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ORIGINAL CONTRIBUTION

Comparison of the effects of weight loss from a high-protein versus standard-protein energy-restricted diet on strength and aerobic capacity in overweight and obese men

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Abstract
Purpose To compare the effects of two low-fat, hypo-energetic diets differing in carbohydrate-to-protein ratio, on strength and aerobic capacity measures in overweight and obese men.
Methods In a parallel design, 56 men (age, 45.5 ± 8.7 years; BMI, 33.6 ± 3.9 kg/m^2) were randomly assigned to a low-fat, energy-restricted diet (7,000 kJ/day) with either high protein (HP: protein/carbohydrate/fat % energy, 35:40:25) or standard protein (SP, 17:58:25). Body weight, body composition, muscle strength and aerobic capacity were assessed at baseline and after 12 weeks.
Results Forty-two participants completed the study (HP, $n = 21$; SP, $n = 21$). Both groups experienced similar reductions in body weight (HP, −10.7 ± 5.3 kg [−9.8%]; SP, −8.7 ± 3.5 kg [−8.4%]) and fat-free mass (HP, −2.8 ± 3.6 kg; SP, −3.2 ± 2.7 kg; $P < 0.001$ time; $P > 0.14$ time × group interaction). There was a trend for a greater reduction in fat mass in the HP diet group, (−7.7 ± 4.3 kg [−21.2%] vs. −5.4 ± 3.3 kg [−15.1%]; $P < 0.001$ time; $P = 0.06$ time × group interaction). Absolute peak oxygen uptake did not change in either group ($P = 0.39$ time; $P = 0.50$ time × group interaction). Overall, in both groups, relative peak oxygen uptake increased (2.9 ± 2.8 ml kg^{-1} min^{-1} [8.9%]), peak isometric knee extensor strength increased (14.1 ± 35.7 Nm [7.1%]) and peak handgrip strength decreased (−1.6 ± 4.1 kg [−3%]) ($P \leq 0.02$ time for all), with no diet effect ($P \leq 0.23$ time × group interaction).
Conclusion In overweight and obese men, both a HP and SP diet reduced body weight and improved body composition with similar effects on strength and aerobic capacity.

Keywords Diet composition · Exercise capacity · Weight loss · Physical function · Nutrition

Introduction

In response to the obesity epidemic, there has been marked rise in the prevalence and use of higher-protein diets [36]. Emerging evidence suggests that during energy restriction, a low-fat diet (<30% fat), higher in protein and lower in carbohydrate (HP), compared to a conventional standard-protein, higher-carbohydrate, low-fat diet (SP), may be more favourable for weight loss [28, 35], body composition (increasing body fat mass [FM] loss and preserving fat-free mass [FFM]) [13, 24, 25, 27, 31], promoting satiety [25, 27] and reducing cardiovascular disease (CVD) risk factors [3, 10, 25, 26, 30, 31]. Physical function, including aerobic capacity and strength, are also important independent risk factors of CVD risk and mortality [22, 34, 44] and key determinates of the ability to sustain physical activity [16], which is well recognised as an important adjunct therapy to diet for weight management. However, whether altering the carbohydrate-to-protein ratio of a low-fat diet affects physical function, including strength and aerobic capacity, remains largely unexplored.

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In 2002, Jarvis et al. [21] showed that 1-week consumption of a HP diet decreased endurance (aerobic) performance in recreational trained athletes. In contrast, Dipla et al. [11] showed no changes in upper or lower limb strength and fatigue following 7 days of either an energy-restricted HP diet (40% protein; 30% carbohydrate; 30% fat) or an isoenergetic SP diet (15; 55; 30%) in healthy, normal weight women. However, these studies had relatively small sample sizes ($n \leq 10$) and were conducted in normal weight individuals in the absence of moderate energy restriction. Additionally, the short duration of these studies (7 days) may have been insufficient for any significant differential effects on these outcomes to have been realised. This makes it difficult to draw any definitive conclusions that are warranted regarding the chronic effects of an HP diet combined with moderate energy restriction on exercise tolerance and physical function in overweight and obese individuals. Therefore, the aim of the present study was to compare the effects of an energy-restricted HP diet versus an isoenergetic SP diet on strength and aerobic capacity measures in overweight and obese men.

Methods

Participants

Fifty-six overweight or obese men (body mass index [BMI], $27 \leq 40$ kg/m^2; age, 20–65 years) with at least one American Heart Association metabolic syndrome component [19] were recruited by public advertisement into an outpatient, clinical weight loss study conducted at the Clinical Research Unit of the Commonwealth Scientific and Industrial research Organisation (CSIRO). Prior to study inclusion, participants were screened for metabolic syndrome components at the CSIRO research clinic. Participants were excluded if they had diabetes or uncontrolled hypertension; a history of gastrointestinal, renal, coronary, metabolic or hepatic disease or a malignancy; were taking hypoglycaemic medication or drugs that affect insulin sensitivity, were smokers; had joint or peripheral vascular disease sufficient to impede exercise; or had severe exercise-induced asthma. The study was approved by the Human Research Ethics committee of the CSIRO. All participants were informed that the aim of the study was to compare the effects of two low-fat, weight loss diets differing in carbohydrate-to-protein ratio on measures of physical function, and all participants provided written informed consent prior to commencement.

Experimental protocol

In a parallel study design, participants were initially stratified according to age and BMI and then randomised to consume either an energy-restricted high-protein, low-fat diet (HP, $n = 27$) or an isoenergetic standard-protein, low-fat diet (SP, $n = 29$) for 12 weeks.

At baseline and at the end of the intervention (Week 12), participants attended the research clinic on two consecutive days for the assessment of outcomes. Visits were attended after a minimum 4-h fast with water consumed as required. On the first visit, height, weight, body composition (dual X-ray absorptiometry), and knee extensor and handgrip strength were assessed. On the second visit, participants completed an incremental treadmill test to exhaustion to assess maximal aerobic capacity. At baseline and the completion of the study, participants also completed a validated Baecke physical activity questionnaire [4, 32] to assess habitual activity levels. Participants were asked not to modify their lifestyle patterns during the study other than as required to comply with the study protocol. Research personnel who performed the outcomes assessments (data collectors and data analysts) were blinded to treatment assignment to minimise operator bias. Participants did not receive any financial reward for their participation. The study was registered with the Australian New Zealand Clinical Trials Registry (http://www.anzctr.org.au) ACTR No: 126000002583.

Diets

The diets were isoenergetic and moderately energy restricted (7,000 kJ/day). The planned macronutrient profiles of the diets were as follows: HP diet—protein, 35% (142 g, $\sim$1.30 g kg^{-1} day^{-1}); carbohydrate, 40% (135 g); fat, 25% (total, 53 g; saturated, 14 g). SP diet—protein, 17% (88 g, $\sim$0.85 g kg^{-1} day^{-1}); carbohydrate, 58% (198 g); fat, 25% (total, 51 g; saturated, 14 g). Diets were prepared and consumed in a free-living setting, and in an effort to maximise compliance, participants met individually with a qualified dietician at the clinical research unit at baseline and every 2 weeks during the study. At these visits, participants received detailed dietary prescription and advice, including meal planning and recipe information pertaining to the diet they were prescribed. Both dietary patterns were structured to include daily quantities of specific foods to ensure the correct macronutrient and energy requirements were achieved; these daily food quantities are outlined in Table 1. To further facilitate dietary compliance, participants were also supplied with a selection of these foods ($\sim$60% of total energy; Table 1) on a fortnightly basis. Foods were listed in a semi-quantitative food record that was completed daily by the participants, which provided them with clear dietary targets. The participants were asked to weigh and measure their food daily using provided scales. Dietary composition was assessed on the basis of 3 days from the food records

(2 weekdays and 1 weekend day) within each consecutive 2-week period for the duration of the study using a computerised database (Foodworks Professional Edition, version 4, 1998; Xyris Software, Highgate Hill, Australia). Each 2 weekly food record were then used to calculate the average nutrient intakes for the study period (Weeks 0–12).

Biochemical analysis

Serum HDL cholesterol, serum triglycerides and plasma glucose were measured using commercial enzymatic kits (Roche Diagnostics, Basel, Switzerland) on a Hitachi 902 autoanalyzer (Roche Diagnostics, Indianapolis, IN).

Height, weight, blood pressure and body composition

Height was measured using a stadiometer (SECA, Hamburg, Germany), and body weight was measured using calibrated electronic digital scales (Mercury; AMZ 14, Tokyo, Japan). Body composition was measured using dual-energy X-ray absorptiometry (Lunar Prodigy; General Electric, Madison, WI) to assess total body FM and FFM. Waist circumference was measured on a horizontal plane 2 cm proximal to the uppermost lateral border of the right iliac crest. Seated blood pressure was measured using an automated sphygmomanometer (DYNAMAP™ 8100, Criticon, Tampa, USA).

Aerobic capacity

Peak oxygen consumption ($\dot{V}O_{2\,PEAK}$) was measured during a graded incremental exercise test to symptom-limited exhaustion on a treadmill (Trackmaster TMX425CP, Full Vision Inc., Newton, KS) using a modified Bruce protocol [8]. Metabolic rate during the exercise test was measured by indirect calorimetry (TrueMax 2400; Parvomedics, Sandy, UT). $\dot{V}O_2$ and was recorded every 15-s; the highest $\dot{V}O_2$ achieved during the test was reported as $\dot{V}O_{2\,PEAK}$. Heart rate was recorded throughout the test as 5-s averages (Polar Beat, Polar Electro, Oulo, Finland). To ensure patient safety, a 3-lead electrocardiograph was monitored continually throughout the test (CardioLife Tec-7100 Defibrillator, Nihon Kohdenm Shinjuku-ku, Tokyo, Japan) and blood pressure was measured at the end of each exercise stage. For $\dot{V}O_{2\,PEAK}$ data to be included in the analysis, participants were required to reach $\geq$80% of age predicted maximal heart rate [$207 - (0.7 \times \text{age})$] [17].

Handgrip strength

Handgrip strength was determined on the participant's dominant hand using an adjustable, hydraulic handgrip dynamometer (JAMAR, Model 503J1, Sammons Preston Roylan, Bolingbrook, IL), according to the protocol of the American Society for Hand Therapists [14]. Briefly, following familiarisation with the equipment, participants

Table 1 Daily food quantities prescribed to dietary treatment groups

High-protein, low-fat diet	Standard-protein, low-fat diet
500 mL Milk (reduced fat)	250 mL Milk (reduced fat)
70 g Bread (wholemeal with grain)[a]	140 g Bread (wholemeal with grain)[a]
300 g Fruit salad (non-tropical)	450 g Fruit salad (non-tropical)
50 g Lettuce	50 g Lettuce
100 g Tomato (raw)	100 g Tomato (raw)
300 g Beef (lean, raw, fat trimmed)[a]	100 g Beef/chicken/pork (lean, raw, fat trimmed)[a]
33 g Ham (pre-packed/deli-sliced)	33 g Ham (pre-packed/deli-sliced)
33 g Tuna (canned in brine, drained)	70 g Pasta (dry)[a]
33 g Chicken (breast, baked/roast, without skin)	30 g Cheese (cheddar)[a]
200 g Yoghurt (skim/low fat, fruit, artificially sweetened)[a]	100 g Broccoli (cooked)
100 g Broccoli (cooked)	60 g Carrot (cooked)
60 g Carrot (cooked)	20 g Oil (canola)
20 g Oil (canola)	107 g Wine (red)
107 g Wine (red)	1 Serving instant soup (chicken noodle)
1 Serving instant soup (chicken noodle)	2 Sachet tomato sauce
2 Sachet tomato sauce	2 High-fibre breakfast biscuits [cereal][a,b]
2 High-fibre breakfast biscuits [cereal][a,b]	60 g Green peas (cooked from frozen)
60 g Green peas (cooked from frozen)	20 g Wheat bran [cereal][a,c]
20 g Wheat bran (cereal)[a,c]	

[a] Food item provided to participants

[b] Weet-Bix™, Sanitarium Health and Wellbeing Company, NSW, Australia

[c] All Bran™, Kellogg's, Michigan, USA

performed three separate maximal hand grip contractions on their dominant hand with a 60-s rest interval between each effort; the single highest value was reported as peak handgrip strength.

Isometric knee extensor strength

Isometric knee extensor strength for the dominant leg was assessed using an isokinetic dynamometer (Kin-Com 125AP, Chattecx Corporation, Tennessee, USA). The tested leg was positioned with the knee at 90° of flexion, and peak strength was determined to be the maximal torque produced from 3 separate maximal contractions with a 2-min rest interval between contractions.

Statistical analysis

Statistical analyses were performed using SPSS for Windows (version 18.0, SPSS, Chicago, IL, USA). Differences in baseline characteristics between groups and dietary compliance data were assessed using one-way analysis of variance (ANOVA). The effect of time and the treatment group on continuous variables were assessed using repeated measures ANOVA with time as the within subject factor and treatment (HP vs. SP) as the between-subject factor. Pearson correlation coefficients were used to determine the relationships between the changes in variables using the total number of participants from both groups combined; all significant correlations have been reported. Chi-square tests were used to assess between group differences for the proportion of participants who withdrew from the study and the number of participants with metabolic syndrome and/or each of its components at baseline. Statistical significance was set at $P < 0.05$. Data are reported as means ± standard deviation.

Results

Participants

Of the 56 participants who commenced the study, 42 (HP, 21; SP, 21; 75%) completed the intervention with outcome measurements at Week 12. Dropout rates were similar in both groups (HP, 6; SP, 8; $P = 0.64$). Ten participants were lost to contact (HP 4, SP 6), 1 participant in SP withdrew due to an inability to cope with the study time commitments, 2 participants in HP withdrew due to family/work commitments and 1 participant in SP had an injury unrelated to the study that precluded continuation. At baseline, the number of participants with each metabolic syndrome component and with metabolic syndrome (≥3 components) was similar between groups ($P \geq 0.21$); overall, 83% of participants had abdominal obesity, 60% had elevated triglycerides, 38% had reduced high density lipoprotein, 71% had elevated blood pressure, 60% had elevated fasting plasma glucose and 64% had metabolic syndrome. One participant in the HP group was excluded from the dual-energy X-ray absorptiometry body composition analyses due to exceeding the equipment weight limit for scanning at baseline. At baseline, metabolic risk factors were similar between groups ($P \geq 0.18$); overall, 83% of participants had abdominal obesity, 48% had elevated triglycerides, 24% had reduced high density lipoprotein, 67% had elevated blood pressure and 19% had elevated fasting plasma glucose. At baseline, there were no significant differences between the diet groups for any of the outcome variables ($P \geq 0.11$, Table 2).

Dietary composition and study compliance

Based on data from food records, participants in both groups showed good compliance to the prescribed diets (Table 3). The diets were similar in total energy and fat ($P \geq 0.05$), but differed in protein and carbohydrate intake ($P < 0.001$). Both groups reported similar levels of physical activity at Week 0 ($P = 0.46$), and levels had not changed at Week 12 ($P = 0.85$ time; $P = 0.65$ time × group interaction; Table 2). All participants achieved the heart rate requirements for inclusion of $\dot{V}O_{2\,PEAK}$ data.

Body weight and composition

Overall, both groups had similar reductions in body weight (−9.1%) and FFM (−4.4%; $P < 0.001$ time; $P \geq 0.14$ time × group interaction; Table 2). FM reduced in both groups ($P < 0.001$ time effect), with a non-significant, greater reduction in the HP diet group (HP −21.2% vs. SP −15.1%; $P < 0.001$ time, $P = 0.06$ time × group interaction; Table 2).

Aerobic power and muscle strength

At Week 12, treadmill time to exhaustion (TTE) during the graded incremental exercise test increased in both groups ($P < 0.001$ time), independent of diet composition ($P = 0.35$ time × group effect, Table 2). Absolute $\dot{V}O_{2\,PEAK}$ did not change in either group; however, relative $\dot{V}O_{2\,PEAK}$ increased in both groups ($P < 0.001$ for time), with no effect of diet ($P = 0.23$ time × group effect, Table 2). Overall, the increase in TTE correlated positively with the change in relative $\dot{V}O_{2\,PEAK}$ ($r^2 = 0.43$, $P < 0.001$) and inversely with the change in body weight ($r^2 = 0.28$, $P < 0.001$) and FM ($r^2 = 0.22$, $P = 0.002$). The change in relative $\dot{V}O_{2\,PEAK}$ correlated inversely with

Table 2 Age, height, body weight and composition, aerobic capacity, muscle strength and physical activity levels before and after 12 weeks of consumption of either an energy-restricted high-protein, low-fat diet (HP) or an isoenergetic standard-protein, low-fat diet (SP)

	HP ($n = 21$)[a]	SP ($n = 21$)	*P* value		
			Baseline[1]	Time[2]	Time × Group[3]
Age (years)					
Week 0	47.7 ± 8.0	45.9 ± 8.1	0.46		
Height (m)					
Week 0	1.78 ± 0.06	1.78 ± 0.06	0.90		
Body weight (kg)					
Week 0	108.9 ± 14.3	104.1 ± 10.3	0.22	<0.001	0.14
Week 12	98.2 ± 13.3	95.5 ± 9.2			
Change	−10.7 ± 5.3	−8.7 ± 3.5			
Total body fat mass (kg)					
Week 0	36.5 ± 7.4	36.0 ± 6.6	0.82	<0.001	0.06
Week 12	28.8 ± 9.9	30.5 ± 7.3			
Change	−7.7 ± 4.3	−5.4 ± 3.3			
Total body fat-free mass (kg)					
Week 0	70.5 ± 7.0	68.1 ± 8.5	0.33	<0.001	0.69
Week 12	67.7 ± 5.3	64.9 ± 6.8			
Change	−2.8 ± 3.6	−3.2 ± 2.7			
Treadmill time to exhaustion (s)					
Week 0	1,082 ± 96	1,097 ± 78	0.58	<0.001	0.35
Week 12	1,136 ± 112	1,140 ± 74			
Change	55 ± 49	43 ± 30			
Peak heart rate (beats/min)					
Week 0	174 ± 14	175 ± 15	0.93	0.11	0.40
Week 12	172 ± 13	174 ± 15			
Change	−2 ± 6	−1 ± 6			
Peak $\dot{V}O_2$ (l/min)					
Week 0	3.40 ± 0.55	3.40 ± 0.49	0.99	0.39	0.50
Week 12	3.40 ± 0.56	3.36 ± 0.57			
Change	−0.01 ± 0.19	−0.05 ± 0.19			
Peak $\dot{V}O_2$(ml kg^{-1} min^{-1})					
Week 0	31.9 ± 6.4	33.1 ± 5.5	0.53	<0.001	0.23
Week 12	35.3 ± 7.9	35.5 ± 6.7			
Change	3.4 ± 3.2	2.4 ± 2.3			
Peak handgrip strength (kg)					
Week 0	50.4 ± 11.5	55.1 ± 6.6	0.11	0.02	0.71
Week 12	48.6 ± 12.0	53.8 ± 6.9			
Change	−1.9 ± 4.2	−1.4 ± 4.1			
Peak isometric knee extensor strength (Nm)					
Week 0	209.7 ± 52.2	187.7 ± 41.3	0.14	0.02	0.63
Week 12	226.5 ± 64.5	199.1 ± 46.1			
Change	16.8 ± 35.2	11.5 ± 36.8			

Table 2 continued

	HP ($n = 21$)[a]	SP ($n = 21$)	*P* value		
			Baseline[1]	Time[2]	Time × Group[3]
Baecke physical activity total score					
Week 0	7.5 ± 1.4	7.2 ± 1.2	0.46	0.85	0.65
Week 12	7.5 ± 1.5	7.3 ± 1.4			
Change	0.0 ± 1.0	0.1 ± 0.6			

Data are means ± SD

[a] One participant in the HP group was excluded from the total body fat mass and total body fat-free mass analyses due to exceeding the equipment weight limit for scanning at Week 0

[1] Comparison of baseline characteristics at Week 0 (one-way ANOVA)

[2] Changes over time in the groups from Weeks 0 to 12 (repeated measures ANOVA)

[3] Treatment effect between groups for the change from Weeks 0 to 12 (repeated measures ANOVA)

Table 3 Macronutrient composition of the treatment groups

	HP ($n = 21$)	SP ($n = 21$)	*P* value[1]
Energy (kJ)	7,018.6 ± 716.4	7,235.1 ± 632.1	0.31
Protein (g)	128.9 ± 15.9	83.7 ± 6.6	<0.001
Protein (% of energy)	32.4 ± 3.7	20.6 ± 1.3	<0.001
Carbohydrate (g)	154.0 ± 23.9	210.2 ± 18.0	<0.001
Carbohydrate (% of energy)	38.3 ± 3.6	51.2 ± 3.5	<0.001
Fat (g)	49.4 ± 7.2	47.1 ± 6.4	0.30
Fat (% of energy)	27.0 ± 3.2	25.1 ± 2.7	0.05
Alcohol (g)	5.6 ± 4.9	7.9 ± 8.7	0.30
Alcohol (% of energy)	2.4 ± 2.0	3.1 ± 3.2	0.36
Saturated fat (g)	15.9 ± 2.7	14.6 ± 1.6	0.07
Saturated fat (% of total fat)	36.2 ± 4.2	35.2 ± 4.5	0.44

Data are means ± SD. The treatment groups were a high-protein, low-fat diet (HP) or an isoenergetic standard-protein, low-fat diet (SP). The values presented for nutrient intakes represent a calculated average of each 2 weekly food record analysis (3 days; 2 weekdays and 1 weekend day) across the study period (Week 0–12)

[1] Differences between groups (one-way ANOVA)

the changes in body weight ($r^2 = 0.35$, $P < 0.001$) and FM ($r^2 = 0.35$, $P < 0.001$).

In both groups, maximum handgrip strength decreased and peak isometric knee extensor strength improved during the intervention ($P \leq 0.02$ for time), with no effect of diet ($P \geq 0.63$ time × group effect, Table 2).

Discussion

The results of this study show that both a HP and an isoenergetic SP diet had similar effects on weight loss, change in FFM, and markers of strength and aerobic capacity in overweight and obese men.

Overall, both diet groups experienced similar weight loss (~9.1%). Interestingly, although statistical significance was not reached, the trend ($P = 0.06$) for a greater reduction in FM observed in the HP vs. SP group is consistent with the findings of other clinical studies [25, 31], which showed, compared to a SP diet, an energy-restricted HP diet promotes greater reductions in FM.

Despite achieving a daily protein intake of ~1.30 g/kg of body weight in the HP diet group, compared to 0.8 g/kg body weight in the SP diet group, no difference in FFM changes between the groups was observed. The level of protein intake in the HP group is consistent with protein intakes reported in a meta-analysis [24] that showed attenuation of FFM loss following calorie-restricted diet–induced weight loss. Contrary to the present findings, Leidy et al. [27] and Farnsworth et al. [13] showed attenuated FFM reduction with a HP diet compared to an isoenergetic SP diet. However, these studies only included women and gender differences in protein turnover, with women oxidising less protein to meet energy demands at rest compared to men [40, 43, 45], may have contributed to the contradictory findings. Whether the absence of any measurable differences in FFM between the dietary patterns in the present study was due to gender requires further investigation.

In the present study, overall, FFM reductions accounted for 31% of total weight loss. This is markedly greater than the ~20% reported in a meta-analysis by Krieger et al. [24]. It has been recently reported that the rate of weight loss is positively related to the proportion of weight lost as FFM [9]. It is therefore possible that the greater reduction in FFM observed in the present study may be explained by the higher rate of weight loss compared to the mean reported in the meta-analysis [24] (0.8 vs. ~0.65 kg week^{-1}).

Since both diet groups experienced similar changes in weight and FFM, the absence of any differential effect between the diet groups for absolute $\dot{V}O_{2\,PEAK}$ is not surprising. It is interesting that despite overall reductions in body weight and FFM, absolute $\dot{V}O_{2\,PEAK}$ did not decrease from baseline. Although the reliability of maximal treadmill testing for determination of maximal aerobic power is high [38], studies assessing test–retest reproducibility have observed small improvements in $\dot{V}O_{2\,PEAK}$ between the 1st and 2nd tests [15, 38]. This improvements could be attributed to a number of non-physiological reasons [2, 20], including a learning effect of performing a maximal bout of exercise [15], acclimatising to the treadmill, and/or motivation to perform [2]. Hence, systematic increases in $\dot{V}O_{2\,PEAK}$ that can occur with repeat testing may explain why absolute $\dot{V}O_{2\,PEAK}$ remained constant in the current study, despite reductions in body weight and FFM and maintenance of baseline exercise levels. Similarly, treadmill TTE may have also improved following the intervention due to a learning effect [41] or due to improved mechanical efficiency with weight loss [7]. Alternatively, previous studies have demonstrated that cardiorespiratory fitness is inversely associated with insulin resistance [1, 5, 29, 39, 42] and that insulin resistance may limit exercise tolerance by several proposed mechanisms [1, 39] including altered glucose transport that limits the availability of extracellular glucose to exercising muscle [12]. Improvements in insulin sensitivity with weight loss are well documented [18]. Hence, although exploration of these mechanisms extend beyond the current data, it is plausible that weight loss-induced improvements in insulin sensitivity may have been responsible for the maintenance of absolute $\dot{V}O_{2\,PEAK}$ despite reductions in body weight and FFM observed in the present study. Irrespective of the causes of the within group changes, the primary objective of this study was to compare between group changes. The lack of any apparent effects suggests macronutrient composition, at least during energy restriction with low-fat diets differing in the protein/carbohydrate ratio, does not appear to alter aerobic capacity.

No differential diet effects were evident for changes in muscle strength, assessed by either isometric knee extensor muscle strength or handgrip strength. Combined with the absence of any differential group responses for changes in FFM, these findings are similar to a previous study [7] that also observed no diet effect for changes in FFM, peak isometric knee extensor strength and handgrip strength following 8 weeks of diet-induced weight loss (6.7–8.4 kg) achieved with either a very low-carbohydrate, high-fat diet or an isoenergetic low-fat diet in overweight and obese participants. Collectively, these data suggest that dietary macronutrient composition does not appear to influence muscle strength over the short term, at least independently of similar changes in FFM in metabolically at risk, sedentary, overweight and obese individuals.

At Week 12, isometric knee extensor strength increased despite reductions in FFM, which most likely included some muscle loss. Although a definitive explanation for this effect cannot be provided, since study participants did not perform any familiarisation sessions with the testing procedures, it is possible that a learning effect with isokinetic dynamometer testing could have been responsible. A reliability study [37] reported higher scores (7.4%) on the repeated testing day that was of similar magnitude to the post-intervention increases (7.1%) observed in the current study. Nevertheless, both groups were treated similarly, and there was no differential effect between groups indicating no differential effect of diet.

Both diet groups experienced a small (3%), but significant reduction in handgrip strength. This is consistent with previous studies that have shown a reduction in handgrip strength following weight loss induced by energy restriction [7, 23]. In middle-aged men, handgrip strength represents a reliable marker of future functional capacity and disability [33]. Although the specific effect of the observed small reduction in handgrip strength on predisposition to disability is unknown, it is unlikely to be of clinical significance for the participants in this study since, despite the reduction, handgrip strength at Week 12 (mean 51.2 kg) remained comparable to the normative reference value established for this age group (~50.4 kg) [6].

It is estimated that a sample sizes in excess of 350 persons per group would have been needed for the observed between groups differences of 0.04 L/min for peak $\dot{V}O_2$, 0.5 kg for peak handgrip strength and 5.3 Nm for peak isometric knee extensor strength to have been statistically significant (80%, $P < 0.05$). Furthermore, this difference represents a very small effect size (partial eta$^2 \leq 0.01$); collectively, this suggests that these small differential effects achieved under the current experimental conditions in this patient group are unlikely to have any substantial clinical relevance.

In conclusion, altering the carbohydrate-to-protein ratio of an energy-restricted, low-fat diet that achieved similar weight loss and reductions in FFM had similar effects on strength and aerobic capacity in sedentary, overweight and obese men. However, these results are limited to middle-aged men and whether these similar effects occur in younger or older individuals and/or in women and are maintained over the longer-term remains unknown and warrants investigation.

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Conflict of interest The authors declare no conflict of interest.

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