

EFFECTS OF LIQUID CARBOHYDRATE INGESTION ON MARKERS OF ANABOLISM FOLLOWING HIGH-INTENSITY RESISTANCE EXERCISE

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ABSTRACT. Thyfault, J.P., M.J. Carper, S.R. Richmond, M.W. Hulver, and J.A. Pottenger. Effects of liquid carbohydrate ingestion on markers of anabolism following high-intensity resistance exercise. *J. Strength Cond. Res.* 18(1):173–178, 2004.—We examined the effects of liquid carbohydrate (CHO) supplementation on markers of anabolism following high-intensity resistance exercise. Nine resistance-trained men consumed either CHO or placebo (PLC) 10 minutes before and immediately following 2 resistance exercise sessions. Cortisol (CORT), insulin (INS), ammonia (AMM), and glucose (GLU) were measured before, immediately after, and 1.5 and 4 hours after exercise. Urinary nitrogen (NH^{+3}) was measured 24 hours before and after exercise. There was a significant difference in INS levels immediately after exercise and 1.5 hours after exercise. No significant differences were observed for CORT, AMM, GLU, or NH^{+3} between treatments. Significant within-group differences were found for the PLC group: CORT before compared with immediately after exercise; INS before compared with immediately after exercise and before compared with 1.5 hours after exercise. Significant within-group differences were found for the CHO group: CORT immediately after compared with 1.5 hours after exercise and immediately after compared with 4 hours after exercise; INS before compared with 1.5 hours after exercise; and AMM before compared with immediately after exercise. Liquid CHO ingestion leads to a more favorable anabolic environment immediately following a resistance exercise bout; however, our indirect measures of protein degradation were not altered by CHO ingestion.

KEY WORDS. insulin, cortisol, catabolism, ammonia, urinary nitrogen

INTRODUCTION

Individuals perform resistance exercise to increase skeletal muscle size and force production. The adaptations to skeletal muscle that occur following resistance exercise are complex and require considerable training time and effort. Protein turnover is a specific area of concern for individuals who want to increase lean tissue mass. Skeletal muscle protein turnover has been shown to increase after short-term bouts of high-intensity resistance exercise (1, 3, 6, 17, 26). The components of protein turnover, protein degradation, and protein synthesis must summarily be equal for skeletal muscle mass to be maintained. However, for skeletal muscle to increase in size and force production, there must be an increase in protein synthesis without a concomitant increase in protein degradation (13).

Past research has shown that high-intensity resistance exercise can cause a short-term, rapid increase in plasma cortisol (CORT) concentrations (9, 11, 12). Cortisol, a hormone produced by the adrenal cortex, is catabolic and increases the rate of protein degradation in skeletal muscle and therefore may elicit an increase in muscle protein degradation following resistance exercise (19). Several investigations have demonstrated that ingesting liquid carbohydrate (CHO) during prolonged endurance exercise maintains blood glucose (GLU) levels and attenuates the release of CORT (4, 14, 15). A study from our laboratory has examined the effect of CHO on CORT concentrations following resistance exercise. Koch et al. (8) fed resistance-trained individuals a CHO supplement immediately before and after an approximately 15-minute squat workout using 10 sets of 10 repetitions with 1-minute rest periods between sets. The CHO supplement did not attenuate a CORT response, because, we believe, blood GLU concentrations were not challenged. A study investigating both a longer and total body resistance exercise session is warranted. A reduced plasma CORT concentration following resistance exercise may lead to a more favorable anabolic environment, resulting in a decreased level of muscle protein degradation and an overall increase in protein synthesis. It was the purpose of this investigation to determine if ingesting liquid CHO before and following a resistance exercise session would attenuate a rise in CORT levels and thus lead to a more favorable anabolic environment. We hypothesized that liquid CHO ingestion would lead to a decreased CORT concentration, increased insulin (INS) concentration, and a decreased urinary nitrogen (NH^{+3}) excretion that would be indicative of a positive NH^{+3} balance. This postworkout scenario would thus create an environment for enhanced protein synthesis and skeletal muscle growth.

METHODS

Experimental Approach to the Problem

We compared the effects of liquid CHO supplementation vs. placebo (PLC) on plasma CORT, INS, ammonia (AMM), GLU, and NH^{+3} concentrations following high-intensity resistance exercise. Plasma GLU and INS levels were measured to determine the effect of supplementation on blood GLU availability and INS response. Plasma AMM and urinary NH^{+3} levels were measured as indicators of protein degradation. We therefore examined the targeted hormone CORT; the variables that we hypothe-

Table 1. Subject characteristics ($n = 9$).*

Characteristics	Mean \pm SD
Age (y)	24.2 \pm 2.7
Weight (kg)	86.8 \pm 14.4
Body fat (%)	16.3 \pm 2.9
Height (cm)	179.3 \pm 2.1
10RM bench press (kg)	84.3 \pm 13.2
10RM squat (kg)	109.2 \pm 20.5

* 10RM = 10 repetitions maximum.

sized would influence CORT, INS, GLU, and the effect of a change in CORT, protein degradation.

This study used a randomly assigned, double-blinded, crossover design to compare the effects of a liquid CHO supplement vs. a PLC. Subjects completed 2 resistance training sessions in which they consumed either CHO or PLC. This allowed for a comparison of the supplements in the same subject. In addition, neither the subject nor the investigator knew which supplement was being consumed at any time point. Other influential factors, including dietary intake and work output, were also controlled and maintained the same between sessions. Therefore, any changes that occurred with the measured blood variables are most likely a result of the composition of the administered supplements (CHO or PLC).

Subjects

Nine resistance-trained men participated in this investigation. The subjects' physical characteristics are listed in Table 1. The inclusionary criteria for the subjects were as follows: (a) currently performing total body resistance exercise at least 4 days per week for the 2 years before entering the study and (b) healthy and free of disease. None of the subjects had competed in powerlifting, weightlifting, or bodybuilding for 2 years previous to the study. The subjects provided written informed consent in accordance with guidelines established by the Advisory Committee on Human Experimentation at the University of Kansas.

Research Design

The subjects reported to the laboratory for testing on 3 occasions. On day 1, the subjects were tested for body composition via hydrostatic weighing. This was followed by the determination of each subject's 10 repetition maximum (10RM) for the 8 lifts used during the 2 exercise sessions. The second and third days were treatment days during which the subjects performed a high-intensity resistance exercise session. Subjects consumed either liquid CHO or PLC before and following the exercise session. Blood and urine samples were collected before and following the exercise session. Each treatment condition was performed at approximately the same time of day and was separated by 14 days.

Body Composition and 10RM Strength Testing

Subjects were weighed on an electronic scale (Toledo Scale, model 2084, Toledo Scale Co., Toledo, OH) in their bathing suits, with weight recorded to the nearest 0.1 kg. Eight trials of underwater weighing were performed, and the mean of the 3 heaviest trials was used to calculate body density. Residual lung volume was estimated. Body density and percentage of body fat were calculated using the Siri equation (23). The subjects' 10RMs for the exer-

Table 2. Timeline of test day procedures.

Time	Procedure
6:00 AM	Preexercise blood collection
6:10 AM	Drink consumption
6:20 AM	Begin workout
~7:00 AM	Postexercise blood collection
7:10 AM	Drink consumption
8:30 AM	1.5 hours postexercise blood collection
11:10 AM	4.0 hours postexercise blood collection

cises used in the treatment sessions were determined using previously described procedures (10).

Treatment Conditions

Table 2 presents a timeline of the test day procedures. Subjects reported for the treatment conditions in an 8-hour fasted state. Following a baseline blood sample collection, subjects ingested the first dose of the beverage. Ten minutes following beverage consumption, the subjects began the resistance exercise session. The 10-minute window between ingestion and exercise was chosen in an attempt to increase blood GLU levels while avoiding the possibility of reactive hypoglycemia.

The subjects performed the following exercises in this order: bench press, leg extension, shoulder press, leg curl, lateral pull-down, seated rows, biceps curls, and parallel squat. The training session began with 2 warm-up sets of 10 repetitions of back squats and bench press at 60% of the 10RM. This was followed by 3 sets of 10 repetitions of each exercise at 85–90% of the 10RM. One minute of rest was given between each set. If subjects were unable to complete the prescribed number of repetitions for a given set, the resistance was lowered by 2.5 kg for the following set. The subjects were expected to complete at least 8 repetitions on each set and were given assistance when needed. Exercise volume was calculated by multiplying the number of repetitions per set times the number of sets times the weight. The total time to complete the exercise session was between 40 and 50 minutes. Body position (e.g., grip width and joint angles) was held constant across both sessions. Kraemer et al. (9, 12) have demonstrated short-term increases in plasma CORT levels with similar resistance exercise protocols. The subjects second training session used the same sets, repetitions, and loads as the first session to ensure the same workload. Subjects consumed the second dose of their assigned treatment beverage 10 minutes after completion of exercise. Subjects were sequestered in the laboratory for 1.5 hours, after which the subjects were free to leave the laboratory. Subjects returned to the laboratory for blood sample collection at 4.0 hours of recovery. Subjects were not allowed to consume food or caloric beverages during the 4.0 hours of recovery.

Treatment Beverage Supplementation

On each testing session, the subjects consumed either a CHO supplement (Gatorlode, 20% maltodextrin and dextrose solution, Quaker Oats, Inc., Chicago, IL) or a PLC beverage (aspartame and citrus flavoring, Quaker Oats, Inc.). The treatment beverages consisted of a volume of fluid that provided 1.0 g·kg body mass⁻¹ of CHO or an equal volume of PLC. Two doses of the assigned treatment beverage were consumed each test day, the first at

Table 3. Blood glucose (GLU), ammonia (AMM), cortisol (CORT), and insulin (INS) before and following a resistance training session with carbohydrate (CHO) or placebo (PLC) supplementation ($n = 9$).

	Mean \pm SD			
	Before	Immediately after	1.5 hours after	4.0 hours after
GLU (mmol·L ⁻¹)				
CHO	6.2 \pm 0.5 ^{a*}	6.2 \pm 1.2 ^a	5.2 \pm 1.2 ^a	6.1 \pm 0.9 ^a
PLC	6.2 \pm 0.8 ^a	6.3 \pm 1.3 ^a	5.7 \pm 0.6 ^a	5.8 \pm 1.2 ^a
AMM (μ g·ml ⁻¹)				
CHO	1.3 \pm 0.7 ^a	4.1 \pm 2.6 ^b	1.6 \pm 0.7 ^a	1.7 \pm 0.9 ^a
PLC	1.4 \pm 0.6 ^a	5.4 \pm 2.7 ^b	1.0 \pm 0.8 ^a	2.1 \pm 1.6 ^a
CORT (μ g·dl ⁻¹)				
CHO	17.0 \pm 5.7 ^a	28.4 \pm 4.7 ^b	22.3 \pm 9.5 ^c	9.0 \pm 4.0 ^a
PLC	15.7 \pm 6.6 ^a	24.3 \pm 7.5 ^b	18.7 \pm 6.6 ^a	9.7 \pm 4.1 ^a
INS (IU·ml ⁻¹)				
CHO	8.3 \pm 4.7 ^a	10.5 \pm 2.7 ^{a**}	21.6 \pm 8.5 ^{b**}	6.7 \pm 3.8 ^a
PLC	5.6 \pm 2.5 ^a	3.8 \pm 2.6 ^b	4.7 \pm 1.2 ^b	3.6 \pm 1.4 ^a

* Significant within-group differences; same letter values are not significantly different ($p \leq 0.05$).

** Significant difference between groups ($p \leq 0.05$).

10 minutes before initiating exercise and the second 10 minutes following the postexercise blood draw.

Blood Collection and Analysis

Blood was collected from an antecubital vein before exercise (PRE), immediately after exercise (POST), and at 1.5 hours (1.5 hours POST) and 4.0 hours (4.0 hours POST) of recovery. For each of the 4 time points, 3 tubes of blood were collected. Blood for the determination of plasma INS and CORT levels was collected in a standard serum tube. One sodium heparin and 1 EDTA Vacutainer were used to collect samples for AMM and GLU, respectively. Plasma GLU was determined in duplicate using a commercially available kit (Sigma, St. Louis, MO; coefficient of variation [CV] = 6.51%). Plasma AMM was determined in duplicate using a commercially available kit (Sigma; CV = 5.40%). Serum CORT and INS levels were assayed using a competitive, solid-phase, I¹²⁵ radioimmunoassay technique (Diagnostic Products Corporation, Los Angeles, CA; CV = 2.38%).

Urine Collection and Analysis

Urine was collected by each subject for the 24 hours before and the 24 hours following each exercise session. All urine was collected in a specified sanitary container and delivered to the laboratory at the end of each 24-hour period (20, 22). The urine volume was recorded, and aliquots of 1 ml were extracted and stored at -70° C for later analysis of urinary NH⁺₃ concentration. Nitrogen was determined using colorimetric methods in commercially available kits (Kit 640, Sigma; CV = 1.81%).

Pretesting Dietary Control

Subjects recorded diets for 3 days before and 24 hours following each treatment session. The subjects were advised to eat similar diets so that both caloric intake and macronutrient composition were similar for both testing sessions. Diets were analyzed using commercially available software (Food Processor, v. 7.01, ESHA Research, Salem, OR). Macronutrient composition of the 2 dietary intakes were compared to ensure that subjects entered

both treatment conditions under similar dietary conditions.

Statistical Analyses

A 2-way (treatment by time) repeated-measures analysis of variance was used to determine significant differences between treatments for the major dependent variables of GLU, CORT, INS, and AMM. The post hoc analysis was conducted using a paired sample *t*-test if there were significant differences between treatments. A paired *t*-test was also used to determine differences for nutritional consumption and urinary NH⁺₃. The level of significance was set at $p \leq 0.05$.

RESULTS

The subjects' physical characteristics and 10RMs for the bench press and squat are listed in Table 1. The subjects were highly trained, as the average 10RMs for bench and squat were above the average body weight. No significant difference in total volume load was observed between the treatment conditions. The volume load lifted during both treatments equaled $34,986 \pm 4,295$ kg.

There were no significant differences in macronutrient consumption between treatments, indicating a consistent dietary intake. The average energy intake for the subjects was $2,850 \pm 243$ kJ·d⁻¹ before the CHO treatment and $2,935 \pm 198$ kJ·d⁻¹ before PLC. The macronutrient composition of the dietary intake was also similar between treatments (CHO: CHO = $1,453 \pm 61$ g·d⁻¹, fat = 912 ± 45 g·d⁻¹, protein = 484 ± 32 g·d⁻¹; PLC: CHO = $1,585 \pm 82$ g·d⁻¹, fat = 880 ± 38 g·d⁻¹, protein = 440 ± 24 g·d⁻¹).

The values for plasma GLU, AMM, CORT, and INS are listed in Table 3, with the values for urinary NH⁺₃ listed in Table 4. There was a significant difference between treatments for INS at POST (36% greater) and 1.5 hours POST (78% greater), with the values for CHO greater than PLC. Within the PLC treatment, significant within-group differences were found for CORT for PRE compared with POST (35% greater), for INS for PRE compared with POST (32% decrease) and PRE compared with

Table 4. Urinary nitrogen (NH^{+3}) 24 hours before and 24 hours following a resistance training session with carbohydrate (CHO) or placebo (PLC) supplementation.*

	Mean \pm SD	
	24 hours before exercise	24 hours after exercise
NH^{+3} (g/24 h)		
CHO	20.7 \pm 13.3	22.6 \pm 14.7
PLC	16.6 \pm 8.4	16.2 \pm 5.8

* No significant differences between or within groups ($p > 0.05$).

1.5 hours POST (16%), respectively, and for AMM PRE compared with POST (74% increase) and PRE compared with 1.5 hours POST (29% decrease), respectively. Within the CHO treatment, significant differences were found for CORT PRE compared with POST (40% increase), POST compared with 1.5 hours POST (21% decrease), and POST compared with 4 hours POST (68% decrease), respectively, for INS PRE compared with 1.5 hours POST (62% increase), and for AMM PRE compared with POST (68% increase). There were no significant differences between treatments for CORT, AMM, and GLU. There were no significant differences between the CHO and PLC treatments for urinary NH^{+3} .

DISCUSSION

The primary findings of this study were that CHO consumption before and after high-intensity resistance training elevated plasma INS concentrations both immediately after exercise and 1.5 hours after exercise but did not affect short-term plasma concentrations of CORT. In addition, our indirect measure of protein degradation was also not affected by CHO supplementation. Therefore, our hypothesis was proven untrue, since CHO consumption did not attenuate a rise in CORT concentrations or effect protein degradation following resistance exercise. However, the increase in plasma INS with CHO supplementation is a positive finding and theoretically improves the anabolic environment following resistance exercise.

Our hypothesis was based on previous endurance training studies in which GLU concentrations were elevated and a rise in postexercise CORT concentrations was attenuated as a result of CHO supplementation (4, 14, 15). Obviously, resistance exercise provides a different challenge than endurance training to the neuroendocrine system. Two previous studies have examined the influence of CHO supplementation on plasma CORT concentrations following similar resistance exercise protocols (10RM and short rest periods). Kraemer et al. (12) examined the hormonal response to 3 consecutive days of heavy resistance exercise with or without protein or CHO supplementation. Cortisol was increased in both groups following resistance exercise, with the supplementation group having a visually larger CORT response. Interestingly, on days 2 and 3 lower CORT concentrations and similar responses within both the supplementation and PLC groups were observed. It is difficult to make comparisons between the current study and that of Kraemer et al., since the subjects in their study (12) did not fast before supplementation and exercise, performed fewer sets of exercises, and were given 2-minute rests between sets.

Koch et al. (8) fed resistance-trained individuals a CHO supplement immediately before and after an approximately 15-minute long squat workout using 10 sets of 10 repetitions with 1-minute rest periods between sets. This study also showed no effect of CHO supplementation on CORT concentrations following resistance exercise. We had hypothesized that this workout was too short to adequately stress blood GLU levels. However, this study is in agreement with ours. It is clear that although CHO supplementation can attenuate a rise in CORT following endurance exercise, it has no effect following resistance exercise. Therefore, mechanisms that augment the release of CORT following the 2 types of exercise are apparently different.

Insulin has a significant impact on protein metabolism (5, 19). Previous in vivo human investigations have demonstrated that elevated INS levels stimulate an increase in skeletal amino acid uptake (2) and protein synthesis (1, 16) and decrease proteolytic activity associated with protein degradation (19, 22). There is currently a scientific debate about the amount of INS needed to promote protein synthesis particularly following resistance exercise (7). However, it has clearly been demonstrated that INS slows protein degradation (19, 22). Therefore, increasing INS levels following resistance exercise could deter a rapid flux of protein degradation and allow for a positive protein balance. Significant within-group decreases in plasma INS concentration from before exercise to immediately after exercise and 1.5 hours after exercise for the PLC group demonstrate a response similar to a previous investigation where INS concentrations decrease or are maintained following resistance training (20, 21). However, the CHO supplement in the present study resulted in an increase in plasma INS concentration for a period of at least 1.5 hours after exercise. These findings support earlier studies from Roy et al. (20, 21) and Chandler et al. (2), who found that a CHO supplement given immediately after and 1 hour after resistance training resulted in elevated plasma INS concentration above a comparable PLC supplement.

Ammonia concentration increases during exercise as a result of adenosine diphosphate and/or amino acid catabolism (24). The breakdown of amino acids provides an energy source for the contracting muscle to synthesize adenosine triphosphate while producing AMM. Although this process likely provides only a minor amount of energy, it may become more important with increasing exercise duration and/or CHO depletion (13, 25). For example, Snow et al. (24) demonstrated a decrease in muscle AMM production during prolonged endurance exercise with CHO supplementation. These investigations have used endurance exercise to study the effect of CHO supplementation on AMM concentrations. Little is known about the effects of CHO on AMM production during resistance exercise training. In the current investigation we were unable to demonstrate an effect of CHO supplementation on plasma AMM concentrations. This may be due to several factors. It is possible that the exercise duration or volume was not sufficient to cause a reduction in blood GLU and stimulate an increase in amino acid catabolism and a concomitant rise in muscle AMM production. Additionally, with the exercise intensity being identical between the 2 treatment conditions, it is possible that AMM production in the muscle was a result of adenosine mono-

phosphate catabolism, an action likely to be unaffected by CHO supplementation.

Surprisingly, supplementation with CHO did not result in a significant elevation in plasma GLU concentration. Koch et al. (8) used a similar CHO supplementation before and after an intensive 10 sets of 10-repetition squat workout with 1-minute rest periods. Their findings demonstrated a significant increase in post-resistance exercise plasma GLU concentrations when compared with rest. The subjects in that protocol endured approximately 15 total minutes of leg exercise, which did not provide as large a demand on plasma GLU as our approximately 45-minute total body session. So, although there was a preexercise supplementation of CHO, plasma GLU concentration most likely remained unchanged across treatments due to the extended length of time of the workout. In the current investigation, the greater INS concentration in response to the CHO drink is indicative of GLU consumption and absorption.

Previous investigations have found positive influences for CHO consumption following resistance exercise, including increasing the rate and amount of glycogen replenishment (21) and increasing plasma INS concentrations (2, 21). As stated earlier, INS plays an anabolic role in skeletal muscle tissue by possibly promoting protein synthesis and definitely deterring protein degradation (1, 16, 19, 22). In support of this, Roy et al. (22) found that supplementation with CHO immediately after completion of a resistance exercise session decreased myofibrillar protein breakdown and resulted in a more positive body protein balance. Additional support comes from Roy et al. (20), who found that CHO ingestion resulted in an increase in leucine flux and nonoxidative leucine disposal approximately 4 hours after completion of a resistance exercise training session. Although we did not observe a decrease in urinary NH_4^+ excretion, the possibility still exists that increased INS had a positive effect on protein synthesis. A more sensitive measure of protein degradation and a measure of protein synthesis may have revealed a difference between treatments. Additionally, we used resistance-trained subjects in this study. The subjects all produced 10RMs for bench press and squat that were above their individual body weights, thus indicating a high level of previous training. Previous work has demonstrated that trained individuals have a lower flux of protein degradation and synthesis immediately following resistance training compared with untrained individuals (18, 20). We did not make cellular measurements of protein metabolism, and our positive findings with INS can only be speculated to improve the anabolic environment.

PRACTICAL APPLICATIONS

The use of liquid CHO supplementation during exercise has traditionally been limited to endurance exercise but may also play a positive role with resistance exercise. In the current study, CHO supplementation has been shown to elevate INS concentration in the short term, which in turn may provide a favorable anabolic environment for protein metabolism following resistance exercise. The possibility of positive effects shown here in combination with other benefits, such as enhanced glycogen replenishment and recovery, provide evidence for the use of CHO supplementation before and after resistance exercise.

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