/mL), with significant increases noted IP (16.0 ± 1.6 μIU/mL, P < 0.01), followed by a peak increase of 170% at P15 (21.2 ± 3.5 μIU/mL, P < 0.001); thereafter, insulin remained significantly higher for at least P30 (20.3 ± 2.5 μIU/mL, P < 0.001). CHO ingestion resulted in significantly higher insulin levels than occurred with PLA IP, P15, and P30 (P < 0.05). The CHO + EAA treatment resulted in a pronounced increase in insulin throughout the exercise bout compared with the pre-exercise value of 7.6 ± 0.6 μIU/mL. Significant increases occurred by the end of the exercise bout (IP; 17.3 ± 0.8 μIU/mL, P < 0.01), with this response continuing into the recovery period. Insulin remained significantly higher at P15 (21.0 ± 1.6 μIU/mL, P < 0.001), finishing 189% above the pre-exercise value at P30 (22.0 ± 4.5 μIU/mL, P
< 0.001). It is noteworthy that insulin appeared to still be increasing after this time point. CHO + EAA consumption resulted in significantly higher insulin levels than did PLA IP, P15, and P30 (P < 0.05).

**Serum cortisol**

Figure 4 shows the serum cortisol response during and after a single bout of resistance exercise. With ingestion of the PLA beverage, cortisol increased immediately after commencement of the exercise bout, with values for all time points higher than the pre-exercise value (294.1 ± 30.8 nmol/L). Significant increases in cortisol occurred within 30 min of initiating the exercise bout (473.6 ± 52.1 nmol/L, P < 0.01), with a peak increase of 105% IP (602.4 ± 60.4 nmol/L, P < 0.001). Cortisol remained 54% above the pre-exercise value at P30 (452.3 ± 69.1 nmol/L, P < 0.05). In contrast, the EAA group showed no significant change in cortisol concentration to the exercise bout from the pre-exercise value (294.4 ± 33.4 nmol/L).

Consequent to the CHO and CHO + EAA treatments, the cortisol response was blunted, resulting in a significant decrease before to after exercise. Both groups displayed a noticeable decrease in cortisol concentration during the exercise bout compared with pre-exercise values (303.1 ± 45.7 and 317.1 ± 27.7 nmol/L, respectively). This decrease continued during the recovery period, finishing 27% and 23%, respectively, below the pre-exercise value at P30 (221.5 ± 45.8 nmol/L, P < 0.01; 245.4 ± 23.2 nmol/L, P < 0.05, respectively). This blunted response was associated with significantly lower cortisol levels compared with PLA at 45 min, IP, P15, and P30, with the greatest difference occurring IP (602.4 ± 60.4 nmol/L versus 268.5 ± 45.9 and 295.5 ± 31.4 nmol/L, respectively).

**Serum total testosterone**

Figure 5 shows the serum total testosterone response during and after a single bout of resistance exercise. All groups displayed an acute increase in total testosterone immediately after the initiation of the exercise bout; opposing responses were noted for the PLA and EAA groups versus the CHO and CHO + EAA groups. The PLA group demonstrated significant increases in total testosterone compared with the pre-exercise value (10.1 ± 1.2 nmol/L) and at P15 and P30 (12.2 ± 1.8 nmol/L, P < 0.05; 12.5 ± 1.9 nmol/L, P < 0.01, respectively). Thereafter, total testosterone remained statistically unchanged from the pre-exercise value for all remaining time points. The EAA group displayed a trend similar to that of the PLA group. Total testosterone values increased significantly at all time points during the exercise bout compared with the pre-exercise value (9.1 ± 1.0 nmol/L), with a peak increase of 32% at 45 min (12.3 ± 1.8 nmol/L, P < 0.001), and returned to the pre-exercise value at P30 (9.2 ± 1.2 nmol/L).

Subsequent to the CHO and CHO + EAA treatments, both groups demonstrated a significant increase in total testosterone 15 min after the initiation of exercise (15.1 ± 1.1, P < 0.01; 15.9 ± 2.4 nmol/L, P < 0.01, respectively) compared with pre-exercise values (12.9 ± 1.2 and 12.9 ± 1.8 nmol/L, respectively). CHO ingestion resulted in a significant decrease before to after exercise (P30; 10.2 ± 1.0 nmol/L, P < 0.001). Total testosterone for the CHO + EAA...
In untrained young men. Specifically, the objective was to determine whether exercise-induced cortisol release could be attenuated by such interventions, thereby creating a hormonal milieu conducive to enhance skeletal muscle hypertrophic adaptation to resistance training. The primary findings from this investigation were that performing a single bout of resistance exercise in conjunction with liquid CHO ingestion resulted in significantly higher insulin concentrations and a significant decrease in cortisol after exercise. Moreover, such responses were amplified when the treatments were combined (CHO + EAA), thus creating a hormonal milieu associated with anabolism. These results are in contrast to the non-significant change in insulin concentration and significantly higher cortisol levels shown by the PLA group.

Excessive levels of cortisol elicit several physiologic responses, some of which may be detrimental to the positive adaptations frequently attributed to resistance training [24], namely improving nitrogen balance and increasing muscle mass and strength. A primary function of increased cortisol secretion has been reported to accelerate gluconeogenesis [27]. Because of this glucose-regulatory action, it was hypothesized that, if an individual ingested a CHO solution while exercising, the exogenous glucose load would increase blood glucose levels. In turn, the increased blood glucose level would inhibit the stimulus for the adrenal cortex to secrete cortisol to catabolize cellular protein for gluconeogenic purposes. Moreover, this response may be augmented by the addition of EAA, thus amplifying the acute biochemical signals associated with resistance exercise.

In the present experiment, the exercise-induced cortisol response was somewhat antagonistic to that of glucose (i.e., when glucose levels were unchanged, cortisol concentration increased, and when glucose levels were increased, cortisol concentration decreased). The PLA group exhibited a peak cortisol increase of 105% (P < 0.001) IP, which corresponded with no change in glucose levels (7%). Similar increases in cortisol have been previously reported in untrained men [22,28,29]. Conversely, resistance exercise performed in conjunction with CHO and CHO + EAA consumption resulted in a blunted cortisol response. Time matched for PLA, the CHO and CHO + EAA groups showed decreases in cortisol of 11% and 7% IP, respectively, with this decrease becoming significant at P30 (27%, P < 0.01; 23%, P < 0.05, respectively). In addition, this corresponded with significant increases (P < 0.001) in glucose levels of 31% and 40%, respectively. These data provide evidence in support of the hypothesis by demonstrating that the stimulatory effect of resistance exercise on cortisol release can be overcome by CHO and/or CHO + EAA ingestion, with this response mediated, at least to some extent, by higher blood glucose levels. Such findings are in agreement with those reported by Tarpenning et al. [10].

In contrast to the catabolic effects of cortisol, the anabolic effects of insulin on muscle include stimulating amino 

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**Serum growth hormone**

Figure 6 shows the serum growth hormone response during and after a single bout of resistance exercise. The resistance exercise protocol resulted in a dramatic increase in growth hormone above the pre-exercise value in all treatment groups (PLA 1.0 ± 0.4 mIU/L; EAA 1.3 ± 0.3 mIU/L; CHO 1.4 ± 0.5 mIU/L; CHO + EAA 2.0 ± 0.7 mIU/L). Significant increases occurred within 15 min of initiation of the exercise bout, with peak increases occurring at 30 min for the PLA, EAA, and CHO + EAA groups (36.1 ± 11.1 mIU/L, P < 0.01; 54.9 ± 9.2 mIU/L, P < 0.001; 40.7 ± 9.1 mIU/L, P < 0.001, respectively) and 45 min for the CHO group (44.2 ± 13.7 mIU/L, P < 0.001) compared with the pre-exercise value. This increase remained significant IP for EAA (41.7 ± 8.9 mIU/L, P < 0.001), CHO (35.2 ± 15.2 mIU/L, P < 0.01), and CHO + EAA (30.4 ± 8.3 mIU/L, P < 0.01). Growth hormone concentrations remained statistically unchanged from the pre-exercise level during the recovery period. No group-by-time interactions were present for growth hormone.

**Discussion**

The present investigation examined the influence of nutritive interventions (a 6% CHO solution, a 6-g EAA mixture, or a combined CHO + EAA beverage) on acute biochemical responses to a single bout of resistance exercise in untrained young men. Specifically, the objective was to
acid transport and protein synthesis [18,30] and inhibiting protein degradation [31]. According to Goldberg [32] a key signaling event in the hypertrophic response of skeletal muscle is an increased rate of amino acid transport, and this directly corresponds to muscle contractile activity and insulin concentrations. However, an acute bout of resistance exercise is generally accompanied by a decrease in insulin levels [11,33,34]. Moreover, it has been observed that ingestion of amino acid mixtures alone [35] or in combination with CHO [36] can produce strong insulinotropic effects. Such a response may increase the exercise-induced insulin response after resistance exercise. In theory, increasing insulin could influence the subsequent phase of recovery by modulating anabolic and catabolic processes [37].

The insulin response in the present experiment mirrored changes in glucose kinetics (i.e., when glucose levels were unchanged, insulin levels were unchanged, and when glucose levels were increased, insulin levels were increased). The PLA group showed a minor decrease in insulin (8%) and glucose (9%) concentrations before to after exercise. However, ingestion of CHO and/or EAA demonstrated a stimulatory effect on insulin response, with the CHO and CHO + EAA groups displaying significantly increased insulin and glucose levels. CHO consumption resulted in an approximately 2.5-fold increase in insulin concentration. Further, addition of EAA (CHO + EAA) improved insulin responsiveness approximately 3.0-fold. These findings are in agreement with those of several reports [36–38], indicating that inclusion of EAA with CHO acts in a synergistic fashion to enhance the acute insulin response after resistance exercise. It is noteworthy that the EAA group displayed an approximately 2.0-fold increase in insulin concentration during the recovery period. Interestingly, this was associated with a minor decrease in glucose (6%). Collectively, these findings indicate that the inhibitory effect of resistance exercise on insulin secretion can be overcome by nutritive interventions. Although measurements of protein turnover were not determined in this investigation, it is possible that the modified hormonal response associated with CHO + EAA ingestion, that of increased insulin and decreased cortisol, resulted in a hormonal profile more favorable for positive nitrogen balance and protein accretion.

In summary, the findings of the present investigation suggest that CHO ingestion during the exercise bout can suppress exercise-induced cortisol release, thereby altering the balance between hormone-mediated anabolic and catabolic activities. Further, such biochemical responses are augmented with the addition of EAA (CHO + EAA) toward a profile more favorable for anabolism. However, the biochemical events associated with resistance exercise and nutrient status, and by which this phenomenon regulates protein degradation, are yet to be elucidated.

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