

Short Communication

An isoenergetic high-protein, moderate-fat diet does not compromise strength and fatigue during resistance exercise in women

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Resistance exercise is recommended to individuals following high-protein diets in order to augment changes in body composition. However, alterations in macronutrient composition may compromise physical performance. The present study investigated the effects of an isoenergetic high-protein diet on upper and lower limb strength and fatigue during high-intensity resistance exercise. Ten recreationally active women, aged 25–40 years, followed a control diet (55, 15 and 30% of energy from carbohydrate, protein and fat, respectively) and a high-protein diet (respective values, 30, 40 and 30) for 7 d each in a random counterbalanced design. Each participant underwent strength testing of upper limb (isometric handgrip strength and endurance) and lower limb (four sets of sixteen maximal knee flexions and extensions on an isokinetic dynamometer) before and after applying each diet. Body weight, body fat and RER were significantly reduced following the high-protein diet ($P < 0.05$). No differences were found between diets in any of the strength performance parameters (handgrip strength, handgrip endurance, peak torque, total work and fatigue) or the responses of heart rate, systolic and diastolic arterial pressure, blood lactate and blood glucose to exercise. Women on a short-term isoenergetic high-protein, moderate-fat diet maintained muscular strength and endurance of upper and lower limbs during high-intensity resistance exercise without experiencing fatigue earlier compared with a control diet.

High-protein diet: Fatigue: Resistance exercise: Handgrip: Women

A considerable percentage of the population has reported using a low-carbohydrate, high-protein diet for weight loss and/or maintenance⁽¹⁾. Although low-carbohydrate ketogenic diets have produced favourable effects on body weight, they have raised concerns on health issues, since these diets are accompanied by increased fat and protein intake. Another criticism of these dietary plans was that they did not recommend physical activity as an integral part of weight loss⁽¹⁾.

Recently proposed high-protein diets advocate the consumption of lean protein sources and allow unrefined carbohydrates from fruits and vegetables. Such high-protein (35–45% of energy), low-carbohydrate (20–35%) and moderate-fat (<30%) diets (high-protein diets) have attracted much attention and are frequently recommended for weight loss and maintenance to individuals with obesity or diabetes^(2,3). There is evidence that high-protein diets induce a number of favourable changes along with weight loss (reduction in body fat,

improvement in lipidaemic and glycaemic profiles and resting blood pressure)^(2,4). The addition of exercise (aerobic and/or resistance) to a high-protein diet had additive effects on body composition during weight loss⁽⁵⁾.

Despite the popularity of high-protein diets, few studies have investigated their effects on exercise performance^(6,7). These studies reported that a 7 d high-protein diet decreased endurance (aerobic) performance of recreational and trained athletes. Muscle glycogen is the major energy source during high-intensity resistance exercise, and glycogen depletion is observed earlier in fast-twitch than slow-twitch fibres⁽⁸⁾. Thus, the lower carbohydrate content of a high-protein diet may result in reduced pre-exercise muscle glycogen levels and precipitate fatigue during resistance exercise.

Although resistance exercise is recommended to individuals on high-protein diets for additional positive effects on body composition⁽⁵⁾, the effects of a high-protein diet on strength

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parameters have not been investigated. It is of interest to examine whether high-protein diets lead to an earlier appearance of fatigue during resistance exercise compared with conventional diets and whether individuals on high-protein diets should modify the intensity or volume of their resistance exercise programmes. The purpose of the present study was to investigate the effects of a high-protein diet on strength and fatigue parameters of the upper and lower limbs during high-intensity resistance exercise in women.

Experimental methods

Subjects

Ten healthy women (age 25–40 years) with stable body weight over the past 6 months participated in the study. All volunteers engaged in low- to medium-intensity recreational physical activities one or two times per week. The institutional review board approved the experimental protocol, which was in accordance with the Helsinki Declaration of 1975, revised in 1983, and participants provided written consent. Individuals previously consuming high-protein diets were excluded.

Study design

On the basis of a 4 d dietary log (including one weekend day) completed by each participant, two isoenergetic weekly dietary plans were constructed: a control diet, as recommended by WHO⁽⁹⁾ (55 % carbohydrate, 15 % protein and 30 % fat by energy) and a high-protein diet (30, 40 and 30 %, respectively). Each participant followed the two diets at random order during the second week of two consecutive menstrual cycles and completed four exercise testing sessions, one at the beginning and one at the end of each diet. During each exercise session the participants underwent resistance exercise testing of upper (handgrip strength and fatigue) and lower (peak torque, work and fatigue) limbs. Body weight, fat and water, O₂ uptake (VO₂), RER, and systolic and diastolic arterial pressure were measured. During the 3 weeks between the experimental diets the participants followed their habitual diets.

Procedure

On the morning of the exercise session each participant reported to the testing facility after an overnight fast. The participant was weighed on a scale (Seca, Hamburg, Germany) in her underwear and remained supine for 45 min for the determination of body fat and water by bioelectrical impedance (Bodystat 1500; Bodystat Ltd, Onchan, Isle of Man, UK), resting systolic arterial pressure and diastolic arterial pressure (OSZ5; Welch Allyn, New York, NY, USA), VO₂ and RER (VO2000; Med-Graphics, St Paul, MN, USA). Blood samples were obtained from a fingertip for lactate (Lactate Pro; Akray, Kyoto, Japan) and glucose (Medisense; Abbott, Chicago, IL, USA) determinations (CV 3.0 and 3.5 %, respectively).

Upper limb strength and fatigue were assessed using a hydraulic dynamometer (5030J; Sammons Preston, Chicago, IL, USA). The participant performed three maximal handgrip trials with a 60 s interval (elbow at 90°; highest reading was taken as maximum voluntary contraction). After 5 min she was instructed to hold at 80 % maximal voluntary contraction

for as long as possible. Testing was terminated when a ≥ 10 % reduction persisted for ≥ 5 s. The times at 80 % maximal voluntary contraction and heart rate (Polar Electro S610; Polar Electro Oy, Kempele, Finland) were recorded.

Lower limb strength and fatigue were assessed on a Cybex-Norm dynamometer (Lumex, Ronkonkoma, NY, USA). Peak torque of knee flexors and extensors was determined by three maximal efforts. After a 5 min rest, participants performed the fatigue protocol⁽¹⁰⁾, four sets of sixteen maximal extension–flexion cycles at 120° per s with 60 s intervals. Peak torque and work produced in each set were recorded; total work was calculated as the sum of work produced at the four sets. Fatigue was assessed as the percentage reduction in work produced in the last set relative to the first. Heart rate and rate of perceived exertion (6–20 Borg scale) were recorded at the end of each set. Four min after the completion of exercise, blood samples for lactate and glucose were obtained.

Following exercise testing each volunteer received counselling and was supplied with a specific weekly dietary plan (high-protein or control) that included specific brands, food items, and quantities, a scale for weighing foods, and detailed instructions on measuring and recording food quantities. Since the participants followed the diets under free-living conditions, they were asked to keep a dietary log during the diet (recording every item and quantity eaten next to the prescribed item). They were contacted daily (once or twice) by phone for dietary counselling and to ensure compliance. At the end of the week they returned the dietary log and were subjected to the same testing procedures as at the beginning. The entire testing and dietary intervention was repeated 3 weeks later with the alternative diet. Food records were analysed on the basis of published data⁽¹¹⁾.

Statistics

Statistical analysis was performed using Statistica 5.0 (Statsoft, Tulsa, OK, USA). One-way, two-way (diet \times time of diet) and three-way (diet \times time of diet \times time of exercise) ANOVA with repeated measures were used. Significant interactions were followed by Tukey's test ($\alpha = 0.05$).

Results

The actual daily energy intake consumed and percentages of energy from carbohydrate, protein and fat were, respectively, 5520 (SE 192) kJ, 48.7 (SE 0.8), 15.2 (SE 0.1) and 36.1 (SE 0.8) % in the habitual diet, 5503 (SE 242) kJ, 54.5 (SE 0.3), 16.1 (SE 0.4) and 29.3 (SE 0.5) % in the control diet and 5460 (SE 294) kJ, 30.2 (SE 0.5), 40.1 (SE 0.4) and 29.7 (SE 0.3) % in the high-protein diet. Energy did not differ significantly among diets.

Data on the physiological, metabolic and strength parameters are presented in Table 1. ANOVA indicated a significant interaction of 'diet' and 'time of diet' for body weight ($P=0.005$), body fat ($P=0.025$) and RER ($P=0.021$). All three parameters were significantly reduced in high-protein-post compared with high-protein-pre and/or control-post ($P<0.035$). Body water, VO₂ and systolic arterial pressure were not significantly affected by diet ($P=0.182$ – 0.240). A significant interaction of 'diet' and 'time of diet' was observed in diastolic arterial pressure ($P=0.008$). However,

Table 1. Effects of diet on physiological, metabolic and strength parameters (Mean values with their standard errors for ten subjects)

Variable	Control-pre		Control-post		HP-pre		HP-post	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Body weight (kg)	55.9*	2.5	56.2*	2.6	55.8*	2.6	55.2	2.6
Body fat (%)	23.1	1.6	23.0	1.5	23.9*	1.4	22.7	1.5
Body water (%)	56.0	1.2	56.4	1.3	55.6	1.3	56.5	1.4
Resting VO ₂ (ml/kg per min)	3.79	0.11	3.60	0.12	3.69	0.13	3.84	0.24
Resting RER	0.83	0.01	0.85*	0.01	0.84	0.01	0.79	0.02
Resting SAP (mmHg)	105	2	104	3	106	3	102	3
Resting DAP (mmHg)	63	2	65	2	65	2	62	3
Upper limb								
MVC (kg)	32.7	1.3	33.5	1.0	33.6	1.3	32.5	1.3
Time at 80 % MVC (s)	20.8	2.3	19.8	1.6	21.2	2.5	22.2	2.8
Lower limb								
Peak torque flexors (J)	58.9	3.0	61.3	2.6	59.5	3.3	61.7	3.2
Total work flexors (J)	4266	197	4354	182	4259	231	4098	226
Fatigue flexors (%)	15.1	4.0	18.8	2.4	15.5	2.8	16.7	2.1
Peak torque extensors (J)	91.5	6.2	91.7	6.7	92.3	7.2	91.2	6.6
Total work extensors (J)	5550	352	5663	347	5631	397	5691	351
Fatigue extensors (%)	33.4	2.5	33.1	2.1	32.1	1.9	31.6	1.4
Blood lactate (mmol/l)								
Rest	0.99	0.04	1.00	0.03	1.04	0.04	0.96	0.04
Exercise	7.17	0.54	7.18	0.68	7.57	0.59	6.87	0.47
Blood glucose (mmol/l)								
Rest	4.85	0.12	4.79	0.11	4.88	0.10	4.91	0.10
Exercise	5.18	0.14	5.23	0.21	5.38	0.17	5.13	0.15

HP, high-protein; SAP, systolic arterial pressure; DAP, diastolic arterial pressure; MVC, maximal voluntary contraction.
* Mean value is significantly different from that of the HP-post condition ($P < 0.05$).

the decrease in high-protein-post was not significant compared with high-protein-pre ($P = 0.051$) and control-post ($P = 0.087$).

Handgrip maximal strength and fatigue (time at 80 % maximal voluntary contraction), peak torque, total work and fatigue produced by knee muscles were not affected by diet ($P = 0.192$ – 0.933). Work produced by flexors and extensors decreased significantly ($P < 0.001$) from sets 1 to 4 in all four exercise sessions by following similar patterns.

Heart rate in the four exercise sets ranged 160–174 beats per min with no dietary effect ($P = 0.619$). Rate of perceived exertion increased significantly from set to set ($P < 0.001$) reaching 'very hard' on the Borg scale at the end of the exercise protocol, with no dietary effect ($P = 0.833$). Blood lactate and glucose increased with exercise ($P < 0.001$), with no dietary effects ($P = 0.101$ and $P = 0.152$, respectively).

Discussion

The main finding of the present investigation is that women following an isoenergetic high-protein, moderate-fat diet maintained maximal strength and endurance of upper and lower limbs during resistance exercise, although physiological and metabolic changes (body weight, resting RER) were observed. Furthermore, the high-protein diet did not affect the rating of perceived exertion during resistance exercise.

Previous studies that investigated the effects of changes in macronutrient composition on performance have focused mainly on a reduction in carbohydrate intake accommodated by an increase in fat intake⁽¹²⁾. They reported that 2–7 d on low-carbohydrate diets (3–10 % of energy intake) resulted in reduced muscle glycogen, diminished power output and earlier onset of fatigue during running or cycling⁽¹²⁾. The few studies

that examined the effects of alterations in macronutrient composition on strength performance have focused on high (70–80 % of energy) v. moderate carbohydrate intake^(13,14). In these studies the lower carbohydrate intake was compensated for by higher fat intake, while protein intake was maintained.

The need to implement studies on high-protein diets and physical activity has been stressed recently⁽¹⁵⁾. The effects of a 7 d high-protein diet on endurance performance have been investigated by Jarvis *et al.*⁽⁶⁾ and Macdermid & Stannard⁽⁷⁾, who reported ergolytic effects on cycling endurance performance in recreational and highly trained athletes, respectively. A comparison of these studies with ours is obscured by the different modes of exercise (endurance v. resistance) and characteristics of participants (trained males v. recreationally active females). Furthermore, the negative effects of the high-protein diets on endurance performance were observed when participants exercised to exhaustion. However, recreationally active individuals do not typically perform resistance training to muscular exhaustion. This investigation employed a resistance exercise protocol that resulted in levels of muscular fatigue close to the ones observed during resistance exercise prescribed in health and fitness centres.

Possible contributors to fatigue during high-intensity exercise after consuming a low-carbohydrate diet are low muscle glycogen, metabolic acidosis through ketosis and ionic disturbances across cell membranes⁽¹²⁾. The role of these factors in exercise performance when following a high-protein diet warrants further investigation. However, on the basis of our findings, it appears that the amount of carbohydrate in the high-protein diet did not compromise muscle glycogen to the degree of causing an early onset of fatigue during resistance exercise.

Although both experimental diets were isoenergetic, the high-protein diet resulted in reductions of body weight (by 0.6 kg) and body fat (by 1.2 percentage units), although the latter should be interpreted with caution due to the limited ability of bioelectrical impedance to detect small changes. A greater reduction in body weight and body fat through a hypoenergetic high-protein diet *v.* control diet has been previously reported and attributed to factors such as greater energy expenditure, reduction in body water, differences in the calculation of metabolisable energy, and protein-related satiety^(3,4,15–19). It appears that none of the factors alone explain the decrease in body weight and fat after the high-protein diet.

In accordance with previous findings⁽⁷⁾, resting RER decreased in the high-protein diet, indicating a shift toward fat oxidation. The slight (NS) decrease in resting diastolic arterial pressure after the high-protein diet is similar to that reported previously⁽⁷⁾.

In conclusion, women consuming an isoenergetic high-protein, moderate-fat diet, which resulted in body-weight reduction over a period of 1 week, maintained maximal strength and work capacity during resistance exercise without experiencing fatigue earlier compared with a control diet. Future studies should focus on long-term effects of high-protein diets on resistance exercise performance in healthy and pathological populations.

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