Eur J Nutr (2014) 53:49–60
DOI 10.1007/s00394-013-0497-7

ORIGINAL CONTRIBUTION

Eating carbohydrate mostly at lunch and protein mostly at dinner within a covert hypocaloric diet influences morning glucose homeostasis in overweight/obese men

Raquel Duarte Moreira Alves · Fernanda Cristina Esteves de Oliveira · Helen Hermana Miranda Hermsdorff · Itziar Abete · María Ángeles Zulet · José Alfredo Martínez · Josefina Bressan

Received: 14 September 2012 / Accepted: 16 January 2013 / Published online: 7 February 2013

Abstract
Purpose To evaluate the effects of two dietary patterns in which carbohydrates and proteins were eaten mostly at lunch or dinner on body weight and composition, energy metabolism, and biochemical markers in overweight/obese men.
Methods Fifty-eight men (30.0 ± 7.4 years; 30.8 ± 2.4 kg/m^2) followed a covert hypocaloric balanced diet (−10 % of daily energy requirements) during 8 weeks. Subjects were randomly assigned to three groups: control diet (CT); diurnal carbohydrate/nocturnal protein (DCNP); and nocturnal carbohydrate/diurnal protein (NCDP). Main analyzed outcomes were weight loss, body composition, diet-induced thermogenesis (DIT), and glucose/lipid profile.
Results In all groups, a significant decrease in body weight, BMI, and fat mass (kg and %) was verified, without differences between groups. Interestingly, within group analyses showed that the fat-free mass (kg) significantly decreased in NCDP and in CT after 8-week intervention, but not in DCNP. A detrimental increase in fasting glucose, insulin, and homeostasis model assessment of insulin resistance ($HOMA_{IR}$) was verified only in DCNP, while NCDP and CT groups presented a non-significant reduction. Moreover, significant differences between DCNP and the other groups were detected for fasting insulin and $HOMA_{IR}$. After the adjustments, NCDP presented a significantly higher DIT and energy expenditure after lunch, compared with DCNP, but after dinner, there were no differences among groups.
Conclusion Eating carbohydrates mostly at dinner and protein mostly at lunch within a hypocaloric balanced diet had similar effect on body composition and biochemical markers, but higher effect on DIT compared with control diet. Moreover, eating carbohydrates mostly at lunch and protein mostly at dinner had a deleterious impact on glucose homeostasis.

Keywords Obesity · Weight management · Body composition · Macronutrients · Energy metabolism · Glucose homeostasis

R. D. M. Alves · H. H. M. Hermsdorff · J. Bressan (✉)
Department of Nutrition and Health, Federal University of Viçosa, Av. PH Rolfs, s/n, Viçosa, Minas Gerais 36570-000, Brazil
e-mail: jbrm@ufv.br

F. C. E. de Oliveira
Department of Food Science and Technology, Federal University of Viçosa, Av. PH Rolfs, s/n, Viçosa, Minas Gerais 36570-000, Brazil

I. Abete · M. Á. Zulet · J. A. Martínez
Department of Nutrition, Food Science, Physiology and Toxicology, University of Navarra, C/Irunlarrea 1, 31008 Pamplona, Navarra, Spain

M. Á. Zulet · J. A. Martínez
CIBERobn : Fisiopatologia de la Obesidad y la Nutricion; Instituto Carlos III, Madrid, Spain

Introduction

Obesity is a chronic disease whose prevalence is dramatically increasing worldwide [1, 2]. Furthermore, obesity is an independent risk factor in the development of other chronic diseases such as metabolic syndrome, type 2 diabetes, dyslipidemia, hypertension, and cardiovascular diseases [1, 2].

Dietary management for weight control is one of the major focuses of studies on nutrition. Many studies that investigate different diets aim at greater weight loss and

fat-free mass maintenance associated with improvement in hormonal patterns, metabolic syndrome markers, and/or inflammation and oxidative status [3–10].

However, the effects of the dietary macronutrient composition and their distribution throughout the day on these parameters are still controversial [3, 4, 6, 9, 11, 12]. In addition, the studies that have evaluated the effectiveness of macronutrient-balanced diets with different proportions of macronutrients in meals in promoting metabolic improvement are insufficient [13–15].

In fact, different sorts of prescribed dietary regimens have become widespread with an array of outcomes concerning their potential benefits [13, 16]. In this context, a diet in which the macronutrient intake is spread throughout the day with a systematic pattern for separately proteins, lipids, and carbohydrates have been described [13, 15]. In turn, recent evidences have suggested that balanced diets with carbohydrates eaten mostly at dinner contribute to a greater weight loss, related to appetite control and fat oxidation as well as to improvement in glucose/lipid profile, hormonal patterns, and inflammation status [14, 15]. Nevertheless, to our knowledge, no studies have investigated the effects of a balanced diet with carbohydrates eaten mostly at lunch and proteins eaten mostly at dinner. There may be a difference between those diets, mainly considering glucose and insulin responses, since human body has different metabolic responses to identical test meals consumed at different times of the day [17].

Thus, the purpose of the present study was to investigate the effects of two dietary patterns in which carbohydrates and proteins were eaten mostly at lunch or dinner within a covert calorie-restricted program on weight loss, body composition, energy metabolism, and biochemical markers in overweight and obese men.

Subjects and methods

Subjects

Participants of the current research were involved in a study of Interuniversity Cooperation between the Federal University of Viçosa (Brazil, CAPES/MECD-DGU 218/10) and the University of Navarra (Spain, PHB-2009-0050-PC). This dietary intervention study was carried out between September 2006 and December 2009 at both research centers.

One hundred and fifty-nine potential men were recruited by means of public advertisements and posted flyers. Subjects underwent a brief nutritional screening which consisted of measuring their body weight and height and also fill in a questionnaire about their medical, sports, and nutritional history, including weight gain/loss. They were required to be aged between 18 and 45 years, with body mass index (BMI) ranging from 26 to 35 kg/m^2 and stable weight ($\pm$3 kg) during the previous 3 months. Subjects presenting any chronic or acute diseases and/or eating disorders were not included. Other exclusion criteria included the use of any medication that might affect the results and/or be under weight-loss diets over the past 3 months prior to the study; the use of drugs or alcohol (drinking more than 168 g of alcohol/week); or participation in a formal athletics program. Furthermore, subjects were excluded during the study when they quitted or when they failed to follow the dietary prescription or any other protocol. The study was conducted in accordance with the guideless laid down in the Declaration of Helsinki, and the applied protocol was approved by the ethical committee in human research of each institution (Brazilian institution protocol number: 009/2008; Spanish institution protocol number 129/2006). All participants signed a written informed consent and received no financial compensation or gifts for their cooperation.

Study design

This study was a single-blinded, single-randomized, single-controlled clinical trial divided into two periods: maintenance period (3 days) and intervention period (8 weeks). After completing the screening process, subjects consumed a weight-maintaining diet for three consecutive days. Subsequently, the subjects were randomly assigned to one of the three experimental groups: control (CT), diurnal carbohydrate/nocturnal protein (DCNP), and nocturnal carbohydrate/diurnal protein (NCDP). Then, during 8 weeks and under free-living conditions, they followed a hypocaloric diet ($\approx$10 % of caloric restriction), balanced in proteins, carbohydrates and lipids, which differed only in macronutrient concentration at lunch and dinner (see "Dietary intervention" section). The subjects were asked to maintain habitual physical activity level during the study. The analysis and testing were performed before (baseline) and at the end of the intervention period and included fasting blood samples, measurements of anthropometry, body composition, and energy expenditure. Additionally, the diet-induced thermogenesis (DIT) was assessed at the end of the intervention period using an indirect calorimetry approach (see "Measurements" section).

Dietary intervention

Daily energy requirements were assessed by calculating the total energy expenditure (TEE) of each subject according to the dietary reference intakes (DRI) for Energy [18]. The selection of the physical activity coefficient applied to the equation depended on the physical activity level of each subject which was classified according to the DRI [18].

For the weight-maintaining initial period, TEE of each subject was applied without any caloric restriction. The target macronutrient composition followed the acceptable macronutrient distribution range (AMDR) of the DRI recommendations [18].

We applied a covert hypocaloric diet that is considered a mild in the energy intake with respect to TEE of each individual ($\approx$10 % of calorie-restriction). Thus, nearly 250 kcal per day were subtracted from the TEE to induce an approximate loss of 1 kg per month. The three experimental diets were balanced, and the daily macronutrient distribution was calculated to provide 18 % of the calories from protein, 30 % from fat and 52 % from carbohydrate in all experimental diets. The mean protein prescription was 1.2 g of protein per kg of body weight.

The CT diet provided a macronutrient-balanced lunch and dinner (18.0 % protein, 46.8 % carbohydrate, 35.2 % fat) while DCNP and NCDP groups received an unbalanced lunch and dinner. Thus, DCNP received a prescription of a high-carbohydrate/low-protein lunch (69.3 and 7.2 % respectively) and a high-protein/low-carbohydrate dinner (41.7 and 18.8 %, respectively), while NCDP received prescription of a high-protein/low-carbohydrate lunch (41.0 and 18.3 %, respectively) and a high-carbohydrate/low-protein dinner (67.6 and 7.6 %, respectively). For the three experimental groups, besides lunch and dinner, all the other meals were similar in macronutrient composition.

Dietary intervention was implemented in a free-living condition; thus, each subject received a nutritional advice and education from registered dietitians. Subjects were instructed to use an exchange-based self-selected food list, which assigned foods into categories according to their macronutrient composition, so that the subjects could plan their own menus and choose foods for their meals based on a dietary prescription as described elsewhere [4, 7]. Each research center had its own list, containing the foods most commonly eaten in their local community.

Test meal for postprandial measurements

At the end of the intervention period (day 56), subjects received two test meals (lunch and dinner) for DIT measurements in the metabolic unit of each study center. Each test meal was calculated to provide 35–36 % of the TEE of each subject. Thus, lunch and dinner were isocaloric meals. CT lunch and dinner consisted of 22.5 % of the calories from protein, 44.5 % from carbohydrate, and 27.0 % from fat. In the DCNP lunch and the NCDP dinner (high-carbohydrate/low-protein meal), 6.0 % of the calories was from protein; 69.0 %, from carbohydrate; and 25.0 %, from fat. In the DCNP dinner and NCDP lunch (high-protein/low-carbohydrate meal), 49.0 % of the calories was from protein; 22.0 %, from carbohydrate; and 29.0 % from fat.

Dietary intake assessment

Subjects provided two 3-day food records (2 week days and 1 weekend day), one before the maintenance period and the other at the end of the intervention period. The dietitian reviewed the food records with the subjects to check for errors or omissions. The food records were analyzed for nutrient composition in each center by specific computer software systems (Dietpro 5.2i—Agromídia, Viçosa, Brazil and DIAL 1.0—Alce Ingenieria, Madrid, Spain), based on reliable Brazilian and Spanish food composition tables [19–22]. Moreover, it was evaluated whether the participants made an additional daily caloric restriction to that established, which was calculated by subtracting the caloric intake obtained in the 3-day food record of the intervention period from the prescribed calories.

Measurements

All measurements were taken under standardized protocols at the baseline and end of the intervention trial. The subjects were instructed not to consume caffeine and alcohol, to refrain from heavy physical activity and to maintain a regular sleep-wake schedule (8 h per night) during 72 h before each measurement. They were also instructed to fast overnight (12 h) prior to assessments.

The anthropometric measurements (body weight, height, skinfold thicknesses, and waist and hip circumferences) were taken using standard procedures in accordance with previously described protocols, as agreed by both the research center [23]. The BMI was then calculated by dividing weight (kg) by height (m) squared. The truncal fat was expressed as a percentage and was calculated as follows: truncal fat = (subscapular + suprailiac)/(tricipital + bicipital + subscapular + suprailiac). The waist to hip ratio also was calculated. Central fat accumulation was described as waist circumference, waist-hip ratio, and truncal fat percentage [24].

Body composition was assessed by a single-frequency bipolar bioelectrical impedance analysis device (Tanita, model TBF-300, Tanita Corp., Arlington Heights, IL, USA) in full compliance with the manufacturer's guidelines. After at least 10 min of resting, blood pressure was measured with the use of a sphygmomanometer by trained specialists.

The blood samples were drawn by venipuncture after a 12-h overnight fast, centrifuged immediately for 15 min at 2,200$\times g$ and 5 °C, and stored at −80 °C. Serum glucose, total cholesterol, high-density lipoprotein cholesterol (HDL-c), and triacilglycerol were quantified by an automated analyzer system using available commercial colorimetric assay kits. The serum very-low-density lipoprotein cholesterol (VLDL-c) and low-density lipoprotein cholesterol

(LDL-c) were calculated using the Friedewald equations [25]. The total-cholesterol:HDL-c and LDL-cholesterol:HDL-c ratios were also computed [26]. Serum fasting insulin level was quantified according to validated procedures. The homeostasis model assessment of insulin resistance ($HOMA_{IR}$) was calculated according to the equation proposed by Matthews et al. [27].

Respiratory gas exchange measurements were taken using indirect calorimetry with the use of a ventilated hood system (Deltatrac II, MBM-200; Datex Instrumentarium Corporation, Helsinki, Finland) in full compliance with the operational procedures recommended by the manufacturer's guidelines. The volume of oxygen consumption (VO_2) and of carbon dioxide production (VCO_2), resting energy expenditure (REE), and respiratory quotient (RQ) were measured over 30 min under fasting conditions at baseline and at the end of the intervention period. Additionally, at the end of the intervention period, the gas exchange measurements were also hourly taken for 30 min, during 3 h after lunch and dinner to evaluate the postprandial metabolic rate for the DIT calculation. The DIT was calculated as the incremental increase in energy expenditure above REE, expressed as percentage of the caloric intake of each test meal [28]. Cumulative energy expenditure (kcal × 3 h) was expressed as the incremental area under the curve (using the trapezoidal method) from 0 to 180 min after consumption of the test meals [29].

Statistical analysis

The minimum sample size was estimated at 14 volunteers per group considering weight loss as the primary outcome. Thus, it was assumed a standard deviation of 0.5 for weight loss based on a previous study [30] and 10 % of expected difference between groups at the end of the intervention using a statistical power of 90 %. To estimate the drop-out impact, a χ^2 test was implemented.

The analysis included subjects who successfully completed the intervention period. The statistical analyses were performed by using the procedures of the SAS statistical package (Version 9.2; SAS Institute Inc, Cary, NC, USA). The normal distribution and homogeneity of variance were evaluated using Kolmogorov–Smirnov and Levene tests, respectively, with the rejection level of significance of 0.1 %. Accordingly, parametric or nonparametric tests were performed for all analyses using the statistical significance of 5 %. For descriptive baseline data, the results are presented as mean ± SD. Other data results are also presented as median (interquartile interval).

Changes (Δ = final − baseline data) after 8 weeks of intervention in anthropometric data, fat mass (kg; %), fat-free mass (kg), blood pressure, dietary and biochemical variables, and fasting REE and RQ were compared within each group by using the paired t test or the Wilcoxon test, as appropriate. These same variables and the percentage of weight loss and postprandial metabolic rate, RQ, and DIT were compared between groups using one-way analyses of variance (ANOVA) followed by the Tukey's post hoc test or using the Kruskal–Wallis test followed by the Dunn's post hoc test, as appropriate. Multivariate stepwise analyses followed by the Tukey–Kramer post hoc test were used to assess baseline-adjusted end-of-intervention between-group differences.

In order to compare the difference between lunch and dinner within each group for results of DIT, RQ, postprandial metabolic rate, and macronutrient intake, either the paired t test or the Wilcoxon test was applied, as appropriate. Additionally, the t test or the Mann–Whitney U test were performed, as appropriate, for the same variables to compare the results for lunch of one group with the results for dinner of other group.

Results

Subjects and baseline characteristics

A total of 84 subjects were finally randomized to the trial. Overall, 31 % ($n = 26$) of the participants withdrew. CT presented the highest dropout rate (40 %; $n = 12$) followed by DCNP (27.6 %; $n = 8$) and NCDP (24 %; $n = 6$), although no statistical differences among groups were found ($P = 0.625$). Two of the subjects who completed the study were excluded from the analyses due to non-compliance to the fasting protocol at the end of the intervention period.

Baseline characteristics including age, anthropometry, body composition, biochemical variables, blood pressure, and resting energy expenditure were not significantly different between groups (Table 1).

The dietary data obtained from the food record filled out before the maintenance period showed that the habitual dietary intake did not differ between groups ($P > 0.05$) (Table 2).

Changes after the intervention period

Dietary intake

The changes in average daily intake of calories, carbohydrate, protein, fat (total, saturated, monounsaturated, polyunsaturated), fiber, and cholesterol from baseline to the end of treatment did not differ between groups ($P > 0.05$). Furthermore, the intake of those nutrients was not significantly different between groups at the end of the intervention period (Table 2). As this study worked at living-free

Table 1 Baseline characteristics of the participants, randomized in control, diurnal carbohydrate/nocturnal protein, and nocturnal carbohydrate/diurnal-protein groups

	Overall ($n = 58$)	CT ($n = 18$)	DCNP ($n = 21$)	NCDP ($n = 19$)
Age (years)	30.0 ± 7.4	31.4 ± 7.6	29.3 ± 7.34	29.5 ± 7.5
Body weight (kg)	93.7 ± 11.4	95.6 ± 11.7	93.9 ± 12.1	91.6 ± 10.5
BMI (kg/m^2)	30.1 ± 2.8	31.0 ± 3.2	29.5 ± 2.5	29.9 ± 2.8
Waist (cm)	102.0 ± 7.9	104.0 ± 8.7	101.1 ± 8.9	101.3 ± 5.7
Hip (cm)	109.3 ± 6.6	110.3 ± 7.8	108.9 ± 6.2	108.8 ± 6.0
Waist-hip ratio	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.1
Fat mass (kg)	25.9 ± 6.6	27.1 ± 7.7	25.1 ± 5.9	25.9 ± 6.5
Body fat percentage (%)	27.4 ± 4.6	27.9 ± 5.7	26.5 ± 3.7	28.0 ± 4.3
Fat-free mass (kg)	67.7 ± 6.7	68.5 ± 6.8	68.8 ± 7.6	65.7 ± 5.7
Truncal fat (%)	65.4 ± 7.0	65.7 ± 6.6	65.8 ± 8.1	64.7 ± 6.3
Systolic BP (mmHg)	117.3 ± 10.4	114.7 ± 8.7	117.1 ± 10.6	120.0 ± 10.5
Diastolic BP (mmHg)	75.5 ± 7.4	74.7 ± 5.8	75.2 ± 8.6	76.6 ± 7.5
Glucose (mg/dL)	86.3 ± 10.8	86.7 ± 12.9	85.3 ± 10.6	86.9 ± 9.2
Insulin (μU/mL)	7.2 ± 3.4	8.3 ± 4.1	6.1 ± 2.5	7.4 ± 3.2
$HOMA_{IR}$	1.6 ± 0.8	1.8 ± 1.0	1.3 ± 0.6	1.6 ± 0.8
Total cholesterol (mg/dL)	176.6 ± 43.3	179.8 ± 54.6	169.8 ± 33.9	181.1 ± 42.1
Triglycerides (mg/dL)	100.6 ± 69.8	97.3 ± 45.8	110.7 ± 100.4	92.5 ± 45.0
VLDL-c (mg/dL)	20.1 ± 14.0	19.5 ± 9.2	22.2 ± 20.1	18.5 ± 9.0
LDL-c (mg/dL)	114.5 ± 40.4	119.5 ± 48.2	106.0 ± 35.6	119.2 ± 37.9
HDL-c (mg/dL)	42.0 ± 8.5	40.8 ± 7.3	41.7 ± 6.9	43.4 ± 11.1
Total cholesterol:HDLc	3.6 ± 0.9	3.8 ± 1.0	3.4 ± 0.9	3.6 ± 0.8
LDL-c:HDL-c	2.8 ± 1.1	3.0 ± 1.3	2.6 ± 1.1	2.8 ± 1.0
TEE (kcal/day)	2822.5 ± 235.7	2855.3 ± 254.6	2861.7 ± 233.5	2748.2 ± 213.3
REE (kcal/day)	1924.0 ± 209.4	1867.3 ± 154.4	1954.3 ± 221.7	1944.2 ± 238.9
RQ	0.83 ± 0.05	0.84 ± 0.04	0.82 ± 0.04	0.82 ± 0.07

Values are mean ± SD. Baseline values did not differ between the groups (ANOVA; $P > 0.05$)

CT control group, *DCNP* diurnal carbohydrate/nocturnal protein group, *NCDP* nocturnal carbohydrate/diurnal protein group, *BMI* body mass index, *$HOMA_{IR}$* homeostasis model assessment for insulin resistance, *BP* blood pressure, *VLDL-c* very-low-density lipoprotein cholesterol, *LDL-c* low-density lipoprotein cholesterol, *HDL-c* high-density lipoprotein cholesterol, *TEE* total energy expenditure, *REE* resting energy expenditure, *RQ* respiratory quotient

condition and volunteers used an exchange-based self-selected food list, they have eaten carbohydrates and proteins from different sources. Main sources of protein were meat, chicken, and fish as well as dairy products and legumes. Dietary carbohydrates came mainly from fruits, cereals, tubers, and milk.

When dietary intake during intervention was compared with baseline for each treatment group, caloric intake was significantly reduced for the three groups (Table 2). An additional daily caloric restriction was verified in all groups, with no difference between them ($P > 0.05$). Subjects from DCNP restricted 680.2 kcal (26.1 % of TEE) more than the 250 kcal initially prescribed, while CT presented an additional caloric restriction of 547.6 kcal (21.5 % of TEE). NCDP showed the lowest additional restriction (364.4 kcal; 14.6 % of TEE).

Moreover, carbohydrate, protein, and fat (total, saturated, monounsaturated, polyunsaturated) intakes did not change ($P > 0.05$). However, the CT subjects reported significantly decreased fiber intake, and the NCDP subjects significantly decreased cholesterol intake after the intervention ($P < 0.05$).

During the study, the daily macronutrient intake did not differ significantly between groups. Dietary intake was balanced since the macronutrient distribution matched the AMDR of the DRI recommendation. It is important to note that, for all experimental groups, the mean daily protein intake followed the DRI (IOM, 2002) [18] recommendation, since it was 18 % of the caloric intake. Besides, the mean protein intake was 0.98 g per kg of body weight.

The analysis of macronutrient distribution of lunch and dinner revealed that there were no shifts of carbohydrates

Table 2 Habitual and interventional energy, macronutrients, fiber, and cholesterol intake according to the experimental group

	CT ($n = 18$)		DCNP ($n = 21$)		NCDP ($n = 19$)	
	Habitual	Intervention	Habitual	Intervention	Habitual	Intervention
Total energy intake (kcal/day)	2608 ± 346	2002 ± 442**	2275 ± 511	1896 ± 297**	2527 ± 964	2083 ± 514*
Carbohydrates (% total energy)	46.8 ± 6.1	47.7 ± 7.0	45.6 ± 8.0	48.7 ± 4.8	45.8 ± 4.3	46.8 ± 6.0
Carbohydrates (g)	304.3 ± 52.0	242.4 ± 73.9**	262.4 ± 81.2	230.6 ± 41.9*	290.1 ± 124.5	243.8 ± 65.9
Proteins (% total energy)	16.2 ± 2.9	17.0 ± 3.0	17.2 ± 3.8	18.7 ± 3.9	17.6 ± 3.0	18.3 ± 3.3
Proteins (g)	105.4 ± 20.6	83.7 ± 17.2**	95.2 ± 18.9	87.8 ± 19.0	109.0 ± 36.0	93.7 ± 22.8
Total Fat (% total energy)	36.5 ± 5.8	35.0 ± 5.6	37.1 ± 7.2	32.7 ± 4.9	35.8 ± 4.3	33.6 ± 6.1
Total Fat (g)	106.4 ± 25.9	77.0 ± 17.8**	93.6 ± 25.1	69.2 ± 17.4**	100.9 ± 40.5	77.3 ± 22.8*
Saturated fat (% total energy)	11.4 (9.5–12.6)	9.4 (8.9–10.8)	10.5 (9.8–11.0)	10.1 (8.9–11.2)	11.4 (9.0–12.1)	10.6 (8.1–11.6)
Saturated fat (g)	31.9 (26.8–36.3)	21.2** (19.3–25.1)	28.1 (22.9–34.2)	21.1* (17.2–23.8)	25.9 (19.5–38.8)	22.7* (17.8–28.2)
MUFA (% total energy)	13.1 ± 6.8	14.5 ± 8.2	11.6 ± 7.0	10.7 ± 5.5	12.9 ± 4.4	12.2 ± 5.2
MUFA (g)	37.9 ± 22.5	31.0 ± 18.1*	27.6 ± 13.9	23.3 ± 14.1	34.0 ± 11.1	27.6 ± 13.4
PUFA (% total energy)	4.9 ± 2.3	4.6 ± 1.3	5.2 ± 2.3	4.6 ± 1.8	5.5 ± 1.6	5.1 ± 1.6
PUFA (g)	14.2 ± 7.4	10.0 ± 3.5*	13.0 ± 6.3	9.8 ± 3.8*	16.1 ± 9.5	11.9 ± 5.1*
Cholesterol (mg/day)	308.6 ± 112.6	249.1 ± 67.6	308.8 ± 69.5	247.8 ± 119.6	330.9 ± 140.2	243.2 ± 92.7**
Fiber (g/day)	22.2 ± 6.3	17.9 ± 6.3*	16.5 ± 5.7	15.2 ± 6.1	21.2 ± 10.5	15.6 ± 8.0

Values are mean ± SD or median (interquartile interval). The changes did not differ between the groups ($P > 0.05$; ANOVA)

CT control group, *DCNP* diurnal carbohydrate/nocturnal protein group, *NCDP* nocturnal carbohydrate/diurnal protein group, *MUFA* monosaturated fatty acid, *PUFA* polyunsaturated fatty acid

* $P < 0.05$, ** $P < 0.01$, significant difference from baseline (paired *t* test or Wilcoxon test)

and protein in the CT meals (Fig. 1). Moreover, the CT did not experiment daily, neither a high-protein nor a high-carbohydrate meal as was observed in DCNP and NCDP (Fig. 1). In accordance with the DCNP and NCDP prescriptions, for both groups, there was a significant difference in the macronutrient distribution between lunch and dinner within group, and also a significant difference between protein and carbohydrate contents in the same meal of different groups (NCDP vs. DCNP) (Fig. 1).

Due to the dissociation pattern, the carbohydrate intake represented more than 60 % of the meal caloric content in DCNP lunch and NCDP dinner, and the protein intake represented more than 30 % of the meal caloric content in DCNP dinner and NCDP lunch. In addition, the carbohydrate intake was significantly lower than the protein intake in the NCDP lunch, but there was no difference between carbohydrate and protein intake in the DCNP dinner ($P > 0.05$), suggesting less dissociation in this group (Fig. 1).

When the lunch of one group was compared with the dinner of another group, there was no difference between the DCNP lunch and the NCDP dinner for macronutrient composition ($P > 0.05$), as expected. However, although the protein intake of the NCDP lunch did not differ from the DCNP dinner, the carbohydrate intake was statistically different between those meals (Fig. 1).

Anthropometry, body composition, and biochemical parameters

The intervention led to significantly decreasing body weight, BMI, fat mass (kg and %), waist, and hip circumferences in all groups (Table 3). Changes in anthropometry and body composition did not differ between groups, even after adjustment for baseline values ($P > 0.05$).

Within groups, the waist–hip ratio was significantly reduced in CT and NCDP, and the fat-free mass was significant decreased only in CT (−1.04 kg) and NCDP (−0.94 kg) ($P < 0.05$). Although changes were not statistically significant ($P > 0.05$), while CT and NCDP decreased the percentage of truncal fat, an increment was verified in DCNP ($P > 0.05$) (Table 3).

The systolic and diastolic blood pressure did not differ between groups at the end of the intervention period. Moreover, changes in those variables were not different between and within groups ($P > 0.05$; data not shown).

Regarding biochemical variables, glucose and insulin concentrations as well as $HOMA_{IR}$ were significantly increased after the intervention period only in DCNP (Table 4). In addition, fasting insulin presented a non-significant decrement in NCDP and CT. Furthermore, after adjustments, the increment in fasting insulin and $HOMA_{IR}$

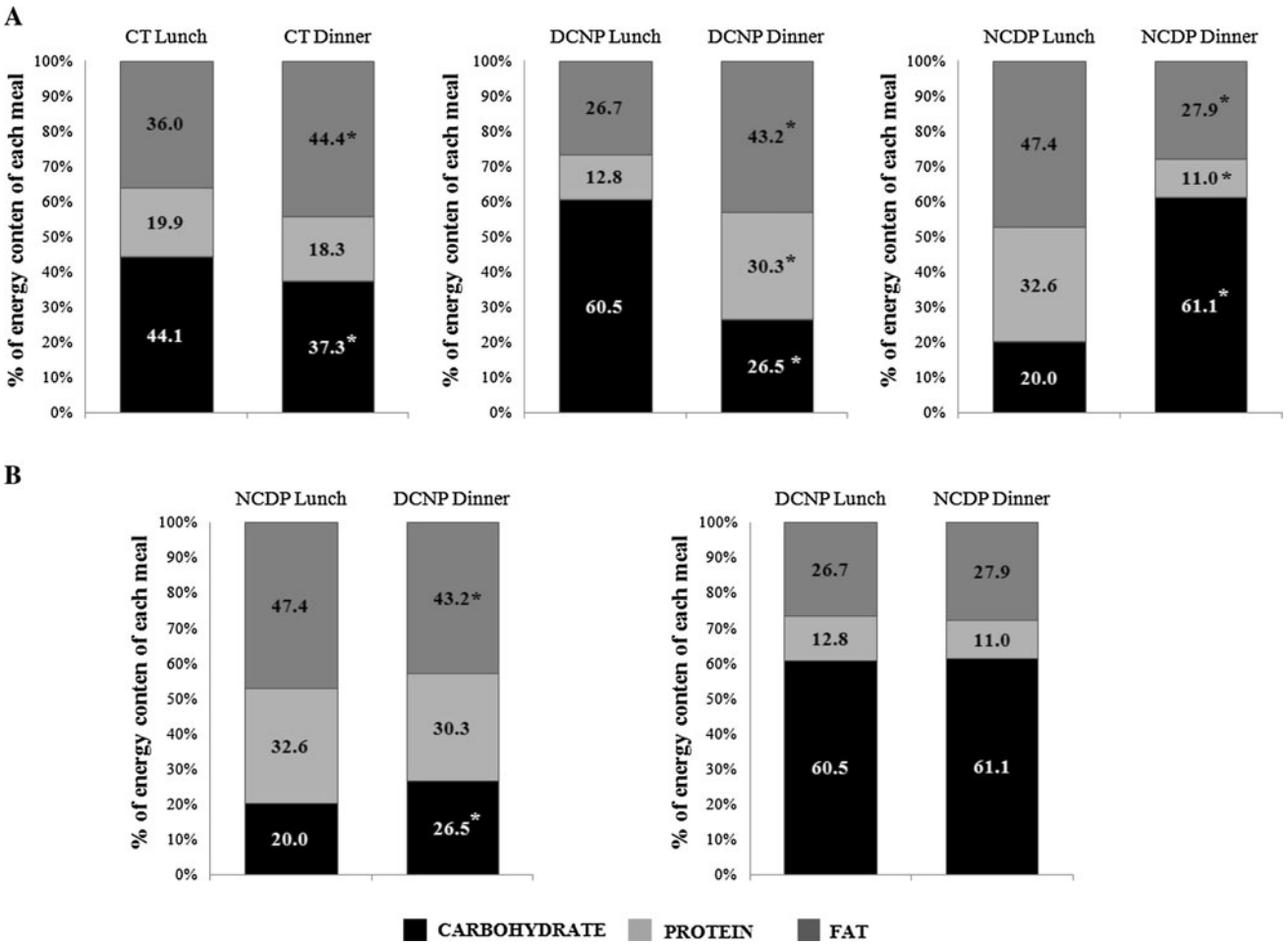

Fig. 1 Macronutrient composition of the lunch and dinner eaten during the intervention period. **a** Comparison of macronutrient composition between lunch and dinner within groups. *Asterisk* represents significant differences ($P < 0.05$ from t test) between lunch and dinner for each macronutrient within of the dietary groups; **b** comparison of macronutrient composition between similar meals of NCDP and DCNP dietary groups. *Asterisk* represents significant differences ($P < 0.05$ from t test) between lunch and dinner for each macronutrient in the different dietary groups. *CT* control group, *DCNP* diurnal carbohydrate/nocturnal protein group, *NCDP* nocturnal carbohydrate/diurnal protein group, *CHO* carbohydrate. Values are mean of each group

observed in the DCNP was also statistically significant compared with other groups (Table 4). Additionally, at the end of the intervention period, subjects included in the NCDP and CT showed a significant decreased in total cholesterol:HDLc and LDL-c:HDL-c ratios ($P < 0.01$), while subjects included in CT also had the total cholesterol and LDL-c concentrations reduced ($P < 0.05$). However, there was no difference between groups.

Energy metabolism

After the intervention, a decrease in the REE was verified in all groups, but it was statistically significant only in NCDP ($P < 0.01$). The average of the decrement of the REE (kcal/day) was 46.2 ± 124.9 in CT, 50.48 ± 114.8 in DCNP and 80.8 ± 104.8 in NCDP. The fasting RQ did not differ between groups at the end of the intervention, even after adjustments ($P > 0.05$).

The results of testing performed at the end of the intervention for DIT and postprandial RQ are shown in Table 5. Before the adjustments, there was no significant difference between the groups in DIT and in iAUC of the energy expenditure either after lunch or after dinner. However, after the adjustments, NCDP presented a significantly higher DIT and iAUC values (kcal × 3 h) after lunch, compared with DCNP.

The comparison between lunch and dinner within groups revealed significant difference only in DCNP, in which the DIT (%) after lunch was lower than after dinner ($P < 0.05$). Furthermore, within the groups, after lunch, the iAUC (kcal × 3 h) was significantly different in all groups, compared with dinner (Table 5).

Table 3 Changes in anthropometric and body composition variables after 8 weeks following covert calorie-restricted diets (CT vs. DCNP vs. NCDP)

	CT ($n = 18$)	DCNP ($n = 21$)	NCDP ($n = 19$)
Δ Weight (kg)	−4.04 ± 1.97**	−3.29 ± 2.47**	−3.81 ± 3.67**
Δ BMI (kg/m^2)	−1.33 ± 0.67**	−0.94 ± 0.59**	−1.20 ± 1.26**
Δ Waist (cm)	−4.95 ± 3.23**	−4.20 ± 2.78**	−5.05 ± 3.56**
Δ Hip (cm)	−2.2 (−3.1 to −1.8)**	−2.5 (−3.5 to −1.8)**	−3.70 (−4.9 to −2.4)**
Δ Waist-hip ratio	−0.02 (−0.04 to -0.01)**	−0.01 (−0.03 to 0.00)	−0.02 (−0.03 to 0.00)*
Δ Fat mass (kg)	−3.01 ± 2.30**	−2.56 ± 1.99**	−2.87 ± 2.74**
Δ Body fat percentage (%)	−2.11 ± 1.91**	−1.89 ± 1.74**	−2.15 ± 2.28**
Δ Fat-free mass (kg)	−1.04 ± 1.43**	−0.72 ± 1.80	−0.94 ± 1.46*
Δ Truncal fat (%)	−1.46 ± 3.52	0.64 ± 5.31	−0.28 ± 4.43

Values are mean ± SD or median (interquartile interval)

CT control group, *DCNP* diurnal carbohydrate/nocturnal protein group, *NCDP* nocturnal carbohydrate/diurnal protein group, Δ, changes = final − baseline data, *BMI* body mass index, *RQ* respiratory quotient

* $P < 0.05$, ** $P < 0.01$, significant difference from baseline (paired *t* test or Wilcoxon test); the changes did not differ between the groups ($P > 0.05$; ANOVA), even after adjustment, according to Tukey–Kramer multiple group comparisons procedure ($P > 0.05$)

Table 4 Changes in biochemical parameters and $HOMA_{IR}$ after 8 weeks following covert calorie-restricted diets (CT vs. DCNP vs. NCDP)

	CT ($n = 18$)	DCNP ($n = 21$)	NCDP ($n = 19$)	*P* value between groups		
				CT vs. DCNP	CT vs. NCDP	DCNP vs. NCDP
Δ Glucose (mg/dL)	1.1 ± 4.9	4.4 ± 4.3*	2.8 ± 6.6	NS	NS	NS
Δ Insulin (μU/mL)	−0.4 ± 3.63	1.83 ± 2.92*	−0.04 ± 1.99	<0.05†	NS	NS
Δ $HOMA_{IR}$	−0.04 ± 0.81	0.52 ± 0.77*	0.02 ± 0.48	<0.05†	NS	<0.05
Δ Total cholesterol (mg/dL)	−13.8 ± 24.1*	−1.1 ± 19.3	−9.7 ± 20.9	NS	NS	NS
Δ Triglycerides (mg/dL)	−2.7 (−19.1–14.6)	1.0 (−12.0–12.0)	−5.0 (−18.0–5.9)	NS	NS	NS
Δ VLDL-c (mg/dL)	−0.5 (−3.8–2.9)	0.2 (−2.4–2.4)	−1.0 (−14.0–8.8)	NS	NS	NS
Δ LDL-c (mg/dL)	−4.6 (−29.1 to −0.1)*	−0.7 (−19.5–9.1)	−4.0 (−27.4–1.5)	NS	NS	NS
Δ HDL-c (mg/dL)	1.4 ± 4.1	1.3 ± 4.4	0.9 ± 4.2	NS	NS	NS
Δ Total cholesterol:HDLc	−0.36 (−0.63 to −0.20)*	−0.04 (−0.51–0.25)	−0.24 (−0.53 to −0.11)*	NS	NS	NS
Δ LDL-c:HDL-c	−0.28 (−0.64 to −0.11)*	−0.04 (−0.57–0.20)	−0.22 (−0.5 to −0.05)*	NS	NS	NS

Values are mean ± SD or median (interquartile interval)

CT control group, *DCNP* diurnal carbohydrate/nocturnal protein group, *NCDP* nocturnal carbohydrate/diurnal protein group, Δ = final − baseline data, *$HOMA_{IR}$* homeostasis model assessment for insulin resistance, *VLDL-c* very-low-density lipoprotein cholesterol, *LDL-c* low-density lipoprotein cholesterol, *HDL-c* high-density lipoproteincholesterol, *NS* non-significant

* Significant difference from baseline ($P < 0.05$; paired *t* test or Wilcoxon test), *P* value column refer to differences between groups ($P < 0.05$; ANOVA or Kruskal–Wallis test followed by Tukey or Dunn's test, respectively).† Differences between groups, according to the Tukey–Kramer multiple group comparisons procedure ($P < 0.05$)

Diet-induced thermogenesis did not differ between NCDP and DCNP after the high-protein/low-carbohydrate meal (NCDP lunch vs. DCNP dinner), neither after the high-carbohydrate/low-protein meal (NCDP dinner vs. DCNP lunch) ($P > 0.05$). However, the increment in iAUC (kcal × 3 h) after the ingestion of the high-carbohydrate/low-protein meal (NCDP dinner vs. DCNP lunch) and after the high-protein/low-carbohydrate meal (NCDP lunch vs. DCNP dinner) was significantly different between NCDP and DCNP, since higher values of iAUC (kcal × 3 h) were verified after dinner (Table 5).

After lunch, no difference was found between groups in RQ ($P > 0.05$). On the other hand, after dinner, RQ was lower in DCNP, compared with CT ($P < 0.01$). The RQ response did not differ between NCDP and DCNP after the high-protein/low-carbohydrate meal (NCDP lunch vs. DCNP dinner), neither after the high-carbohydrate/low-protein meal (NCDP dinner vs. DCNP lunch) ($P > 0.05$).

Table 5 Respiratory quotient and diet-induced thermogenesis during the 3 h after the ingestion of the test meal at end of intervention trial (day 56)

	CT ($n = 18$)	DCNP ($n = 21$)	NCDP ($n = 19$)	P value between groups		
				CT vs. DCNP	CT vs. NCDP	DCNP vs. NCDP
DIT after lunch (%)	6.2 ± 3.4	5.8 ± 2.7 *	7.5 ± 2.2	NS	NS†	NS†
DIT after dinner (%)	7.0 ± 1.7	7.6 ± 2.9 *	7.5 ± 3.8	NS	NS	NS
iAUC after lunch (kcal × 3 h)	52.5 (29.4–78.8)*	48.8 (21.7–146.0)*§	61.9 (27.3–90.6)*§	NS	NS	NS
iAUC after dinner (kcal × 3 h)	100.4 ± 13.9*	109.6 ± 24.9 *§	102.4 ± 22.4*§	NS	NS	NS
RQ after lunch	0.89 (0.88–0.91)	0.88 (0.87–0.90)	0.86 (0.83–0.89)*	NS	NS	NS
RQ after dinner	0.89 ± 0.03	0.86 ± 0.04	0.89 ± 0.03 *	$P < 0.05$	NS	$P < 0.05$

Values are mean ± SD or median (interquartile interval)

CT control group, *DCNP* diurnal carbohydrate/nocturnal protein group, *NCDP* nocturnal carbohydrate/diurnal protein group, *DIT* diet-induced thermogenesis, *iAUC* incremental area under the curve of the energy expenditure, *RQ* respiratory quotient

* Significant difference between lunch and dinner in the same group ($P < 0.05$; paired t test or Wilcoxon test) §Significant difference between the DCNP lunch and the NCDP dinner and/or DCNP dinner and NCDP lunch ($P < 0.05$; t test or Mann–Whitney U test), P value column refer to differences between groups ($P < 0.05$; ANOVA or Kruskal–Wallis test followed by Tukey or Dunn's test, respectively)† Differences between groups, according to the Tukey–Kramer multiple group comparisons procedure ($P < 0.05$)

Besides, the comparison between lunch and dinner within groups revealed significant differences ($P < 0.01$) in RQ only in NCDP (Table 5).

Discussion

One of the main results of this 8-week study was the negative influence on the glucose homeostasis after eating carbohydrates mostly at lunch and protein mostly at dinner. In addition, beneficial effects on energy metabolism, atherogenic indexes, and glucose tolerance were observed for the group that ate carbohydrates mostly at dinner and protein mostly at lunch, which indicates that the meal-time and the type of macronutrient contained in meals influence the metabolism [31, 32].

Weight and body composition

A reducing body fat associated with a maintained fat-free mass represents an important factor to prevent the weight regain [33]. In the current study, eating carbohydrates mostly at lunch associated with eating protein mostly at dinner contributed to the preservation of the fat-free mass since its decrement was not significant only in the DCNP. Sofer et al. [14] investigated the effect of a low-calorie diet (1,300–1,500 kcal) for 6 months, with carbohydrates eaten mostly at dinner, and found higher reduction in body weight, waist circumference, and fat mass compared with control. In turn, Golay et al. [13] evaluated the effect of a low-caloric (1,000 kcal/day) and high-protein diet on the weight loss of obese subjects, during 6 weeks, with a high-protein lunch and a high-carbohydrate dinner, but significant difference was no found between control and experimental diet group for weight loss. Overall, the high-protein dinner may contribute for a protein oxidation in order to maintain the glucose homeostasis during the fasting period at night since the dinner was a low-carbohydrate meal. Thus, the body fat-free mass would be spared in DCNP by using the eaten protein as an energy substrate, although the mechanisms must still be elucidated by further researches.

Energy metabolism

Higher values of DIT and iAUC were observed in NCDP, compared with CT, after dinner ($P > 0.05$). After the adjustments, NCDP showed a significantly higher DIT and iAUC values (kcal × 3 h) after lunch, compared with DCNP. Some authors believe that the thermic effect of protein may remains longer than 6–7 h, which explains these findings [34–36]. The highest thermic effect of protein is attributed to the high ATP cost for protein synthesis, urea production, and gluconeogenesis [34, 36, 37].

There was a significant reduction in fasting REE, in NCDP, after intervention period. This result may partly explain that this group did not show any difference in weight loss, compared with the other groups. Besides, a higher postprandial RQ was found in NCDP after dinner, compared with that obtained for lunch, which demonstrates that preference for lipid oxidation no longer remains. Corroborating the fact that the consumption of higher amounts of protein promotes higher DIT and lower post-

prandial RQ [37] compared with carbohydrate, DCNP presented such results after the consumption of dinner, with significant difference only for RQ. Moreover, no significant difference was observed in CT between lunch and dinner, which reveals equivalence between these meals.

Differences in the oxidation of nutrients throughout the day have been reported [38]. Indeed, Chwalibog and Thorbek [38] reported a significant reduction in nocturnal carbohydrate oxidation (5–7 g/h), compared with the oxidation of this nutrient during the day (12–14 g/h). Furthermore, they found an important, but not significant, increment in fat oxidation at night compared with the daytime. This difference was attributed to the need for maintaining glucose homeostasis. During the day, while carbohydrate is ingested, the glycogen stores remain saturated and, then, most of the carbohydrate is oxidized. On the other hand, in nocturnal fasting periods, glycogen stores start to be used, thus reducing the level of carbohydrate oxidation for their preservation [35, 38].

In addition, Wutzke et al. [15] evaluated 12 individuals with BMI ranging from 19.3 to 35.2 kg/m^2 after 10 days on a diet with carbohydrates eaten mostly at dinner and protein mostly at lunch. They found increased lipid oxidation and reduced respiratory quotient, without altering the protein turnover [15].

Biochemical analyses

Interestingly, we found an increase in fasting glucose, insulin, and $HOMA_{IR}$, in DCNP. This increase in glycemic biomarkers in DCNP could be related to the difference between carbohydrate contents that individuals received during lunch and dinner in this dietary group. In this context, Sofer et al. [14] had observed an improvement in fasting glucose, insulin, and $HOMA_{IR}$ in those subjects who have eaten mostly carbohydrates at dinner. Golay et al. [13] also found similar findings with a carbohydrate load ingested in the evening. In turn, some regulatory mechanisms are activated in order to maintain the glycemia during the fasting period at night, such as: (1) a decrement of the sympathetic nervous system activity, which leads to a reduction in the muscle tone to minimize the glucose usage [39–41]; (2) a reduction in insulin secretion and its peripheral sensitivity [42].

Thus, our results could suggest that the carbohydrate load intake during periods of decreased glucose tolerance (lunch), compared with NCDP, may have contributed to the significant increased blood glucose observed only for DCNP group. At the same time, the statistical increment in fasting serum insulin would be result of a chronic intake of a high-protein dinner, associated with lower insulin sensitivity, activation of regulatory mechanisms to maintain the blood glucose. Besides, the excessive truncal fat accumulation is known to play a role in increased insulin resistance in non-diabetic individuals [43]. Therefore, those results can also be related to the fact that DCNP showed a non-significant ($P > 0.05$) increment in truncal fat while CT and NCDP had a non-significant decrease ($P > 0.05$). However, the effect of these dietary patterns on body fat deposal, blood glucose, insulin and glucose tolerance in the long term, and in other populations deserve further investigation.

Moreover, high concentrations of triglycerides and LDL-c, and low concentrations of HDL-c have characterized an atherogenic lipid profile, frequently found in the metabolic syndrome [44]. Reduced concentrations of total cholesterol and LDL-c were observed only in CT after the intervention period. Besides, a reduced atherogenic index was observed for both CT and NCDP. These results are probably associated with significant reduction in cholesterol intake and changes in body composition.

Limitations of the study

Firstly, the study presented a 31 % of total dropout, which did not except. Indeed, this current study worked at living-free condition, where a 17.9 % of this dropout occurred by personal reason (family diseases, working, or familiar travels, etc.), independently from diet adherence. Secondly, even though there was no difference between groups for caloric restriction and for weight loss ($P > 0.05$), it is important to note that the DCNP subjects had the highest caloric restriction, compared with CT (4.6 %), and NCDP (11.5 %), which could affect the results. However, overweight individuals typically underreport their total caloric intake compared with normal-weight people [45, 46], what could contribute to the difference in dietary record analyses for those that reported higher caloric restriction jointly with a lower weight loss. Finally, the current study is part of the Interuniversity Cooperation between study's centers of different countries, which present samples with different cultural dietary habits. However, similar dietary intervention regarding daily calorie-restriction, daily macronutrient distribution as well as macronutrient distribution in meals of dietary groups were carefully calculated and compared for achieving the same weight loss and the same dissociation in macronutrient contents in meals for future data analyses all together.

Conclusion

This study demonstrated that following, for 8 weeks, a balanced covert hypocaloric diet with carbohydrates eaten mostly at dinner and protein mostly at lunch may be an alternative dietary practice for men with overweight and

obesity, since this type of diet promoted beneficial changes in energy metabolism (DIT) with similar impact on biochemical profile of control diet. On the other hand, eating carbohydrates mostly at lunch and protein mostly at dinner induced some adverse effects on glucose homeostasis, suggesting its potential deleterious effects during weight loss mainly in individuals with diabetes mellitus, metabolic syndrome and those with insulin resistance. Further studies are needed to corroborate and explain the mechanisms that lead to beneficial or harmful effects of the dietary patterns tested in this translational research.

Acknowledgments We wish to thank Carolina P. Zuconi, Navarra's dietitians, all technical staff and individuals who volunteered for this study. This work was supported by the National Council for Scientific and Technological Development (CNPq/MCT/Brazil), CIBERon and RETICS (Spain) as well as a LE/97 from University of Navarra (Spain). The CAPES Foundation (CAPES/MEC/Brazil) provided research grants to R.D.M. Alves and to F.C.E. Oliveira. Finally, The Capes Foundation (Brazil, CAPES/MECD-DGU 218/10) as well as to Ministry of Education of Spain (Spain, HB-2009-0050-PC) funded the Interuniversity Cooperation between the Federal University of Viçosa and the University of Navarra.

Conflict of interest The authors declared no conflict of interest.

References

1. Foz M, Barbany M, Remesar X, Carrillo M, Aranceta J, Garcia-Luna P et al (2000) Consenso SEEDO'2000 para la evaluación del sobrepeso y la obesity y el establecimiento de criterios de intervención terapéutica: Sociedad Española para el Estudio de la Obesity (SEEDO). Med Clin (Barc) 115:587–597
2. Chopra M, Galbraith S, Darnton-Hill I (2002) A global response to a global problem: the epidemic of overnutrition. Bull World Health Organ 80:952–958
3. Abete I, Astrup A, Martinez JA, Thorsdottir I, Zulet MA (2010) Obesity and the metabolic syndrome: role of different dietary macronutrient distribution patterns and specific nutritional components on weight loss and maintenance. Nutr Rev 68:214–231
4. Abete I, Parra MD, Zulet MA, Martinez JA (2006) Different dietary strategies for weight loss in obesity: role of energy and macronutrient content. Nutr Res Rev 19:5–17
5. Barnea M, Madar Z, Froy O (2010) High-fat diet followed by fasting disrupts circadian expression of adiponectin signaling pathway in muscle and adipose tissue. Obesity (Silver Spring) 18:230–238
6. Dandona P, Ghanim H, Chaudhuri A, Dhindsa S, Kim SS (2010) Macronutrient intake induces oxidative and inflammatory stress: potential relevance to atherosclerosis and insulin resistance. Exp Mol Med 42:245–253
7. Goyenechea E, Holst C, Saris WH, Jebb S, Kafatos A, Pfeiffer A, Handjiev S, Hlavaty P, Stender S, Larsen TM, Astrup A, Martinez JA (2011) Effects of different protein content and glycemic index of ad libitum diets on diabetes risk factors in overweight adults: the DIOGenes multicentre, randomised, dietary intervention trial. Diabetes Metab Res Rev 27:705–716
8. Hermsdorff HH, Zulet MA, Abete I, Martinez JA (2011) A legume-based hypocaloric diet reduces proinflammatory status and improves metabolic features in overweight/obese subjects. Eur J Nutr 50:61–69
9. Navas-Carretero S, Abete I, Zulet MA, Martinez JA (2011) Chronologically scheduled snacking with high-protein products within the habitual diet in type-2 diabetes patients leads to a fat mass loss: a longitudinal study. Nutr J 10:74
10. Sumithran P, Prendergast LA, Delbridge E, Purcell K, Shulkes A, Kriketos A, Proietto J (2011) Long-term persistence of hormonal adaptations to weight loss. N Engl J Med 365:1597–1604
11. Ballesteros-Pomar MD, Calleja-Fernandez AR, Vidal-Casariego A, Urioste-Fondo AM, Cano-Rodriguez I (2009) Effectiveness of energy-restricted diets with different protein:carbohydrate ratios: the relationship to insulin sensitivity. Public Health Nutr 13: 2119–2126
12. Sacks FM, Bray GA, Carey VJ, Smith SR, Ryan DH, Anton SD, McManus K, Champagne CM, Bishop LM, Laranjo N, Leboff MS, Rood JC, de Jonge L, Greenway FL, Loria CM, Obarzanek E, Williamson DA (2009) Comparison of weight-loss diets with different compositions of fat, protein, and carbohydrates. N Engl J Med 360:859–873
13. Golay A, Allaz AF, Ybarra J, Bianchi P, Saraiva S, Mensi N, Gomis R, de Tonnac N (2000) Similar weight loss with low-energy food combining or balanced diets. Int J Obes Relat Metab Disord 24:492–496
14. Sofer S, Eliraz A, Kaplan S, Voet H, Fink G, Kima T, Madar Z (2011) Greater weight loss and hormonal changes after 6 months diet with carbohydrates eaten mostly at dinner. Obesity (Silver Spring) 19:2006–2014
15. Wutzke KD, Heine WE, Koster D, Muscheites J, Mix M, Mohr C, Popp K, Wigger M (2001) Metabolic effects of HAY's diet. Isotopes Environ Health Stud 37:227–237
16. Freedman MR, King J, Kennedy E (2001) Popular diets: a scientific review. Obes Res 9:1S–40S
17. Holmback U, Forslund A, Forslund J, Hambraeus L, Lennernas M, Lowden A, Stridsberg M, Akerstedt T (2002) Metabolic responses to nocturnal eating in men are affected by sources of dietary energy. J Nutr 132:1892–1899
18. Institute of Medicine of the National Academies (2002) Dietary reference intakes—energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC
19. Mataix J (2009) Tabla de composición de alimentos, 5th edn. Universidad de Granada, Granada
20. Moreiras O, Carbajal A, Cabrera L et al (2006) Tabla de composición de alimentos, 10th edn. Ediciones Pirámide, Madrid
21. Nepa-Unicamp Tabela Brasileira de Composição de Alimentos (TACO). http://www.unicamp.br/nepa/taco/tabela.php?ativo=tabela&PHPSESSID=c4e41d036165ceea9049b81d2ff680b1. Accessed from July 2008 to December 2009
22. Philippi S (2002) Tabela de composição de alimentos: suporte para decisão nutricional, 2nd edn. Coronário, São Paulo
23. Hermsdorff HH, Zulet MA, Puchau B, Bressan J, Martinez JA (2009) Association of retinol-binding protein-4 with dietary selenium intake and other lifestyle features in young healthy women. Nutrition 25:392–399
24. Hermsdorff HH, Puchau B, Zulet MA, Martinez JA (2010) Association of body fat distribution with proinflammatory gene expression in peripheral blood mononuclear cells from young adult subjects. OMICS 14:297–307
25. Friedewald WT, Levy RI, Fredrickson DS (1972) Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. Clin Chem 18:499–502
26. Castelli WP (1988) Cholesterol and lipids in the risk of coronary artery disease—the Framingham Heart Study. Can J Cardiol 4:5A–10A

27. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC (1985) Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 28:412–419
28. Schwarz JM, Schutz Y, Froidevaux F, Acheson KJ, Jeanpretre N, Schneider H, Felber JP, Jequier E (1989) Thermogenesis in men and women induced by fructose vs glucose added to a meal. Am J Clin Nutr 49:667–674
29. Acheson KJ, Blondel-Lubrano A, Oguey-Araymon S, Beaumont M, Emady-Azar S, Ammon-Zufferey C, Monnard I, Pinaud S, Nielsen-Moennoz C, Bovetto L (2010) Protein choices targeting thermogenesis and metabolism. Am J Clin Nutr 93:525–534
30. Weigle DS, Breen PA, Matthys CC, Callahan HS, Meeuws KE, Burden VR, Purnell JQ (2005) A high-protein diet induces sustained reductions in appetite, ad libitum caloric intake, and body weight despite compensatory changes in diurnal plasma leptin and ghrelin concentrations. Am J Clin Nutr 82:41–48
31. de Castro JM (2007) The time of day and the proportions of macronutrients eaten are related to total daily food intake. Br J Nutr 98:1077–1083
32. Challet E, Mendoza J (2010) Metabolic and reward feeding synchronises the rhythmic brain. Cell Tissue Res 341:1–11
33. Westerterp-Plantenga MS, Lejeune MP, Nijs I, van Ooijen M, Kovacs EM (2004) High protein intake sustains weight maintenance after body weight loss in humans. Int J Obes Relat Metab Disord 28:57–64
34. Halton TL, Hu FB (2004) The effects of high protein diets on thermogenesis, satiety and weight loss: a critical review. J Am Coll Nutr 23:373–385
35. Hermsdorff HH, Volp AC, Bressan J (2007) Macronutrient profile affects diet-induced thermogenesis and energy intake. Arch Latinoam Nutr 57:33–42
36. Oliveira F, Abranches M, Bressan J (2010) Incretins and proteins: new option in the management of diabetes mellitus and obesity. Braz J Clin Nutr 25:66–72
37. Westerterp-Plantenga MS (2008) Protein intake and energy balance. Regul Pept 149:67–69
38. Chwalibog A, Thorbek G (2002) Energy expenditure and oxidation of carbohydrate and fat in humans during day and night. Thermochim Acta 394:247–252
39. Leproult R, Van Cauter E (2010) Role of sleep and sleep loss in hormonal release and metabolism. Endocr Dev 17:11–21
40. Scheen AJ, Van Cauter E (1998) The roles of time of day and sleep quality in modulating glucose regulation: clinical implications. Horm Res 49:191–201
41. Simon C, Weibel L, Brandenberger G (2000) Twenty-four-hour rhythms of plasma glucose and insulin secretion rate in regular night workers. Am J Physiol Endocrinol Metab 278:E413–E420
42. Atkinson G, Fullick S, Grindey C, Maclaren D (2008) Exercise, energy balance and the shift worker. Sports Med 38:671–685
43. Garg A (2004) Regional adiposity and insulin resistance. J Clin Endocrinol Metab 89:4206–4210
44. Grundy SM, Cleeman JI, Daniels SR, Donato KA, Eckel RH, Franklin BA, Gordon DJ, Krauss RM, Savage PJ, Smith SC Jr, Spertus JA, Costa F (2005) Diagnosis and management of the metabolic syndrome. an american heart association/national heart, lung, and blood institute scientific statement. executive summary. Cardiol Rev 13:322–327
45. Scagliusi F, Lancha-Júnior A (2003) Underreporting of energy intake in dietary assessment methods. Braz J Nutr 16:471–478
46. Swinburn BA, Ravussin E (1994) Energy and macronutrient metabolism. Baillieres Clin Endocrinol Metab 8:527–548