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The Effects of Carbohydrate Intake on Body Composition and Muscular Strength in Trained Men Undergoing a Progressive Resistance Training

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ABSTRACT

International Journal of Exercise Science 16(2): 267-280, 2023. This study's purpose was to compare the effects of different carbohydrate (CHO) intakes on body composition and muscular strength following eight weeks of resistance training (RT) in pre-conditioned men. In addition, we explored the individual responses to different CHO intakes. Twenty-nine young men volunteered to participate in this study. The participants were divided into two groups according to their relative CHO intake: lower (L-CHO; n = 14) and higher (H-CHO; n = 15). Participants performed a RT program four days a week for eight weeks. The lean soft tissue (LST) and fat mass were determined by dual-energy X-ray absorptiometry. Muscular strength was determined by a one-repetition maximum (1RM) test in the bench press, squat, and arm curl exercises. Both groups increased LST ($P < 0.05$) with no statistical differences between conditions (L-CHO = +0.8% vs. H-CHO = +3.5%). Neither group demonstrated changes in fat mass. Both groups increased 1RM ($P < 0.05$) in the bench press (L-CHO = +3.6% vs. H-CHO = +5.8%) and squat (L-CHO = +7.5% vs. H-CHO = +9.4%); however, only H-CHO significantly increased arm curl 1RM ($P < 0.05$) at post-training (L-CHO = +3.0% vs. H-CHO = +6.6%). Responsiveness was greater in H-CHO vs. L-CHO for LST and arm curl 1RM. In conclusion, lower and higher CHO intakes promote similar increase in LST and muscular strength; however, a greater intake may improve the responsiveness to gains in lean mass and arm curl strength in pre-conditioned men.

KEY WORDS: Strength training, nutrition, lean soft tissue, glucose

INTRODUCTION

It is well-established that resistance training (RT) increases muscular strength and muscle mass (37). The improvements are linked to manipulating the acute variables that make up the training session and the adequate intake of calories and macronutrients. Among these nutritional variables, carbohydrate (CHO) is believed to be an essential macronutrient for RT performance given the crucial role of glycolysis in resynthesizing the adenosine triphosphate pool during high-force muscular contractions (23, 26). For example, it has been shown that ingestion of CHO before RT increases total work (13, 14, 22). Moreover, glycogen content may impact muscle growth by mediating intracellular anabolic signaling (9, 11).

Acutely, a typical RT session may reduce muscle glycogen content by approximately 25–40% (5, 16, 35). This reduction may impair training session performance by limiting energy regeneration, leading to an inability to sustain elevated force production throughout the training session (25). For example, some studies have reported impaired performance and adaptations following a low-CHO diet (17, 25, 31, 43). Moreover, some studies report blunted gains in muscle mass when RT is combined with lower- versus higher-CHO diets (17, 18, 31, 43), suggesting that low-CHO diets are suboptimal for maximizing muscle growth. However, it should be noted that the low-CHO-diet groups in these studies were most likely in a caloric deficit, which conceivably impairs anabolic responses to RT (2). Therefore, it is difficult to determine whether the observed detrimental effects were caused by a low-CHO intake, an energy restriction, or a combination of both.

The reduction of glycogen stores is associated with decreased performance in resistance exercises because anaerobic glycolysis is the dominant energy system during typical resistance exercises lasting 15 to 120 seconds (20). Performing one set of 12 repetitions to failure (with a total time under tension of 34 to 40 seconds) elevates muscle lactate levels to 91 mmol/kg, and values increase to 118 mmol/kg after three sets (26), clearly showing the contribution of anaerobic glycolysis in resistance exercises performance. Given that, the CHO intake for RT practitioners should help to ensure the restoration of glycogen stores.

However, the specific CHO requirements for individuals seeking to optimize muscular adaptations are not well established. CHO guidelines for RT are scarce in the literature and do not make particular muscle hypertrophy recommendations for increases in lean mass (19, 40). The recommendations need to be more specific, and more precisely inform the needs of practitioners seeking muscular adaptations (e.g., increase in lean mass and strength). For example, the position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine (40) recommend a CHO intake of 3-5 g/kg/d for low-intensity or skill-based activities, 5-7 g/kg/d for moderate exercise programs (e.g., ~1h per day), 6-10 g/kg/d for endurance program lasting 1-3h, and 8-12 g/kg/d for extreme commitment activity (e.g., >4-5h/d). However, there is no specific recommendation for improvements in muscular strength and lean mass.

There is limited evidence based on usual intake of experienced lifters that suggests CHO intake in the range of 3–7 g/kg/d, optimizing RT performance (24, 38). However, these inferences are largely derived from observational investigation, limiting the ability to draw causality. Moreover, the recommended range of 3-7 is overly wide, making it difficult to decide precisely how much CHO needs to be ingested. Therefore, the effects of CHO intake on RT-induced muscular adaptations are unclear (11, 21).

The purpose of this study was to explore the effects of different amounts of CHO intake on body composition and muscular strength in men undergoing a standardized progressive RT program. We hypothesized that consuming a higher CHO diet would display more significant increases in muscular strength and lean mass than those consuming a reduced CHO diet. The premise for this hypothesis is based on the ability of CHO to affect energy metabolism during training and because CHO intake may affect intracellular signaling pathways that drive the anabolic response to RT.

METHODS

Participants

We estimated the sample size using G*Power (version 3.1.9.6). Previous data on the effects of resistance exercise on lean mass were used to estimate the sample size (29). Thus, we estimated the required sample based on an effect size F = 0.55, a significance level of 0.05, and a power of 0.80. The analysis indicated that at least 29 participants were needed to achieve adequate statistical power. Thirty men were recruited through social media and personal invitations from an ethnically homogeneous population in Brazil to participate in this study. Previously, all participants performed a pre-conditioning phase lasting 16 weeks, that consisted of three RT sessions per week, and performance three sets per exercise (8-12RM) of a whole-body RT routine (10-12 exercises). Participants were included in the study if they had no reported disease symptoms, no orthopedic injuries, were not vegetarian/vegan, were not using any nutritional supplements (i.e., protein and creatine powders), were not using anti-inflammatory medicine, and declared to be free from the use of anabolic steroids. Only one dropped out during the intervention due to personal reasons. Thus, a total of 29 men from a university-based population participated of this study. The participants were analyzed according to their relative CHO intake (g/kg/d) as follows: the lower CHO intake (L-CHO; n = 14) group had a CHO intake of ≤ 5.0 g/kg/d, and the higher CHO intake (H-CHO; n = 15) group consumed > 5.0 g/kg/d. All participants received a detailed description of the study procedures and signed a written informed consent form before participation. This investigation was approved by the local University Ethics Committee and conducted according to the Declaration of Helsinki. The investigation meets the guidelines set forth by the International Journal of Exercise Science (30).

Protocol

This was a retrospective analysis, in which a sample of young adult men who performed a regimented RT program were divided into two groups according to their habitual CHO intake for the purpose of comparing muscular adaptations between conditions. The study was carried out over 12 weeks, with pre- and post-testing conducted at weeks 1–2 and 11–12, respectively. Assessments consisted of anthropometric, body composition, and muscular strength measurements. During the first week of evaluation, anthropometric and muscular strength data were collected, and body composition measures were conducted during the second week of the assessment. The RT took place during weeks 3–10. Dietary intake was monitored in the first and last two weeks of the specific period (weeks 3 and 9-10, respectively). The same evaluators conducted all measurements without having access to the previous measurement data.

Body Composition: Whole-body dual-energy X-ray absorptiometry (DXA) exams were performed in a Lunar Prodigy device (GE Lunar, Madison, WI, USA) to assess lean soft tissue (LST) and fat mass (absolute and relative). Participants were instructed to remove all objects containing metal before the exam. Scans were performed with the participants lying in the supine position along the table's longitudinal centerline axis. Feet were taped together at the toes to immobilize the legs while the hands maintained a pronated position within the scanning region. Participants remained motionless during the entire scanning procedure. Both calibration and analysis were carried out by a skilled laboratory technician according to the manufacturer's recommendations. The software generated standard lines that set apart the limbs from the trunk and head. These lines were adjusted using specific anatomical points determined by the manufacturer. Analyses during the intervention were performed by the same technician blinded to group identity throughout the investigation. The intraclass coefficient correlation (ICC) and standard error of measurement (SEM) for LST were 0.99 and 0.38 kg, for fat mass were 0.99 and 0.10 kg, and for relative fat mass were 0.99 and 0.25%.

Muscular Strength: Maximal dynamic strength was evaluated using the 1RM test assessed on the bench press, squat, and arm curl exercises, performed in this exact order. Three attempts were performed in each exercise preceded by a warm-up set (6–10 repetitions), with approximately 50% of the estimated load used in the first attempt. This warm-up was also used to familiarize the participants with the testing equipment and lifting technique. The testing procedure was initiated 2 minutes after the warm-up. The participants were instructed to try to complete two repetitions with the imposed load in three attempts in both exercises. The rest period was 3 to 5 min between each attempt and 5 min between exercises. The 1RM was recorded as the last resistance lifted in which the participant was able to complete only one single maximal execution. The execution technique for each exercise was standardized and continuously monitored to ensure reliability. All 1RM testing sessions were supervised by two experienced researchers for greater participant safety and data integrity. Verbal encouragement was provided throughout each test. Three 1RM sessions separated by 48-72 h were performed to ensure an accurate score (intraclass correlation coefficient ≥ 0.96). The highest load achieved among the three sessions was used for analysis in each exercise. The ICC and SEM for bench press were 0.99 and 1.30 kg, for squat were 0.99 and 2.14 kg, and for arm curl were 0.99 and 0.60 kg.

Dietary Intake: A nutritionist instructed participants to complete food records on three nonconsecutive days (two weekdays and one weekend). Participants were counseled on how to record portion sizes and quantities to identify all food and fluid intake. Total dietary energy, protein, carbohydrate, and fat content were calculated using Avanutri software, version 3.1.4 (Avanutri Processor Nutrition, Rio de Janeiro, RJ, Brazil). All participants were asked to maintain their regular diet throughout the study period.

Resistance Training: The progressive RT program was performed four times per week, divided into two routines (A and B). Program A was conducted on Mondays and Thursdays and comprised exercises for the chest, shoulders, triceps, and abdominal muscles performed in the following order: (1) bench press, (2) inclined dumbbell fly, (3) cable cross over, (4) barbell military press, (5) lateral raise, (6) upright row, (7) lying triceps French press, (8) triceps pushdown, and (9) crunch. Program B was conducted on Tuesdays and Fridays, incorporating exercises for the back, biceps, forearm, thigh, and calves in the following order: (1) wide-grip lat pulldown, (2) seated cable row, (3) arm curl, (4) alternating dumbbell curl, (5) wrist curl, (6) squat on a smith machine, (8) leg extension, (9) leg curl, and (10) seated calf raise. Participants performed four sets for all exercises, with the load increasing (by 2–4 kg for upper body exercises and 3–6 kg for lower body exercises), and the number of repetitions simultaneously decreasing, for each set (pyramid system). Thus, the number of repetitions performed in each set was 12/10/8/6 of repetition maximum. The load progression was planned so that when the participant was able to perform two more repetitions in the last set for a given exercise on two consecutive sessions, the load for the next session was increased 2–5% for the exercises of the upper limb and 5–10% for the exercises of the lower limbs. Participants were instructed to perform each repetition with a concentric-to-eccentric phase ratio of 1:2, respectively. The rest period between sets lasted 1-2 min, with a 2–3 min rest interval provided between each exercise.

Statistical Analysis

Shapiro-Wilk's test verified data distribution. Levene's test checked the homogeneity of the variances. The independent t-test was used to compare the baseline characteristics and dietary intake between the groups. The comparison of lower and higher CHO effects on outcomes was made using an analysis of covariance (ANCOVA) of the raw difference between pre-training and post-training measures with the basal score, total energy, and the relative protein as covariates. The interpretation of the effect of time was made from the 95% CI of the mean difference pre- to post-training (i.e., when 95% CI of the change delta did not overlap the zero, there was a difference between the baseline score). The Cohen's d effect size (ES) statistic was calculated to provide insight into the magnitude of the changes. An ES of 0.00–0.19 was considered trivial, 0.20–0.49 was considered small, 0.50–0.79 was considered moderate, and ≥ 0.80 was considered as large. Responsiveness of the outcomes was calculated considering the responders as participants who achieved a change equal to, or greater than, the minimum difference to be considered real. This parameter was calculated using the equation:

$$\text{minimum difference} = \text{SEM} \times 1.96 \times \sqrt{2}.$$

A chi-square test was performed to compare the proportion of individuals (responders) with LST, fat mass, and 1RM changes similar to, or greater than, the minimum difference after training between lower and higher CHO conditions. In addition, we calculated the percentage change (Δ%) as post-training mean minus pre-training mean, divided by pre-training multiplied by 100. For all statistical analyses, significance was accepted at $P < 0.05$. The data were stored and analyzed using JASP software, version 0.11.1 (Department of Psychological Methods, University of Amsterdam, Amsterdam, NL). The data are presented as mean and standard deviations, mean differences, and 95% confidence intervals (95% CI).

RESULTS

Adherence to the program was satisfactory, with all participants completing > 85% of the total sessions. There were no statistical differences ($P > 0.05$) between groups for age (L-CHO = 22.9 ± 4.9 years vs. H-CHO = 22.4 ± 2.8 years), body mass (L-CHO = 73.5 ± 10.0 kg vs. H-CHO = 70.9 ± 10.3 kg), height (L-CHO = 175.4 ± 5.7 cm vs. H-CHO = 178.4 ± 7.3 cm), and body mass index mass (L-CHO = 23.8 ± 3.1 kg.m^{-2} vs. H-CHO = 22.1 ± 2.1 kg.m^{-2}). Total energy and macronutrient daily intake are shown in Table 1. As expected, the H-CHO group presented a greater absolute and relative CHO intake compared to the L-CHO group ($P < 0.05$). Moreover, the H-CHO groups also presented higher values for energy, protein, and lipids ingestion than the L-CHO group ($P < 0.05$).

Table 1. Energy and macronutrients intake at different moments according to groups.

	L-CHO (n = 14)	H-CHO (n = 15)	*P*-value
Energy			
kcal.day^{-1}	2104.6 ± 542.6	2965.9 ± 395.4	< 0.001
kcal.kg^{-1}.day^{-1}	28.50 ± 5.7	41.2 ± 3.2	< 0.001
Protein			
g.day^{-1}	94.2 ± 24.7	120.6 ± 17.6	< 0.001
g.kg^{-1}.day^{-1}	1.28 ± 0.32	1.68 ± 0.18	< 0.001
Energy (kcal)	376.7 ± 99.1	482.7 ± 70.4	< 0.001
Carbohydrate			
g.day^{-1}	281.2 ± 79.4	381.0 ± 51.1	< 0.001
g.kg^{-1}.day^{-1}	3.80 ± 0.81	5.29 ± 0.24	< 0.001
Energy (kcal)	1125.1 ± 317.7	1524.0 ± 204.4	< 0.001
Lipid			
g.day^{-1}	66.9 ± 18.7	106.5 ± 23.9	< 0.001
g.kg^{-1}.day^{-1}	0.91 ± 0.22	1.49 ± 0.32	< 0.001
Energy (kcal)	602.6 ± 168.4	959.1 ± 215.7	< 0.001

Note. Data are presented as mean and standard deviation. L-CHO = lower carbohydrate intake; H-CHO = higher carbohydrate intake.

Table 2 presents the covariate means, the adjusted post-training score, and the absolute changes of body composition and strength outcomes according to groups. Both groups displayed statistically significant differences in LST at post-training. For L-CHO, a trivial ES ($d = 0.08$) was found, with 21% (3/14) of the participants deemed responsive; for H-CHO, a small ES ($d = 0.34$) was found, with 80% (12/15) of the participants considered responsive. The chi-square test showed a greater number of responders in the H-CHO group for LST ($\chi^2 = 9.949$, $P = 0.002$). No significant changes in fat mass were observed in either group. For L-CHO, a trivial ES ($d = 0.00$) was found, with 36% (5/14) of the participants deemed responsive; for H-CHO, a trivial ES ($d = 0.04$) was found, with 27% (4/15) of the participants being responsive. There was no significant change for relative body fat in either group. L-CHO had a trivial ES ($d = 0.02$) with 29% (4/14) of the participants deemed responsive, whereas H-CHO had a trivial ES ($d = 0.03$) with 20% (7/15) of the participants deemed responsive. The chi-square test showed no significant differences between the proportion of individuals deemed responders in L-CHO or H-CHO for both absolute and relative fat mass changes ($\chi^2 \leq 0.291$, $P \geq 0.590$). Figure 1 presents pre- to post-training percentage changes in LST, absolute and relative fat mass.

Both groups displayed statistically significant changes in bench press 1RM at post-training. For L-CHO, a trivial ES ($d = 0.16$) was found, with 43% (6/14) of the participants deemed responsive, whereas, for H-CHO, a small ES ($d = 0.26$) was found with 73% (11/15) of the participants considered responsive. Both groups displayed significant changes in squat 1RM at post-training. For L-CHO, a small ES ($d = 0.48$) was found, with 43% (6/14) of the participants deemed responsive, while for H-CHO, a moderate ES ($d = 0.57$) was found, with 73% (11/15) of the participants considered responsive. The chi-square test showed no significant differences between the proportion of individuals deemed responders after L-CHO or H-CHO for both bench press and squat 1RM changes ($\chi2 \leq 2.773$, $P \geq 0.096$). For the arm curl 1RM, only the H-CHO group showed statistically significant differences at post-training. L-CHO had a trivial ES ($d = 0.16$), with 43% (6/14) of the participants deemed responsive, whereas H-CHO had a small ES ($d = 0.40$), with 87% (13/15) of the participants considered responsive. The chi-square test showed a greater number of responders in H-CHO compared to L-CHO for the arm curl ($\chi2 = 6.152$, $P = 0.013$). Figure 2 presents pre- to post-training percentage changes in the bench press, squat, and arm curl 1RM.

Table 2. Covariate mean, adjusted mean by ANCOVA to post-training, and absolute changes.

Variables	Adjusted Pre	L-CHO (n = 14)		H-CHO (n = 15)	
		Post mean (95% CI)	Δ (95% CI)	Post mean (95% CI)	Δ (95% CI)
Lean soft tissue (kg)	60.5	61.9 (60.7–63.0)	1.39 (0.07–2.71)	61.9 (60.8–62.9)	1.37 (0.12–2.63)
Fat mass (kg)	9.3	9.2 (8.2–10.3)	-0.08 (-1.32–1.14)	9.8 (8.8–10.8)	0.45 (-0.72–1.62)
Relative fat mass (%)	12.3	12.2 (10.9–13.5)	-0.07 (-1.57–1.43)	12.6 (11.4–13.9)	0.35 (-1.07–1.78)
Bench press 1RM (kg)	82.4	85.6 (83.2–88.0)	3.17 (0.42–5.91)	87.1 (84.8–89.3)	4.64 (2.03–7.24)
Squat 1RM (kg)	138.3	147.5 (143.2–151.8)	9.23 (4.19–14.2)	152.5 (148.3–156.6)	14.1 (9.41–18.9)
Arm curl 1RM (kg)	46.4	48.0 (46.1–49.9)	1.62 (-0.61–3.85)	49.0 (47.2–50.9)	2.62 (0.50–4.73)

Note. 1RM, one-repetition maximum, ANCOVA analysis used the basal score, the total energy, and the relative protein as covariates. L-CHO = lower carbohydrate intake; H-CHO = higher carbohydrate intake.

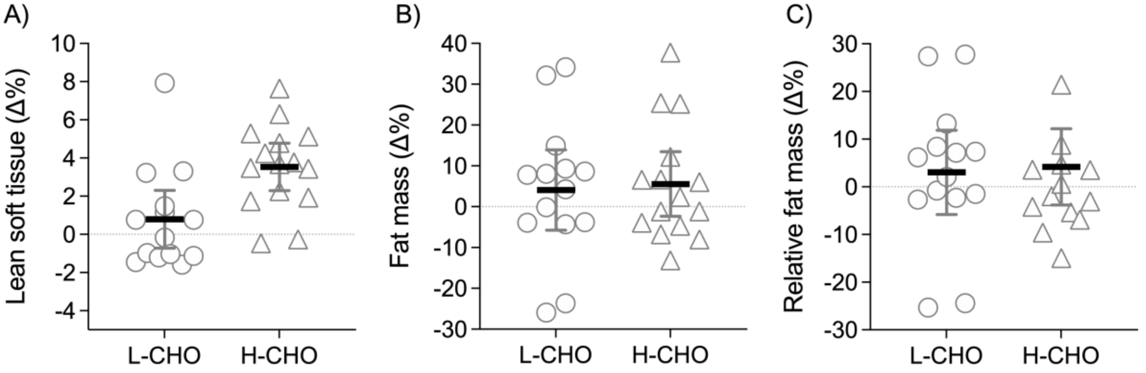

Figure 1. Relative changes from pre- to post-training according to groups for lean soft tissue (Panel A), fat mass (Panel B), and relative fat mass (Panel C). Data are presented as mean and 95% confidence interval. L-CHO = lower carbohydrate intake; H-CHO = higher carbohydrate intake.

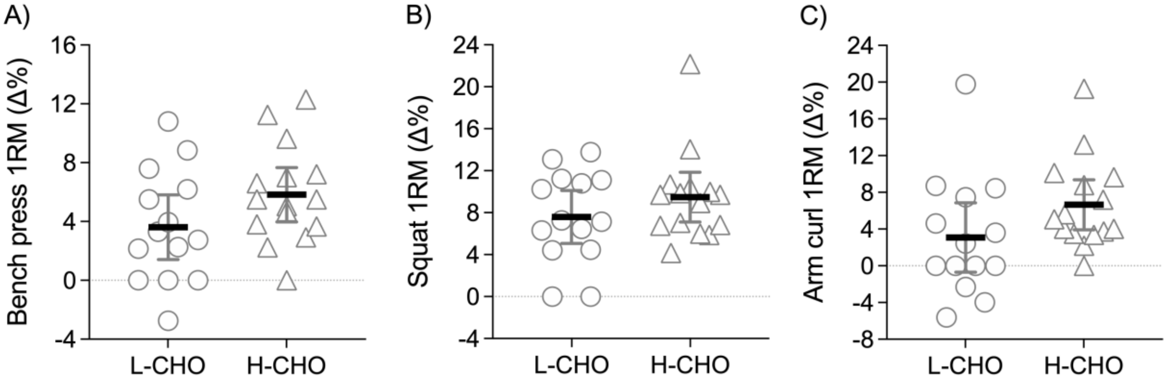

Figure 2. Relative changes from pre- to post-training according to groups for muscular strength in bench press (Panel A), squat (Panel B), and arm curl (Panel C). Data are presented as mean and 95% confidence interval. L-CHO = lower carbohydrate intake; H-CHO = higher carbohydrate intake

DISCUSSION

The primary purpose of this study was to explore the effects of different amounts of CHO intake in combination with RT on body composition and muscular strength in resistance-trained men. We hypothesized that a higher CHO consumption would result in greater muscular strength and LST gains. We based this hypothesis on the supposition that CHO is an essential substrate for resistance exercise performance and on evidence that CHO modulates acute intracellular signaling pathways that may impact chronic muscular adaptations (11, 41). The main finding of our experiment was that CHO intake did not impair the muscular adaptations induced by RT in pre-conditioned men. However, higher consumption of CHO increased responsiveness to LST gain and arm curl strength. Thus, our initial hypothesis was partially confirmed.

The lack of statistical difference between conditions for LST gains observed in our experiment may be related to several factors. For one, the amount of CHO ingested by the L-CHO group may have already reached a minimum threshold for daily CHO intake needs. Therefore, the additional CHO consumed by the H-CHO group may have been redundant and hence non-additive to muscular gains. Some experiments have shown that a diet with higher consumption of CHO does not reflect a better acute performance in RT (10, 28, 32, 36, 42). For example, Van Zant et al. (42) reported that three weeks of a moderate CHO diet (42%) resulted in no difference in muscular strength or endurance as measured by isokinetic knee extension and flexion, bench press 1RM, and repetitions to failure at 80% when compared with a higher CHO diet (62%). Additionally, Hatfield et al. (15) investigated the effect of 4 days of CHO-loading on RT performance in eight recreationally resistance-trained men who consumed 50 or 80% CHO. Results did not show a difference in peak power, mean power, and repetitive jump performance at 30%. Also, Dipla et al. (10) investigated ten recreationally active women who consumed a control diet consisting of 55% of CHO or 30% of CHO for one week, and no differences were found between interventions in isometric handgrip strength, handgrip endurance, and peak torque of knee extension and knee flexion.

Studies have demonstrated that an acute bout of RT can reduce muscle glycogen content by approximately 25–40% when employing training volumes of 6 to 12 sets for a given muscle group (5, 16, 35). Therefore, a CHO-restricted diet may not be sufficient to decrease muscle glycogen stores to the extent that substantially impairs force capacity. Furthermore, glycogen replenishment may occur even in an unfed state (33, 35). Robergs et al. (35) measured the muscle glycogen levels of eight resistance-trained males before, immediately after, and two hours following six sets of 6 repetitions of leg extension at 70% 1RM. Participants were not fed during the two hours post-exercise period. Immediately post-exercise, glycogen concentrations were 61% of pre-exercise values, whereas, after two hours post-exercise, muscle glycogen concentrations were 79% of pre-exercise levels, conceivably aided by lactate recycling. Hence, glycogen content may not be a limiting factor for RT performance, at least within a certain minimum threshold. Furthermore, anabolic intracellular signaling does not appear to be blunted by a low-CHO diet (6-9).

In contrast to our results, previous investigations have reported superior benefits of a high-CHO diet compared to a low-CHO diet for changes in lean mass or measures of muscle hypertrophy. Ribeiro et al. (34) compared the effects of different amounts of energy intake with CHO surplus in eleven male bodybuilders. The results revealed that the group that ingested 12.9 g/kg/d of CHO achieved a greater increase in muscle mass than the group that ingested 8.0 g/kg/d (2.7% vs. 1.1%, respectively). In a study conducted by Vargas et al. 2018 (43), 24 resistance-trained men performed an 8-week RT program while consuming either a ketogenic diet (42 g/d) or a nonketogenic diet (~55% of total calories from CHO). Results showed that only the nonketogenic group increased LST. Similarly, Meirelles and Gomes (27) found that overweight individuals in a hypoenergetic state achieved superior quadriceps hypertrophy when consuming a moderately high carbohydrate versus a ketogenic diet (4.0% vs. −2.1%, respectively), although changes in upper-arm mass were similar between conditions. Moreover, Jabekk et al. (17) showed that a ketogenic diet combined with RT did not increase lean mass after 10 weeks, whereas a control group following their usual diet achieved an increase of 1.6 kg in lean mass. Recently, Paoli et al. (31) investigated the effects of a ketogenic diet compared to a Western diet on body composition changes in competitive natural bodybuilders. All participants were given pre-programmed, calorie-equated diets to follow with a relatively high protein intake (2.5 g/kg/d) over an 8-week study period. The results showed that fat-free mass increased only in the Western diet group. The discrepancies among studies are not readily apparent, but they may be related to the amount of CHO utilized and the different RT protocols applied in studies. Low muscle glycogen levels can be particularly problematic during higher-volume routines because of the associated reduction in resistance exercise performance (38, 45).

Another potential issue when comparing groups with different CHO intakes is that it creates an imbalance between groups regarding other macronutrients or calories. Thus, interventional results may not be due to manipulating the CHO per se but rather other confounding variables. Given this possibility, we employed a statistical procedure that accounted for differences in macronutrients and calorie intake. Despite the absence of statistical differences between conditions, the ES analysis favored the H-CHO group, albeit of a relatively small magnitude.

Due to the large inter-individual variability observed in exercise and nutritional trials, analysis of each participants' responsiveness is relevant to help draw evidence-based inferences. Our findings indicate that the H-CHO group displayed a more homogeneous LST response compared to the L-CHO diet. It is possible that individuals adapted differently to the L-CHO diet so that some participants were better able to sustain muscular performance with a reduced CHO intake while others showed performance decrements. From a practical standpoint, this would suggest that macronutrient needs should consider inter-individual variability, and ingesting a greater amount of CHO may increase the likelihood of responsiveness to RT. On the other hand, consuming less CHO may reduce the probability of higher responsiveness.

Despite some investigations showing a benefit of low-CHO diets in reducing fat mass (17, 31, 32, 43), our results indicated no effect for either condition in this body composition component. Given the well-established theory that energy balance dictates changes in body mass (39), it is possible to believe that the participants in both groups were not in a caloric deficit. A recent meta-analysis (3) evaluated the effects of RT combined with a ketogenic diet on body composition and observed beneficial effects of ketogenic compared to non-ketogenic diets on fat mass reduction in individuals performing RT. It is worth mentioning that in our experiment, the participants in the low CHO group did not follow a ketogenic diet. An important aspect to point out is the interindividual variability observed for changes in fat mass within groups; that is, 36% (5/14) of the participants were deemed responsive in the L-CHO, and 27% (4/15) were considered responsive in the H-CHO condition. These findings suggest that some participants were in a caloric deficit while others were not. This variability in body fat changes in response to different nutritional strategies has been reported previously (1, 4). Further investigations are needed to elucidate the underlying explanatory mechanisms for this phenomenon.

Regarding dynamic strength, our results indicate that CHO intake does not affect increases in the bench press and squat 1RM. Previous investigations also observed no effects of varying amounts of CHO consumption on chronic RT strength-related adaptations. Paoli et al. (31) observed that maximal strength increased similarly in bodybuilders ingesting a ketogenic diet or a western diet for two months. Greene et al. (12) found that a 3-month ketogenic diet did not impair strength-related performance in competitive powerlifters and weightlifters compared to a higher-CHO diet, despite an associated reduction in lean mass with the decreased CHO-intake. Paoli et al. (32) reported that performance of squat jumps, countermovement jumps, consecutive countermovement jumps, push-ups, reverse grip chin-ups, and parallel bar dips were maintained following 30 days of a low-CHO ketogenic diet in a cohort of elite gymnasts. Meirelles and Gomes (27) found no difference between groups for 10RM strength improvements when consuming a CHO restricted diet or a moderate CHO diet. Recently, Vidic et al. (44) found similar increases in muscle strength between a ketogenic diet versus a non-ketogenic diet following an 8-week RT program. Alternatively, Kephart et al. (18) reported that a cohort of CrossFit trainees who followed their regular dietary regimen achieved an approximately 5 kg increase in 1RM squat strength. In contrast, those following a ketogenic diet did not increase strength after 12 weeks. However, the ketogenic group seemingly was in an energy deficit while the control group appeared to be at caloric maintenance.

Importantly, a significant change was observed in elbow flexors strength, where only the high-CHO group showed a significant change from pre- to post-training. However, despite the probabilistic statistic showing a significant effect, it is important to note that the lower limit of 95% CI (0.50) did not exceed the SEM of this assessment (0.60). Therefore, this should be considered a preliminary finding that requires replication.

This study presents some limitations that must be considered when attempting to draw practical inferences. We did not assess the participants' physical activity levels outside of the RT intervention. Thus, we cannot rule out whether there may have been differences in energy expenditure between groups. Moreover, although participants were instructed to maintain their usual eating habits, food intake was not monitored during the study. Therefore, we cannot rule out the possibility that participants misreported their actual food intake. Also, our study did not impose an isoenergetic diet, and groups were not matched for protein intake. We attempted to account for potential confounding in this regard using ANCOVA. In addition, we stratified "higher" and "lower" carbohydrate intakes using a binary cut-point of 5.0 g/kg/d; however, this reflects group means and does not take into account individual variations in CHO consumption within the two groups. Finally, groups were not randomized, which may have compromised internal validity.

Conclusion: Our results suggest that a lower CHO intake does not negatively influence LST changes, bench press, and squat 1RM strength in pre-conditioned men after eight weeks of regimented RT. However, individual analyses suggest that a CHO intake of > 5.0 $g.kg^{-1}.d^{-1}$ seems to increase the responsiveness for gains in LST and arm curl strength.

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