Appetite control and biomarkers of satiety with vegetarian (soy) and meat-based high-protein diets for weight loss in obese men: a randomized crossover trial[1–3]

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ABSTRACT

Background: There is limited evidence with regard to the effect of different sources of protein on appetite during weight loss. Vegetarian and meat-based high-protein diets may have contrasting effects on appetite and biomarkers of protein-induced satiety.

Objective: The aim was to assess appetite response to meat or vegetarian high-protein weight-loss (HPWL) diets in obese men to monitor plasma amino acid profile and gut peptide response as potential satiety biomarkers.

Design: Twenty obese [body mass index (in kg/m^2): 34.8] men participated in a dietary intervention study. After 3 d of a maintenance diet, they were provided in a crossover design with either a vegetarian HPWL (Soy-HPWL) or a meat-based HPWL (Meat-HPWL) diet for 2 wk. Both diets comprised 30% protein, 30% fat, and 40% carbohydrate, provided to measured resting metabolic rate. Body weight and the motivation to eat were measured daily. Plasma satiety biomarkers were collected during a test-meal challenge (5 h) at the end of each diet period.

Results: Over the 2 wk, subjects lost, on average, 2.41 and 2.27 kg with consumption of the Soy- and Meat-HPWL diets, respectively [P = 0.352; SE of the difference (SED): 0.1]. ANOVA confirmed that subjectively rated hunger (P = 0.569; SED: 3.8), fullness (P = 0.404; SED: 4.1), desire to eat (P = 0.356; SED: 3.7), preservation of lean body mass (P = 0.334; SED: 0.2), and loss of percentage fat mass (P = 0.179; SED: 0.2) did not differ between the 2 HPWL diets. There were differences in absolute concentrations of ghrelin and peptide YY between the 2 HPWL diets, although the response as net area under the curve was not different.

Conclusions: Appetite control and weight loss were similar for both HPWL diets. Gut hormone profile was similar between the diets, which suggests that vegetarian diets can be as effective as meat-based diets for appetite control during weight loss. This trial was registered at www.clinicaltrials.gov as NCT02080325. *Am J Clin Nutr* 2014;100:548–58.

INTRODUCTION

Along with the escalating obesity problem comes the need for both preventative nutrition and treatment options. Weight loss is easy in principle, whereby energy intake needs to be less than expenditure. However, in practice, this is a challenge for obese individuals. One of the main limitations to weight loss is hunger, which can undermine the dietary control required, and is one of the main reasons why people fail to comply with a weight-loss diet (1). Diet composition is an important factor in modifying motivation to eat, with a particular interest in protein to achieve appetite control. Previous work indicated that high-protein (30% protein) meat-based weight-loss diets are highly satiating and reduce ad libitum food intake over a 4-wk period (2). In a 6-mo randomized trial in 60 overweight and obese subjects, fat loss was almost double in subjects who received a high-protein diet (25% of energy; 128–139 g/d) compared with those who consumed a moderate-protein diet (12% of energy; 76–80 g/d) (3). The benefits of a higher-protein diet were also shown in longer-term studies. In a 12-mo study, 50 overweight and obese subjects initially spent 6 mo consuming a high-protein (25% of energy) or medium-protein (12% of energy) diet. Consistent with previous studies, weight loss was greater in the high-protein group (−9.4 compared with −5.9 kg) (4). There is limited data on assessing the effect of different types of protein on appetite in chronic feeding studies. Previously, a mixed meat source of protein was used in high-protein diets, but this approach has been criticized both from a policy and public health perspective because of potential negative side effects, especially on gut health (5). Dietary modulation of protein amounts resulted in a significant change in the human gut metabolome: that is, weight-loss diets that were high in protein but reduced in total carbohydrates and fiber resulted in a significant decrease in fecal cancer-protective metabolites and increased concentrations of hazardous metabolites (6). Long-term adherence to such diets may increase the risk of colonic disease (7).

It may be that alternative vegetable sources of protein could be satiating and yet maintain a healthy gut during weight loss. There are limited data on appetite response to different protein sources in chronic feeding studies; indeed, no controlled dietary

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[2] Supported by the Rowett Institute of Nutrition and Health and Biomathematics and Statistics Scotland, Scottish government's Rural and Environment Science and Analytical Services Division (RESAS), and a research grant award from the Alpro Foundation to fund the blood analysis.

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Received October 11, 2013. Accepted for publication May 15, 2014.
First published online June 18, 2014; doi: 10.3945/ajcn.113.077503.

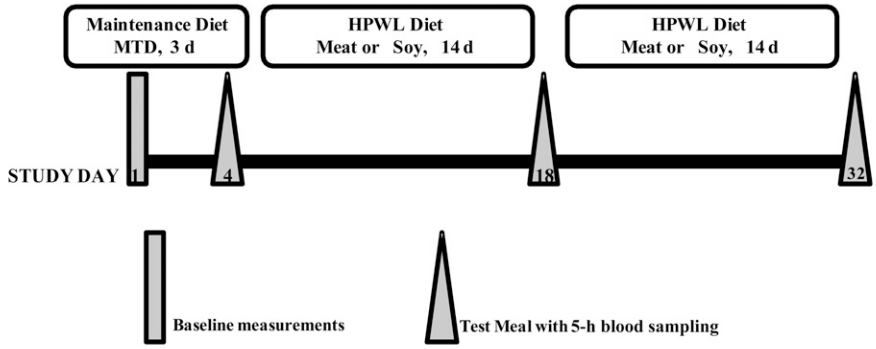

FIGURE 1. Diagram of the study protocol. After a normal-protein MTD for 3 d (days 1–3), the order of treatment was randomly assigned in a within-subject, crossover design, whereby one-half of the subjects began with the meat-based HPWL diet for 14 d (days 4–17) and the other half of subjects began with the vegetarian HPWL diet for 14 d (days 18–31). Test meals were at the end of each diet phase, corresponding to days 4, 18, and 32. HPWL, high-protein weight loss; MTD, maintenance diet.

high-protein weight-loss (HPWL)[4] studies on vegetarian diets have been conducted, even although there is acceptance that a vegetable-based weight-loss diet may offer protection from diseases (8). The current human dietary intervention study therefore investigated the mechanistic processes involved in protein-induced satiety during weight loss, comparing a vegetarian HPWL (Soy-HPWL) diet with a meat-based HPWL (Meat-HPWL) diet. Appetite biomarkers were monitored in response to a test meal challenge, specifically plasma amino acid profile and ghrelin, peptide YY (PYY), and glucagon like peptide 1 (GLP-1). The current study compares hunger and appetite response in healthy obese men who consumed a fixed diet for weight loss as a Soy-HPWL or a Meat-HPWL diet in a controlled dietary intervention setting.

SUBJECTS AND METHODS

Subjects

Twenty overweight or obese men [BMI (in kg/m^2) >27] were recruited by public notice to participate in a dietary trial. The study's starting date was December 2009. Thus, the subjects were nonrandomly selected persons who were sufficiently motivated to actively respond to the request for subjects. Inclusion criteria specified that all subjects should not have existing medical conditions or medications that could influence their appetite or mood. All subjects had normal-range results on clinical biochemistry and hematologic testing prestudy. During recruitment, subjects underwent a medical examination and their general practitioners were contacted to confirm their medical suitability for participation in the study. Written informed consent was obtained from all subjects. The study was approved by the North of Scotland Research Ethics Service. No subjects withdrew from the study; thus, all 20 volunteers completed the study.

For this study, the subjects visited the Human Nutrition Unit (HNU) at the Rowett Institute of Nutrition and Health, Aberdeen, United Kingdom. All food and drink consumed during the maintenance diet (MTD) and Soy-HPWL and Meat-HPWL diet periods were supplied by dietetic staff of the HNU, and the food served was weighed before and after consumption to monitor intake. The protocol was a within-subjects crossover design and lasted 31 d as shown in **Figure 1**: days 1–3, normal-protein MTD (3 d); days 4–17, randomly assigned to receive the Meat-HPWL or Soy-HPWL diet (14 d); days 18–31, randomly assigned to receive the Meat-HPWL or Soy-HPWL diet (14 d), depending on random allocation in the previous period. Subjects attended the HNU for a breakfast test meal (MTD meal, Soy-HPWL meal, or Meat-HPWL meal) at the end of each diet phase, corresponding to study days 4, 18, and 32.

Formulation and preparation of the diets

The MTD (days 1–3) consisted of 15% protein, 30% fat, and 55% carbohydrate supplied to 1.5 × measured resting metabolic rate (RMR). The Soy-HPWL or Meat-HPWL diet was consumed to 100% of RMR on a 5-d rotation menu as 3 meals/d (30% protein, 30% fat, and 40% carbohydrate). The Meat-HPWL diet was based on chicken and beef; the Soy-HPWL diet was based on soy protein or soy–textured vegetable protein. Soy protein is widely available as milk (Alpro); margarine (Pure; Kerry Foods); enhanced bread (Burgen; ABF Grain Products Ltd); sausages, bacon, burgers, and mince (Granose; Symington's Ltd); powdered isolate (Pulsin Ltd); cheese (dairy free; VBites Foods Limited); cream (Soy Dream; The Hain Celestial Group Inc); yogurt (Alpro); and chicken-style filets (Grassingtons; Dalepak Foods). All intervention meals had the same weight and energy content. The composition of each meal, in terms of energy, fat, carbohydrate, and protein, was calculated by using *McCance and Widdowson's The Composition of Foods* (9).

Energy and nutrient intakes were calculated by using WINDIETS software (version 1.0; Univation Ltd; The Robert Gordon University, Aberdeen). During the 3-d MTD (consumed to energy balance), subjects received, on average, 13.6 MJ/d; during the Meat-HPWL or Soy-HPWL diet period, subjects wereprovided with, on average, 8.7 MJ/d, which was 100% of measured RMR. The test meals (MTD meal, Soy-HPWL meal, and Meat-HPWL meal) provided were the same as consumed on other days (within each phase), within the rotating menu. On average, meals provided one-third of daily energy requirements, and each meal had an identical composition within each diet phase.

[4]Abbreviations used: DEBQ, Dutch Eating Behavior Questionnaire; GLP-1, glucagon-like peptide 1; HNU, Human Nutrition Unit; HPWL, high-protein weight loss; Meat-HPWL, meat-based high-protein weight loss; MTD, maintenance diet; PYY, peptide YY; RMR, resting metabolic rate; SED, SE of the difference; Soy-HPWL, vegetarian high-protein weight loss; TFEI, Three-Factor Eating Inventory; VAS, visual analog scale.

Measurement of anthropometric variables, RMR, and blood pressure

Measurements of body composition and RMR were conducted under standardized conditions (10). Before the test, the subjects fasted overnight (10 h) and were advised not to consume caffeine or to smoke. Their height was measured to the nearest 0.1 cm with the use of a stadiometer (Holtain Ltd) at the beginning of the study.

Body density was calculated with the use of air-displacement whole-body plethysmography (Bod Pod Body Composition System; Life Measurement Instruments). Abdominal, gluteal (hip) circumference, and skinfold thickness measurements were taken at the beginning and end of each dietary intervention period, as previously described (11), according to the guidelines of the International Standards for Anthropometric Assessment. RMR was measured at the beginning and end of each dietary intervention period by using indirect calorimetry with the use of a ventilated hood system (Deltatrac II, MBM-200; Datex Instrumentarium Corporation), as previously described (11).

Blood pressure was monitored at the beginning and the end of each dietary intervention period with the use of an automated system (Omron M5-1; Omron Health Care). Subjects remained supine for 10 min before the measurement, and the average of 3 measures taken 5 min apart was recorded.

The subjects visited the HNU daily for weight measurements, which were taken after voiding and while wearing only a previously weighed dressing gown to the nearest 100 g on a digital scale (DIGI DS-410; CMS Weighing Equipment).

Assessment of appetite

Hunger and appetite were measured hourly during the waking hours (0700–2300) with the use of visual analog scales (VASs), as previously described (12). In this study, a handheld electronic computer was used (Visor Handspring; Palm Inc). Six questions were asked on motivation to eat, all in the line scale format related to hunger, thirst, preoccupation with thoughts of food, fullness, desire to eat, and prospective consumption. The scales ranged from "not at all hungry" to "extremely hungry," so that higher scores indicated more intense subjective sensations. These questionnaires were completed by the subjects each day of the study; subjects were instructed to allow at least 5 h between breakfast and lunch and lunch and dinner and to consume all of the food provided. Subjects received feedback on their ad libitum food diaries; they received general leaflets on protein and soy and as well a booklet containing all of the recipes from the study.

Assessment of the pleasantness of the meals

The pleasantness of the study meals was assessed with the use of the VAS, as described previously (12), on the Visor Handspring handheld computer (Palm Inc). Subjects were prompted to record, on a line scale 15 min after eating, responses to 3 questions related to how pleasant, satisfying and enjoyable the meals were. The scales ranged from "extremely unpleasant" to "extremely pleasant," and higher scores indicated more pleasant meals. The questionnaires are used to rate the whole meal, rather than aspects associated with specific food items. The use of the questionnaires after eating captures subjects' feelings of meal palatability in the early postingestion phase. These questionnaires were completed by the subjects each day of the study.

Self-reported influences of eating behavior on mood

Subjects self-completed 2 questionnaires on the days of the test meals (days 4, 18, and 32 of the study): the Dutch Eating Behavior Questionnaire (DEBQ) (13) and the Three-Factor Eating Inventory (TFEI). The DEBQ assesses "restrained," "emotional," and "external" eating. Influences on eating behavior were assessed by using the TFEI (14), which relates to "hunger," "cognitive restraint of eating," and "disinhibition." No changes in DEBQ or TFEI scores were detected during the study, and subjects were not classified as restrained eaters (data not shown).

Compliance and metabolic profile

Subjects attended the HNU at the Rowett Institute on days 4, 18, and 32 for a test meal with blood sampling hourly for 5 h. Blood samples were collected from the hand by using a cannula and used to measure plasma amino acid concentrations, determined by isotope dilution with a gravimetric approach (to provide μmol/L), as described previously (15), as well as homocysteine (16) and arginine. The latter was monitored at an *m/z* of 442 and 448 as a nitrile breakdown product of the derivative eluted between lysine and histidine (17). Replication of in-house analysis of plasma samples (n = 10) produced a CV for most amino acids ranging from 0.5% to 1.0%. The recovery of 25, 50, 100, and 250 nmol amino acids added to plasma ranged from 96% to 103%. Total amino acid concentrations were used as a biomarker for protein metabolism.

All of the plasma metabolites (including lipid profile, glucose, and insulin) were measured as previously described (2), and hormones relating to appetite (total PYY, total ghrelin, and active GLP-1) were analyzed by using ELISA kits from Millipore (catalog nos. EZHPYYT66K, EZGRT-89K, and EGLP-35K), with a within-assay CV of 0.9–5.8% and a between-assay of 3.7–16.5% for the PYY kit; a within-assay CV of 1.1–1.9% and a between-assay of 5.2–7.7% for the ghrelin kit, and a within-assay CV of 7.4 ± 1.1% and a between-assay of 8 ± 4.8% for the GLP-1 kit. Blood samples were additionally collected once a week from overnight-fasted subjects for measurement of urea and electrolytes (data not shown) to ensure diet safety.

Statistical analysis

A sample size of 20 subjects has ∼90% power to detect differences comparable to within-subject variability (Cohen's d = 1.0). A power calculation for hunger scores was conducted. Computer-generated random numbers were used to assign the subjects in pairs to first receive either the Meat-HPWL or the Soy-HPWL diet.

Data on energy intake, body weight and composition, blood metabolites, and meal ratings were analyzed by ANOVA, with subject, period, and day within period as blocking factors (random effect) and diet and day as treatment terms. The VASs were affected by a high rate of noncompliance (47%), leading to highly unbalanced data, and so were analyzed as a mixed model by residual maximum likelihood with random effects for subject, period, day within period, and time within day and fixed effects for diet, day, and time of day and their interactions. In all analyses, the significance of the contrast between the Meat-HPWL and Soy-HPWL diets was also evaluated by repeating the analysis with the MTD omitted and an additional fixed effect for period included. All analyses were carried out by using Genstat 12.1 (Lawes Agricultural Trust, VSN International Ltd). The gut hormone data for AUC and net AUC were estimated by using the trapezoid rule and were also analyzed by hierarchical ANOVA with terms for subject, diet test day within subject, and time within test day. $P < 0.05$ was regarded as significant.

RESULTS

Weight loss and body composition

Subjects' baseline characteristics and body composition are shown in **Table 1**. Body weight loss (±SEM) was no different between Soy-HPWL (−2.41 ± 0.22 kg) and Meat-HPWL (−2.27 ± 0.19 kg) diet groups [$P = 0.352$; SE of the difference (SED): 0.1], which reflects the similar energy intake (**Table 2**). The daily changes in body weight with the Soy-HPWL and Meat-HPWL diets are shown in **Figure 2**. ANOVA of body composition indicated no statistical difference for loss of lean and fat mass between the Soy-HPWL and Meat-HPWL diets. On average, fat-free mass loss was –0.67 ± 0.21 and –0.65 ± 0.32 kg with the Soy-HPWL and Meat-HPWL diets, respectively ($P = 0.334$; SED: 0.2), for absolute values; fat mass loss was –2.07 ± 0.29 and –2.02 ± 0.26 kg with the Soy-HPWL and Meat-HPWL diets, respectively ($P = 0.596$, SED: 0.3), for absolute values. The percentage fat loss for the 2 diets was therefore similar: on average, −1.04 ± 0.27% and –1.03 ± 0.27% with the Soy-HPWL and Meat-HPWL diets, respectively ($P = 0.179$; SED; 0.2).

Food, energy, and nutrient intake

Mean daily energy intakes for the MTD and Meat-HPWL and Soy-HPWL diets are summarized in Table 2. Mean (±SEM) energy intakes were 13.06 ± 0.19, 8.78 ± 0.07, and 8.67 ± 0.07 MJ for the MTD, Meat-HPWL diet, and Soy-HPWL diet, respectively. The composition of macronutrient intakes during the 3 study phases is shown in Table 2. The Soy-HPWL and Meat-HPWL diets were not different in total macronutrient composition; only different protein sources were used.

TABLE 1
Baseline characteristics and body composition of the study subjects

Characteristic	Value
n	20
Age (y)	51 ± 11.4 (34–71)[1]
Height (m)	1.77 ± 0.06 (1.68–1.92)
Weight[2] (kg)	109.6 ± 17.2 (81.6–144.1)
BMI (kg/m^2)	34.8 ± 3.8 (26.5–43.0)
Resting metabolic rate (MJ)	8.850 ± 1.184 (6.834–11.077)
Body fat[3] (%)	38.1 ± 6.90 (27.11–46.70)
Waist circumference (cm)	119.02 ± 12.88 (95.70–142)
Systolic blood pressure (mm Hg)	137.22 ± 9.68 (121–153)
Diastolic blood pressure (mm Hg)	81.88 ± 7.78 (67–93)

[1] Mean ± SD; range in parentheses (all such values).
[2] Body weight was measured at the end of the maintenance diet, with all subject data pooled, before random assignment to the vegetarian high-protein weight-loss diet or the meat-based high-protein weight-loss diet.
[3] Measured by using a 4-compartment model (10).

TABLE 2
Composition of the diets used in the study[1]

	Diet		
	MTD	Meat-HPWL	Soy-HPWL
Energy (MJ)	13.06 ± 0.19	8.78 ± 0.07	8.67 ± 0.07
Fat			
(g)	105.49 ± 1.64	71.15 ± 0.54	70.40 ± 0.53
(MJ)	3.90 ± 0.06	2.63 ± 0.02	2.61 ± 0.02
(%)	29.90 ± 0.03	29.98 ± 0.01	29.99 ± 0.01
Protein			
(g)	115.44 ± 1.71	154.74 ± 1.14	153.03 ± 1.16
(MJ)	1.96 ± 0.03	2.63 ± 0.02	2.60 ± 0.02
(%)	15.04 ± 0.02	29.97 ± 0.01	29.94 ± 0.01
Carbohydrate			
(g)	449.39 ± 6.69	219.81 ± 1.63	217.48 ± 1.59
(MJ)	7.19 ± 0.11	3.52 ± 0.03	3.48 ± 0.03
(%)	55.08 ± 0.03	40.06 ± 0.01	40.08 ± 0.02

[1] All values are means ± SDs. Meat-HPWL, meat-based high-protein weight-loss (14 d); MTD, maintenance diet (for 3 d); Soy-HPWL, vegetarian high-protein weight-loss (14 d).

Motivation to eat

ANOVA confirmed that across the 14 d, subjectively rated hunger ($P = 0.569$), fullness ($P = 0.404$), and desire to eat ($P = 0.356$) were not different between the Soy-HPWL and Meat-HPWL diets; **Figure 3** shows the average daily hunger score for each diet, per hour. The motivation to eat was not different between the Soy-HPWL and Meat-HPWL diets.

Pleasantness of the diets

Palatability was highly rated for all meals (78–89 out of 100 mm on the VAS) for pleasantness, satisfaction, and enjoyment of the meals provided. The statistical analysis (ANOVA) for the free-living subjects showed a significant diet effect ($P = 0.021$), with the Meat-HPWL diet (89.1, 86.6, and 86.0 mm for breakfast, lunch, and dinner, respectively) being preferred over the MTD (78.6, 85.1, and 82.1 mm for breakfast, lunch, and dinner, respectively) or the Soy-HPWL diet (82.7, 78.3, and 80.5 mm for breakfast, lunch, and dinner, respectively), as assessed by postmeal pleasantness ratings. There was also a significant meal × diet interaction for pleasantness ($P = 0.002$), satisfaction ($P = 0.011$), and enjoyment ($P < 0.001$). On average, subjects reported a lower score for the MTD breakfast and the Soy-HPWL lunch compared with the other meal provisions.

Compliance and metabolic profile

Concentrations of blood metabolites after the MTD and the end of each Meat-HPWL and Soy-HPWL diet are shown in **Table 3**. From end of baseline (MTD), there was a significant ($P < 0.001$) increase in plasma albumin, creatine (for the Meat-HPWL diet only, not Soy-HPWL diet), hydroxybutyrate, and urea, reflecting the negative energy balance and higher protein intake. There was a significant ($P < 0.001$) decrease from baseline in average plasma cholesterol, LDL cholesterol, HDL

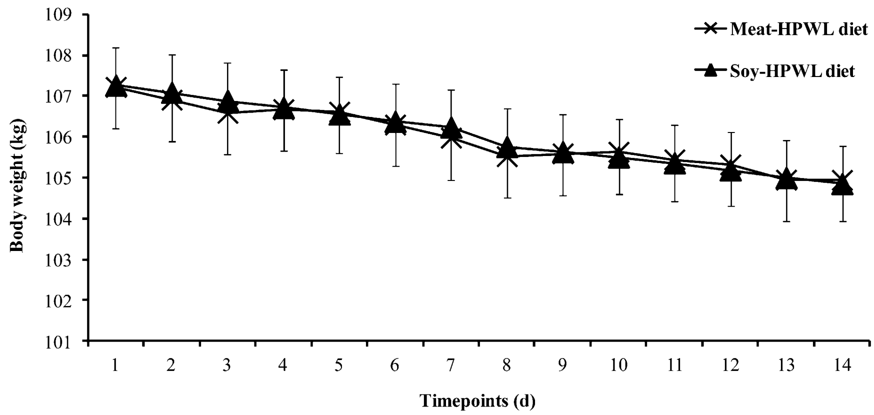

FIGURE 2. Mean (±SEM) daily body weight with consumption of the Meat-HPWL diet and the Soy-HPWL diet for the 20 subjects. On average, subjects lost 2.41 and 2.27 kg with consumption of the Soy-HPWL and the Meat-HPWL diets, respectively ($P = 0.356$; SE of the difference: 3.7), which was confirmed with ANOVA; $n = 20$. Meat-HPWL, meat-based high-protein weight loss; Soy-HPWL, vegetarian high-protein weight loss.

cholesterol, triglycerides, and glucose for both Meat-HPWL and Soy-HPWL diets. A comparison between the Meat-HPWL and Soy-HPWL diets showed that there was a greater increase in creatine with the Meat-HPWL diet ($P < 0.001$) and there was a greater reduction in total cholesterol with the Soy-HPWL diet ($P < 0.001$).

Gut hormones

The gut hormones GLP-1, ghrelin, and PYY were measured in the fasted state in plasma at baseline (time 0) and thereafter every hour after the test meal for 5 h. Mean group data are shown in **Figure 4**. In general, there were diet effects for ghrelin and PYY but not for GLP-1. ANOVA for absolute concentration and AUC or net AUC for GLP-1 confirmed no significant diet effect when comparing all 3 diets (MTD, Meat-HPWL, and Soy-HPWL) or the 2 HPWL diets (Meat-HPWL and Soy-HPWL).

Significant differences in the hunger hormone ghrelin were found when comparing all 3 diets by using ANOVA ($P < 0.001$), AUC ($P < 0.001$), and net AUC ($P = 0.003$). There were no significant differences between the 2 HPWL diets by ANOVA ($P = 0.053$), AUC ($P = 0.075$), or net AUC ($P = 0.497$). Ghrelin concentrations were lower with the Meat-HPWL diet than with Soy-HPWL diet, but this trend was nonsignificant. The PYY gut hormone was significantly affected by diet by using ANOVA, comparing concentrations between all 3 diets ($P = 0.002$) and similarly between the 2 HPWL diets ($P < 0.001$). The PYY average values over the time course were 124.4, 101.1, and 123.7 pg/mL (SEM: 4.77).

When the analysis of the PYY results was conducted by using AUC, similar results were obtained comparing all 3 diets ($P = 0.003$) or the 2 HPWL diets ($P = 0.001$). However, no significant diet effect for PYY was found when considering net AUC data. This indicates that there were different absolute concentrations of PYY in response to diet, but that the patterns of expression were similar for the diets and that they were not different between the 2 HPWL diets.

Amino acid profile

Plasma amino acids were measured before (baseline) and after consumption of each test meal every hour for 5 h. The group results are shown in **Table 4** as mean amino acid concentrations (±SD) (μmol/L) by diet × time. When comparing all 3 diets,

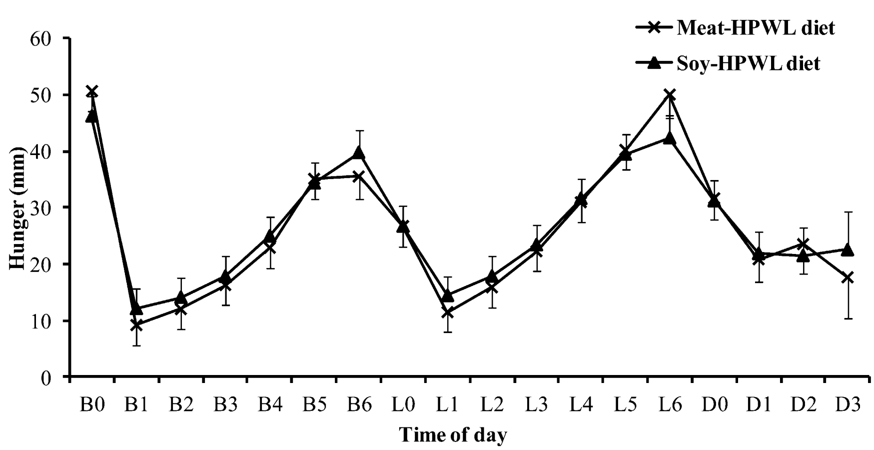

FIGURE 3. Mean (±SEM) daily average hunger as assessed with the visual analog scale presented by time of day (in which B is breakfast, L is lunch, and D is dinner and the number indicates hours after meal) with consumption of the Meat-HPWL diet and the Soy-HPWL diet for the 20 subjects. Over the 2 wk, ANOVA confirmed that subjectively rated hunger ($P = 0.569$; SE of the difference: 3.7) was not different between the 2 HPWL diets; $n = 20$. HPWL, high-protein weight loss; Meat-HPWL, meat-based high-protein weight loss; Soy-HPWL, vegetarian high-protein weight loss.

TABLE 3
Average plasma concentration of metabolites after each study diet[1]

	Blood metabolites in plasma[2]			Comparison between all 3 diets[3]		Comparison between HPWL diets[3]	
	After MTD	After Meat-HPWL diet	After Soy-HPWL diet	*P*	SED	*P*	SED
Albumin (g/L)	40.58 ± 1.14	41.68 ± 1.14	41.63 ± 1.33	<0.001	0.25	NS	0.22
Cholesterol (mmol/L)	4.77 ± 0.80	3.88 ± 0.77	3.52 ± 0.61	<0.001	0.08	<0.001	0.06
Hydroxybutyrate (mmol/L)	0.09 ± 0.07	0.37 ± 0.39	0.49 ± 0.34	<0.001	0.08	<0.05	0.08
LDL cholesterol (mmol/L)	3.21 ± 0.72	2.54 ± 0.75	2.24 ± 0.59	<0.001	0.07	<0.001	0.05
Triglyceride (mmol/L)	1.72 ± 0.39	1.08 ± 0.26	1.06 ± 0.24	<0.001	0.06	NS	0.04
LDL:HDL-cholesterol ratio	3.36 ± 1.03	2.80 ± 0.97	2.60 ± 0.91	<0.001	0.1	<0.05	0.06
Total:HDL-cholesterol ratio	4.97 ± 1.12	4.27 ± 1.06	4.06 ± 0.98	<0.001	0.13	<0.05	0.08
HDL cholesterol (mmol/L)	0.98 ± 0.17	0.93 ± 0.13	0.89 ± 0.15	<0.01	0.02	<0.01	0.01
Glucose (mmol/L)	5.73 ± 0.62	5.38 ± 0.47	5.43 ± 0.42	<0.001	0.09	<0.05	0.06
Urea (mmol/L)	5.70 ± 1.35	6.71 ± 1.48	6.55 ± 1.54	<0.001	0.24	<0.05	0.22
Creatine (μmol/L)	88.60 ± 11.36	90.87 ± 10.81	84.13 ± 10.64	<0.001	1.48	<0.001	1.26
Total bilirubin (μmol/L)	13.52 ± 5.36	13.60 ± 6.12	13.97 ± 5.97	NS	0.6	<0.05	0.56

[1] n = 20. HPWL, high-protein weight-loss; Meat-HPWL, meat-based high-protein weight-loss (14 d); MTD, maintenance diet (for 3 d); SED, SE of the difference; Soy-HPWL, vegetarian high-protein weight-loss (14 d).
[2] Values are mean ± SD plasma concentration of metabolites after each diet: MTD, Meat-HPWL, and Soy-HPWL.
[3] Determined by using ANOVA.

a significant time × diet interaction was found for all amino acids ($P < 0.05$), except for cysteine ($P = 0.059$). Mean amino acid concentrations (±SD) by diet for the 5 h after each test meal are shown in **Table 5**. When comparing the MTD, Meat-HPWL diet, and Soy-HPWL diet, ANOVA showed a significant diet effect ($P < 0.001$) on amino acid concentrations for alanine, arginine, glutamine, glutamic acid, glycine, histidine, isoleucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, and tyrosine. The diet effect on plasma concentration of amino acids was significant when comparing the 3 diets (MTD, Meat-HPWL, and Soy-HPWL) from the study by using ANOVA ($P \leq 0.05$), except for cysteine, leucine, and valine for which there was no significant effect. For the 20 amino acids measured, concentrations of 12 of them were statistically significantly different between Meat-HPWL and Soy-HPWL diets; concentrations of 10 amino acids were lower in the Meat-HPWL diet compared with the Soy-HPWL diet (arginine, aspartic acid, glutamic acid, isoleucine, phenylalanine, proline, serine, threonine, tryptophan, and tyrosine) and concentrations of 2 amino acids were higher in Meat-HPWL diet (lysine and methionine).

We conducted correlational analysis to assess the relation between the subjective data on appetite (VAS) and the biomarkers (plasma amino acid profile and gut hormones) but failed to identify any significant associations. No significant statistical correlations were observed between gut hormone, hunger, and amino acids data nor between appetite and blood biomarkers (data not shown).

DISCUSSION

The aim of the current study was to assess the impact of a Soy-HPWL diet compared with a Meat-HPWL diet in healthy, overweight men on subjectively rated appetite and biomarkers of satiety as measured by plasma amino acid profile and gut-related hormones (PYY, ghrelin, and GLP-1). To our knowledge, there have been no studies to compare vegetarian and meat-based high-protein diets on appetite control during weight loss. When conducting appetite research, it is difficult to control all variables, and this study will have limitations to the results. Within this study design, there was no washout period between HPWL diets, and this may contribute to short-term fluctuations in motivation to eat and body weight in the initial couple days of dietary changeover. However, these effects were minimized within the statistics by consideration of diet order and had minimal impact by the end of the 2-wk period at test meals. The low compliance of subjects to complete VASs over weeks is a challenge; ANOVA and the related residual maximum likelihood analysis took these missing values into account, and the interpretation of the data did not change. Furthermore, these study diets only lasted 2 wk, and we cannot be sure that weight loss and appetite impact will be maintained over a much longer period of time. Studies tend to indicate that HPWL diets are effective up to 12 mo, and thereafter that compliance to the diet regimen is lacking due to motivational issues linked to dieting (5). We also note that gut hormone blood samples were analyzed from 60 min onward, and that it is possible that there may have been an earlier peak in hormone concentration before this time, which was not detected within this protocol.

We did not measure anticipatory or expected satiety in this study [eg, Bertenshaw et al (24)], which would have been useful to monitor response to the meals. However, we did not observe any VAS data to support the hypothesis that the sensory characteristics of the meals influenced satiety, with no time course effects within diet phase. We did not tell subjects which diet they were receiving, and we did not tell them that appetite was a major outcome in the study.

Biomarkers of appetite and satiety

Gut hormones

The gut hormone data are presented as absolute concentrations, and when interpreting the data one could consider whether it is the change in concentration that represents an appetite cue or whether there are absolute concentrations required to enhance a response. PYY expression in the Meat- and Soy-HPWL diets showed very similar trends but with significantly higher

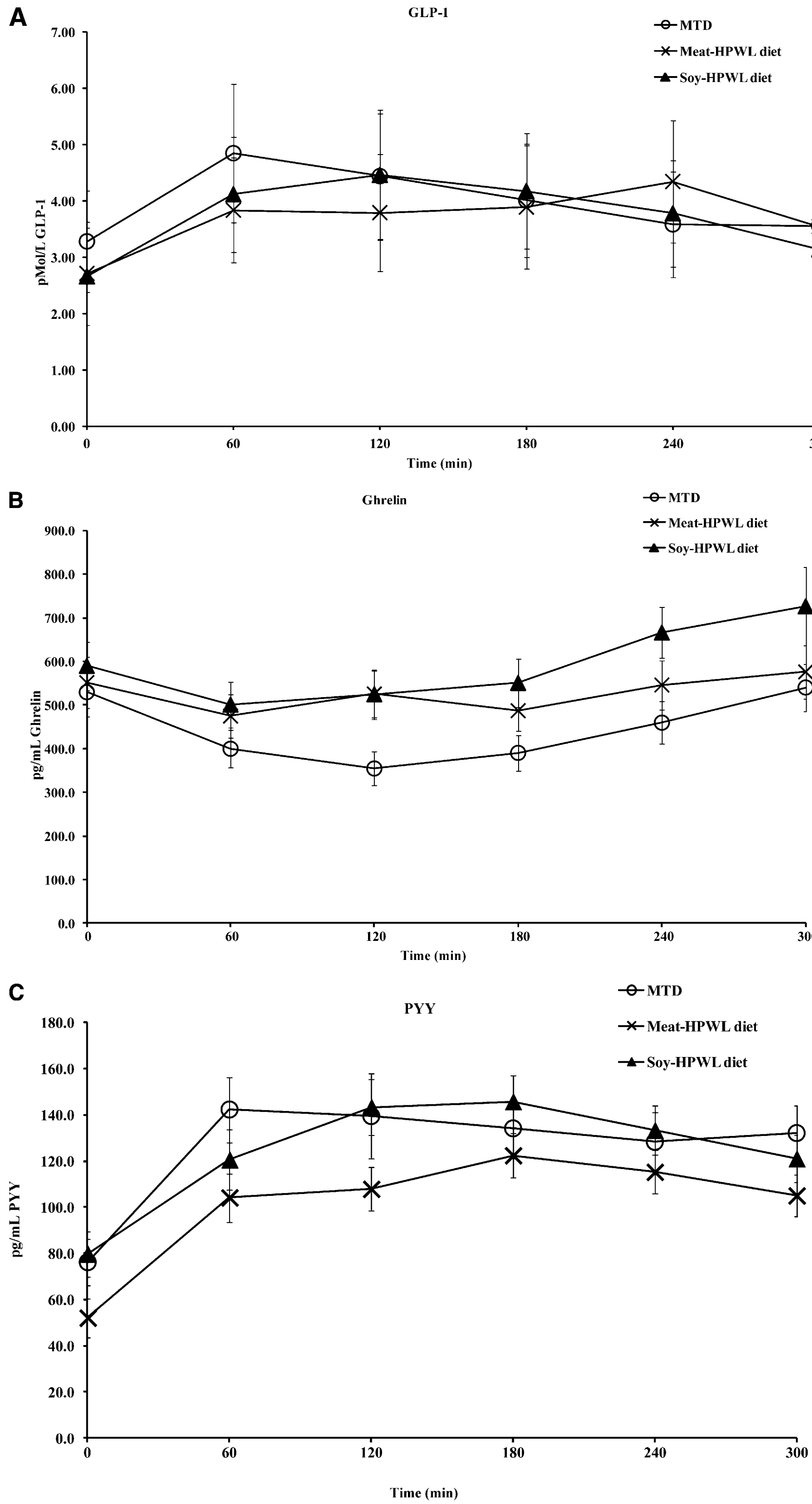

FIGURE 4. Mean (±SEM) 5-h concentrations of GLP-1 (A), ghrelin (B), and PYY (C) (presented as repeated measurements) after intake of a test meal: an MTD meal, a Meat-HPWL meal, or a Soy-HPWL meal. Values were analyzed as repeated measurements by using ANOVA, AUC, or net AUC for 20 subjects. (A) Comparison of MTD and Meat-HPWL and Soy-HPWL diets: $P = 0.718$; AUC, $P = 0.747$; and net AUC, $P = 0.455$. Comparison of Meat-HPWL and Soy-HPWL diets: $P = 0.741$; AUC, $P = 0.662$; and net AUC, $P = 0.083$. (B) Comparison of MTD and Meat-HPWL and Soy-HPWL diets: $P < 0.001$; AUC, $P < 0.001$; and net AUC, $P = 0.003$. Comparison of Meat-HPWL and Soy-HPWL: $P = 0.053$; AUC, $P = 0.075$; and net AUC, $P = 0.497$. (C) Comparison of MTD and Meat HPWL and Soy-HPWL diets: $P = 0.002$; AUC, $P = 0.003$; and net AUC, $P = 0.867$. Comparison of Meat-HPWL and Soy HPWL: $P < 0.001$; AUC, $P = 0.001$; and net AUC, $P = 0.794$. GLP-1, glucagon-like peptide 1; Meat-HPWL, meat-based high-protein weight loss; MTD, maintenance diet; PYY, peptide YY; Soy-HPWL, vegetarian high-protein weight loss.

TABLE 4
Amino acid concentrations by diet × time after the test meal[1]

	Plasma amino acid concentration					
	0 min	60 min	120 min	180 min	240 min	300 min
	μmol/L					
Alanine						
MTD meal	343.2 ± 47.4	461.6 ± 46.9	406.1 ± 37.1	368.1 ± 29.6	361.2 ± 41.6	357.6 ± 37.6
Meat meal	279.5 ± 45.4	403.7 ± 53.4	397.8 ± 64.9	365.2 ± 58.6	336.5 ± 60.6	318.4 ± 52
Soy meal	291.3 ± 33.4	383.0 ± 58.8	387.6 ± 48.2	383.4 ± 52.7	352.1 ± 47.9	340.5 ± 39.8
Arginine						
MTD meal	117.2 ± 20.7	121.5 ± 20.3	114.3 ± 21.2	117.7 ± 14.1	112 ± 20.6	108.4 ± 18
Meat meal	109.9 ± 14	157.0 ± 13.1	150.9 ± 18.1	143.9 ± 19.6	127.9 ± 25	117.4 ± 20
Soy meal	102.0 ± 14.8	107.1 ± 24.5	118.8 ± 22.4	135.9 ± 17.8	124.0 ± 18.2	109.8 ± 15.8
Aspartic acid						
MTD meal	3.2 ± 1.2	4.0 ± 1.4	3.7 ± 1.6	3.3 ± 1.4	3.4 ± 1.2	3.4 ± 1.3
Meat meal	3.2 ± 1.1	5.1 ± 1.3	4.6 ± 1.3	4.2 ± 1.7	3.7 ± 2.1	3.3 ± 1.5
Soy meal	3.0 ± 1.1	3.3 ± 1.5	3.8 ± 1.3	4.4 ± 1.1	4.2 ± 1.2	3.2 ± 1.3
Cysteine						
MTD meal	295.4 ± 31.5	289.1 ± 29.2	280.4 ± 28.5	274.7 ± 27	274.2 ± 29.3	280.2 ± 29.3
Meat meal	289.3 ± 35.4	286.1 ± 30.1	279 ± 31.7	272.6 ± 30.2	274.7 ± 27	282.5 ± 29.4
Soy meal	299.9 ± 33.7	290.1 ± 32.7	285.1 ± 29.9	275.8 ± 29.4	274.8 ± 31.6	280.7 ± 29.9
Glutamine						
MTD meal	552.1 ± 78.3	541.5 ± 81.6	511.0 ± 73.8	491.1 ± 59.3	507.2 ± 64	517.5 ± 62
Meat meal	546.5 ± 66.4	567.3 ± 72	527.4 ± 64.3	520.8 ± 62.8	532.1 ± 71.1	522.2 ± 75
Soy meal	514.8 ± 61.6	495.3 ± 64.3	483.8 ± 51.1	502.6 ± 60.2	500.6 ± 61.7	502.6 ± 65.4
Glutamic acid						
MTD meal	111.7 ± 28.9	120.5 ± 29.7	115.7 ± 30.6	111.4 ± 27.6	108.2 ± 27.6	108.4 ± 27.1
Meat meal	98.9 ± 25.7	113.2 ± 32.6	105.4 ± 28.5	100.3 ± 29.8	96.6 ± 33	95.6 ± 33.2
Soy meal	91.0 ± 28.9	98.3 ± 28.4	100.3 ± 24.9	102.8 ± 32.1	103.6 ± 28	93.1 ± 34.8
Glycine						
MTD meal	177.7 ± 21.2	169.2 ± 23.2	158.6 ± 24.6	154.0 ± 20.4	156.6 ± 21.7	155.2 ± 17.1
Meat meal	189.6 ± 19.1	211.6 ± 23.8	195.6 ± 30.3	186.2 ± 30.4	180.2 ± 27.9	172.9 ± 26.3
Soy meal	170.6 ± 22.1	170.0 ± 26.1	183.0 ± 25	198.3 ± 25.2	189.2 ± 23.2	179.2 ± 22.7
Histidine						
MTD meal	89.8 ± 11.5	96.9 ± 13.4	85.7 ± 14	83.5 ± 12.3	85.2 ± 11.7	85.3 ± 11.6
Meat meal	80.1 ± 8.4	95.4 ± 10.4	82.4 ± 12.8	81.9 ± 13.1	80.9 ± 13.4	77.8 ± 11.5
Soy meal	76.9 ± 9.3	82.3 ± 14	84.0 ± 15.7	87.7 ± 11.2	83.1 ± 9.7	77.6 ± 9.2
Isoleucine						
MTD meal	71.8 ± 9	99.8 ± 9.2	82.5 ± 10.4	73.2 ± 8.9	73.2 ± 9.2	70.6 ± 9.2
Meat meal	73.4 ± 10.8	121.6 ± 9.6	104.0 ± 13.6	96.2 ± 16.4	90.9 ± 12.3	84.5 ± 10.5
Soy meal	73.1 ± 11.8	80.8 ± 18	78.9 ± 14.1	91.6 ± 14.4	91.6 ± 10.5	83.5 ± 9.5
Leucine						
MTD meal	142.7 ± 15.8	191.6 ± 16.2	160.1 ± 21.2	143.8 ± 18.5	143.9 ± 17.5	139.1 ± 16.7
Meat meal	137.0 ± 17.6	205.6 ± 16.3	172.3 ± 28.3	156.3 ± 27.3	146.5 ± 19.3	137.9 ± 16.4
Soy meal	143.3 ± 17.3	156.9 ± 27.3	148.8 ± 19.6	165.5 ± 20.3	162.4 ± 15.2	149.5 ± 14.1
Lysine						
MTD meal	189.1 ± 27.6	228.0 ± 27.2	205.0 ± 23.3	194.3 ± 22	193.0 ± 26.3	182.2 ± 21.5
Meat meal	161.4 ± 29.3	225.7 ± 26.9	206.9 ± 28.9	192.0 ± 31.4	175.5 ± 38.3	160.9 ± 32.8
Soy meal	192.7 ± 24.4	209.7 ± 27.9	222.9 ± 26.4	241.1 ± 27.1	222.5 ± 24.9	197.7 ± 22.9
Methionine						
MTD meal	30.6 ± 4.2	39.0 ± 4.3	32.4 ± 3	27.6 ± 2.8	26.3 ± 3.7	24.5 ± 3.3
Meat meal	26.5 ± 3.7	33.5 ± 3.6	28.6 ± 4	24.4 ± 3.2	21.9 ± 5.6	21.1 ± 4.7
Soy meal	27.6 ± 3.4	31.1 ± 3.7	30.6 ± 3.6	31.8 ± 3.4	29.2 ± 3.4	26.4 ± 2.9
Phenylalanine						
MTD meal	62.3 ± 8.5	73.2 ± 8.8	67.1 ± 7	63.5 ± 7.3	62.3 ± 8.1	59.9 ± 7.2
Meat meal	59.3 ± 7	81.9 ± 7	79.4 ± 6.9	74.3 ± 6.6	69.2 ± 9.6	65.7 ± 8.5
Soy meal	59.8 ± 5.8	67.1 ± 8.2	66.6 ± 9.3	66.3 ± 8.1	62.2 ± 8.4	58.8 ± 8
Proline						
MTD meal	196.6 ± 38.4	274.1 ± 40	266.3 ± 37.1	263.8 ± 39.1	264.8 ± 49.1	253.2 ± 42.1
Meat meal	209.0 ± 34	280.8 ± 33	275.3 ± 34.5	260.0 ± 33.1	240.9 ± 40.3	220.9 ± 38.6
Soy meal	156.7 ± 48.3	214.5 ± 46.4	226.1 ± 45.1	230.5 ± 51.3	218.0 ± 54.2	200.6 ± 50.6
Serine						
MTD meal	93.0 ± 14.5	103.5 ± 14.6	88.3 ± 15.2	81.9 ± 12.4	81.6 ± 13.9	80.0 ± 14.1

(Continued)

TABLE 4 (*Continued*)

	Plasma amino acid concentration					
	0 min	60 min	120 min	180 min	240 min	300 min
Meat meal	110.8 ± 19.8	137.5 ± 18.1	120.4 ± 20.3	112.1 ± 19	109.4 ± 21.4	105.9 ± 17.9
Soy meal	102.8 ± 16.8	107.2 ± 13	103.3 ± 14.1	107.5 ± 17.1	106.8 ± 15.5	100.8 ± 14.7
Threonine						
MTD meal	126.9 ± 19.4	142.8 ± 20.4	123.0 ± 17.1	112.0 ± 15.8	111.9 ± 19.3	109.2 ± 15.6
Meat meal	121.3 ± 20.9	150.2 ± 21.6	135.7 ± 20.9	127.8 ± 21.5	123.8 ± 23.9	117.8 ± 22.1
Soy meal	118.3 ± 17.8	123.9 ± 16.9	121.7 ± 16.5	127.6 ± 18.7	123.1 ± 19.2	115.9 ± 16.7
Tryptophan						
MTD meal	59.6 ± 8.3	66.2 ± 8.3	60.4 ± 7.6	56.1 ± 7	55.1 ± 6.6	54.1 ± 5.9
Meat meal	54.2 ± 8.8	69.3 ± 8.1	66.9 ± 8.9	62.6 ± 9.2	58.8 ± 8.4	54.3 ± 6.9
Soy meal	56.8 ± 8.6	58.8 ± 9.5	59.7 ± 8	61.2 ± 8.2	59.3 ± 7.5	54.7 ± 6.9
Tyrosine						
MTD meal	73.9 ± 10.9	91.7 ± 12.5	84.1 ± 11.2	78.6 ± 10.5	78.2 ± 11.4	77.2 ± 10.9
Meat meal	67.6 ± 9.4	93.8 ± 9.9	89.1 ± 11.1	85.2 ± 10.8	79.3 ± 12.4	73.3 ± 12.4
Soy meal	67.2 ± 8.9	73.0 ± 10.2	72.9 ± 13.4	74.5 ± 11.9	71.9 ± 11.7	67.8 ± 10.5
Valine						
MTD meal	264.1 ± 25.4	310.1 ± 25.6	280.9 ± 30.6	267.6 ± 26.4	266.1 ± 25.5	260.0 ± 25.6
Meat meal	242.1 ± 31.9	310.2 ± 29.4	286.8 ± 33.7	272.9 ± 40.9	262.3 ± 33.1	250.8 ± 30.9
Soy meal	262.5 ± 25.9	274.1 ± 37.8	269.2 ± 29.4	283.7 ± 30.6	283.1 ± 26.7	268.0 ± 26.8
Homocysteine						
MTD meal	10.5 ± 2.2	10.7 ± 2.8	10.4 ± 2.6	10.3 ± 2.6	10.3 ± 2.5	10.6 ± 2.6
Meat meal	10.1 ± 2.4	10.2 ± 2.2	10.0 ± 2.5	9.7 ± 2.1	9.8 ± 2.1	10.0 ± 2.3
Soy meal	10.5 ± 2.7	10.2 ± 2.6	10.1 ± 2.7	9.7 ± 2.3	9.7 ± 2.5	10.0 ± 2.7

[1] All values are means ± SDs. $n = 20$. ANOVA for time and diet interaction for all amino acids was significant ($P \leq 0.05$), with the exception of cysteine ($P = 0.059$). Meat meal, test meal after the meat-based high-protein weight-loss diet; MTD meal, test meal after maintenance diet; Soy meal, test meal after the vegetarian-based high-protein weight-loss diet.

concentrations with the Soy-HPWL diet. However, these do not translate to differences in appetite. There are insufficient data to support either hypothesis, and it is thought that small changes in single hormones are likely to have just a subtle effect on the appetite system.

Our finding is similar to that observed by Veldhorst et al (25), who measured GLP-1 concentrations up to 3 h postconsumption of a soy breakfast meal of 10% and 25% protein, suggesting no effect of amount of protein on GLP-1 concentration. We also found that GLP-1 is not stimulated by high-protein diets; rather, its secretion is stimulated by carbohydrate content from diets (26). Batterham et al (27) found that fasting PYY concentrations were lower in obese subjects than in lean subjects, and BMI correlated negatively with PYY concentrations. Postprandial PYY release was also lower in the obese subjects, despite the fact that they consumed more energy. This raises the hypothesis (possibility) that a deficiency in circulating PYY could be involved in the development of obesity, although it is currently unclear whether low concentrations of PYY are a cause or an effect of obesity. The present study results show that PYY concentrations were affected by the Soy-HPWL and Meat-HPWL diets, which is in accordance with other studies, and prove that PYY release is stimulated by a high-protein meal (27). The GLP-1 and PYY results suggest that there could have an earlier peak on their concentrations, before the first sample at 60 min (Figure 4). However, a recent study by Belza et al (28) on high-protein meals suggests that we did not miss an earlier peak in PYY but that the GLP-1 data are less conclusive, with their samples at 30 and 120 min showing a double peak.

The suppression of ghrelin after meals is proportional to the energy intake at the meal (29), which is supported by current data on the differences between the MTD and Soy-HPWL and Meat-HPWL diets. A significant effect on ghrelin results was found with comparison between all 3 diets by using ANOVA, AUC, and net AUC. The present data are also supported by one other study that used vegetarian protein (lupin) (30) in which the test meal significantly altered the 3-h postmeal plasma ghrelin response.

Blood biochemistry

The present study indicates an improvement in blood biochemistry after both the Soy-HPWL and Meat-HPWL diets. We found significant decreases associated with weight loss for cholesterol, glucose, triacylglycerols, and LDL cholesterol, which is in accordance with other HPWL studies (3, 18, 19, 31–33). The results from the current study also indicate that the total:HDL-cholesterol ratio and LDL:HDL-cholesterol ratio were significantly lower with the Soy-HPWL diet than with MTD, whereas equivalent changes were not observed after the Meat-HPWL diet. Total cholesterol and LDL cholesterol were also much lower after the Soy-HPWL diet in comparison with the Meat-HPWL diet. These findings could possibly be attributed to the source of protein. The Soy-HPWL diet used a vegetarian source of protein, which is richer in carbohydrates (fiber and unrefined carbohydrates) and other phytochemicals that are not present in the Meat-HPWL diet, and these components could contribute to a better blood biochemistry and prevention of cardiovascular diseases (34–36).

Protein type, plasma amino acid profile, and satiety

There is no consensus about type of protein in diet-induced thermogenesis (20–23); overall evidence suggests that the source

TABLE 5
Amino acid concentrations in subjects by diet for the 5 h after the test meal[1]

	Plasma amino acid concentration[2]			Comparison between all 3 diets[3]		Comparison between HPWL diets[3]
	After MTD meal	After meat meal	After soy meal	*P*	SED	*P*
		μmol/L				
Alanine	382.9 ± 37.6	356.3 ± 52	350.18 ± 39.8	<0.001	8.2	NS
Arginine	115.19 ± 18	116.28 ± 20	134.52 ± 15.8	<0.001	2.7	<0.001
Aspartic acid	3.48 ± 1.3	3.65 ± 1.5	4.03 ± 1.3	<0.01	0.16	<0.05
Cysteine	282.35 ± 29.3	284.39 ± 29.4	280.68 ± 29.9	NS	1.96	NS
Glutamine	520.1 ± 62	499.9 ± 75	536.04 ± 65.4	<0.001	8.06	NS
Glutamic acid	112.67 ± 27.1	98.18 ± 33.2	101.66 ± 34.8	<0.001	3.59	<0.001
Glycine	161.87 ± 17.1	181.73 ± 26.3	189.36 ± 22.7	<0.001	3.37	NS
Histidine	87.75 ± 11.6	81.94 ± 11.5	83.08 ± 9.2	<0.001	1.35	NS
Isoleucine	78.51 ± 9.2	83.24 ± 10.5	95.08 ± 9.5	<0.001	1.91	<0.001
Leucine	153.54 ± 16.7	154.4 ± 16.4	159.27 ± 14.1	NS	3.02	NS
Lysine	198.58 ± 21.5	214.44 ± 32.8	187.07 ± 22.9	<0.001	3.34	<0.001
Methionine	30.07 ± 3.3	29.47 ± 4.7	26 ± 2.9	<0.001	0.61	<0.001
Phenylalanine	64.7 ± 7.2	63.45 ± 8.5	71.63 ± 8	<0.001	0.84	<0.001
Proline	253.14 ± 42.1	207.72 ± 38.6	247.8 ± 50.6	<0.001	4.65	<0.001
Serine	88.04 ± 14.1	104.72 ± 17.9	116.02 ± 14.7	<0.001	1.56	<0.001
Threonine	120.98 ± 15.6	121.74 ± 22.1	129.41 ± 16.7	<0.001	2.23	<0.05
Tryptophan	58.56 ± 5.9	58.42 ± 6.9	61.01 ± 6.9	<0.001	0.63	<0.001
Tyrosine	80.6 ± 10.9	71.21 ± 12.4	81.38 ± 10.5	<0.001	1.59	<0.001
Valine	274.77 ± 25.6	273.44 ± 30.9	270.84 ± 26.8	NS	4.69	NS
Homocysteine	10.5 ± 2.6	10.03 ± 2.3	9.96 ± 2.7	<0.05	0.18	NS

[1] *n* = 20. HPWL, high-protein weight-loss; meat meal, test meal after the meat-based high-protein weight-loss diet; MTD meal, test meal after maintenance diet; soy meal, test meal after the vegetarian-based high-protein weight-loss diet; SED, SE of the difference.
[2] Values are means ± SDs by diet.
[3] Determined by using ANOVA.

of protein itself, at feasible amounts in foods, does not have a large and consistent effect on subsequent appetite and food intake, and the current study data support this notion. Because no difference was detected between the Soy-HPWL and Meat-HPWL diets over 2 wk, the effects on appetite of mixed protein sources in meals are likely to be subtle. In 1956, Mellinkoff et al (37) suggested that an elevated concentration of blood or plasma amino acids, which cannot be channeled into protein synthesis, may serve as a satiety signal for a food intake–regulating mechanism and thereby result in depressed appetite. The current data also indicate a significant diet effect on amino acid plasma concentrations but do not substantiate the presence of a strong relation between amino acid concentration and appetite response, at least in obese men during dieting. Few human dietary studies have systematically monitored plasma amino acid profile in response to a dietary manipulation (22, 23). A number of studies provided different amounts and types of protein for a single day only (22, 23, 25, 38), with 2 studies using dietary soy protein. The results suggest that a difference in appetite ratings between types of protein appears when certain amino acids are above and below particular threshold values (23). Potier et al (39) suggested that the circulating concentration of leucine could affect food intake. A high soy protein breakfast is more satiating than a normal soy protein breakfast due to elevated taurine and insulin concentrations (25). We found higher concentrations of leucine, tryptophan, isoleucine, and threonine after the Soy-HPWL meal than after the Meat-HPWL meal. Leucine has been shown to modulate the activity of the energy and nutrient sensor pathways controlled by 5′-AMP–activated protein kinase and mammalian target of rapamycin in the hypothalamus (39). When all results are considered as a whole, it can be concluded that it is likely that complex and redundant pathways are involved in protein- and amino acid–induced satiety.

Conclusions

The Soy-HPWL diet had an impact on subjective appetite and motivation to eat similar to the Meat-HPWL diet. Weight loss was not different between the diets, with a reduction in fat mass and preservation of fat-free mass. Due to the weight loss there was a significant improvement in blood biochemistry after both the Soy-HPWL and Meat-HPWL diets, particularly for total cholesterol and LDL cholesterol after the Soy-HPWL diet. Gut hormone profile indicated diet effects for ghrelin and PYY but not for GLP-1 plasma concentrations. The diet effect on plasma concentrations of amino acids was not related to change in appetite. Because appetite control and weight loss were similar in both the Soy-HPWL and Meat-HPWL diets, a vegetarian high-protein diet could be a healthier alternative to a meat-based HPWL diet, achieving desired results without any negative health effects (eg, risk of colonic disease).

The present study findings suggest that vegetarian proteins (soy) are a good alternative to meat-based proteins in weight-loss diets. However, soy is not a sustainable source of protein in Europe. Beans and pulses are rich sources of vegetarian proteins and already are known for their cardiovascular disease and other health benefits. Therefore, they could represent an alternative source of protein, possibly to replace unsustainable protein sources, that could be considered for future human dietary intervention studies.

We are grateful for the assistance from Karen Taylor, Jean Bryce, and Nina Lamza for the preparation of the study diets and Sylvia Stephen and Lorna Hermitage for their support in the Human Nutrition Unit.

The authors' responsibilities were as follows—AMJ, CF, and GH: were responsible for the study concept and design; AMJ, MN, and CF: were responsible for data collection and collation; and AMJ, MN, CF, and GH: were responsible for data analysis and for the first draft and critical revision of the manuscript for important intellectual content. None of the authors had a personal or financial conflict of interest.

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