

# Substrate oxidation and control of food intake in men after a fat-substitute meal compared with meals supplemented with an isoenergetic load of carbohydrate, long-chain triacylglycerols, or medium-chain triacylglycerols<sup>1-3</sup>

Virginie Van Wymelbeke, Jeanine Louis-Sylvestre, and Marc Fantino

## ABSTRACT

**Background:** It has been suggested that hunger may be delayed and food intake reduced under metabolic conditions that spare carbohydrate oxidation.

**Objective:** Our objective was to examine the role of glucose metabolism in the control of food intake in men by using medium-chain triacylglycerols (MCTs) to spare carbohydrate oxidation.

**Design:** In 10 male volunteers, isolated and deprived of any time cues, we studied the effects of 4 lunches on hunger ratings, the duration of satiety, the amount of food ingested at dinner, energy expenditure, substrate oxidation, and plasma variables until the time of the dinner request. One lunch was a basic 2310-kJ meal containing 40 kJ fat substitute (Sub lunch). The 3 other lunches consisted of the same basic meal supplemented with either 1200 kJ long-chain triacylglycerols (LCT lunch), 1200 kJ MCTs (MCT lunch), or 900 kJ carbohydrate plus 300 kJ LCTs (Cho lunch).

**Results:** Energy expenditure was not significantly different after the different lunches, but carbohydrate oxidation was lower after the MCT and LCT lunches than after the Cho lunch. Fat oxidation was greater after the MCT and LCT lunches. The time of the dinner request was significantly delayed after the Cho lunch. Food intake at dinner was significantly lower after the MCT lunch than after the Sub and Cho lunches, but the dinner meal request was not delayed.

**Conclusion:** Carbohydrate may have a greater role in the duration of satiety than does fat, but MCTs may play an active role in other aspects of the control of food intake, especially in satiation at the next meal. *Am J Clin Nutr* 2001;74:620-30.

**KEY WORDS** Humans, hunger signal, satiety, satiation power, glucose oxidation, lipids, carbohydrate, energy expenditure, nutrient balance, postprandial metabolism, postprandial hormones, France

## INTRODUCTION

Evidence indicates that in free-feeding rats (1) and in free-living humans (2), the postmeal interval is related to the energy intake from a meal and the rate of glucose utilization. The classic glucostatic theory focuses on signals associated with glucose metabolism measured in the central nervous system (3, 4). The glucose signal is thought to be sensed by glucoreceptors and

glucosensitive neurons in the hypothalamus (5, 6). It was shown that a decrease in blood glucose precedes meal onset in free-feeding rats (7, 8) and humans (9), and a recent study corroborated a synchronization between hunger and a decline in blood glucose concentrations (10).

According to the Randle effect (11), the rate of glucose utilization is dependent on fatty acid utilization because the rate of carbohydrate oxidation appears to be modulated by the rate of fat oxidation via simple substrate competition in healthy (12) and type 2 diabetic (13) subjects. We observed that fat added to a nonfat meal delayed the time of the next meal (14), probably because fat was oxidized and spared some carbohydrate. Therefore, if less carbohydrate and more fat are ingested, fats are utilized because fat oxidation is favored (15). However, if fat is added to a fat-containing meal, it is likely that there is no additional effect on carbohydrate sparing and thus fat is stored (16, 17). This finding may explain why inhibition of fatty acid oxidation by antimetabolic agents that force glucose oxidation increases food intake (18-21). The effect of  $\beta$ -oxidation inhibitors on food intake may also reflect the possibility that the lipids directly contribute to the control of food intake via the intracellular energy they provide, and it has been proposed that the hunger signal appears when fatty acid and glucose oxidation are insufficient to cover immediate expenditures (22, 23).

To explore the role of glucose on the control of food intake, it is possible to exploit the Randle effect by manipulating fat metabolism to spare glucose oxidation (11). The metabolic consequences of lipids depend on their type and structure (24), mainly chain length. Medium-chain triacylglycerols (MCTs), which are more rapidly absorbed into the portal circulation and are also more rapidly oxidized in tissues than are long-chain triacylglycerols (LCTs)

<sup>1</sup>From the Groupe Nutrition et Métabolisme Humain, Faculté de Médecine, Dijon, France.

<sup>2</sup>Supported by grants from the University of Burgundy, the Regional Council of Burgundy, the Ministère de la Recherche et de la Technologie of France (Programme AGROBIO-Aliments demain), and the Institut Benjamin Delessert. The Ceres margarine was supplied by Astra Calve, Paris.

<sup>3</sup>Address reprint requests to M Fantino, Département de Physiologie, Faculté de Médecine, Boîte postale 87900, 21079 Dijon Cedex, France. E-mail: [mfantino@u-bourgogne.fr](mailto:mfantino@u-bourgogne.fr).

Received May 8, 2000.

Accepted for publication January 3, 2001.

(24–26), may spare more glucose than do LCTs postprandially, and thus may prolong satiety. In a study by Flatt et al (17), the temporal pattern of the respiratory quotient (RQ) was lower 4 h after an MCT lunch than after a low-fat or LCT lunch, indicating less glucose oxidation after the MCT lunch. Unfortunately, subsequent food intakes and satiety were not addressed in that study.

In another study from our laboratory, MCTs did not delay the request of the next meal but decreased the amount ingested at the next meal (27). These results are puzzling because we expected a sparing of glucose oxidation by MCTs, but could not draw any conclusions in the absence of direct measurements. Therefore, in the present study we used continuous indirect calorimetric measurements and continuous blood sampling in men to examine the effect of dietary carbohydrate, fat (MCTs or LCTs), and a basic hypoenergetic lunch with identical flavors—obtained by adding a fat substitute—on nutrient oxidation, blood variables, the duration of satiety, and spontaneous food intake at the next meal, ie, dinner.

## SUBJECTS AND METHODS

### Subjects

Ten healthy men aged 19–24 y ( $\bar{x} \pm \text{SEM}$ :  $22 \pm 0.6$  y) with a body mass index (in  $\text{kg}/\text{m}^2$ ) of 19–24 ( $\bar{x} \pm \text{SEM}$ :  $21.9 \pm 1.7$ ) were recruited from the Burgundy student population (Dijon, France). None of the subjects smoked, none had any personal or family history of metabolic disorders, and all had had a stable body weight over the previous 6 mo. Highly trained individuals ( $>5$  h physical activity/wk) were excluded. The subjects were instructed to maintain a constant pattern of activity during the study, to not change their eating habits during the study, and to avoid alcohol intake on the 2 d preceding each experimental day. A 7-d food record indicated that all subjects had a normal food pattern (ie, consumed 3 meals/d and did not indulge in either snacking or nibbling) and that their daily energy intake was 10–15 MJ from which a mean of 35% was derived from fat (range: 29–38% of energy). The protocol was approved by the Advisory Committee of Protection for Humans in the Biomedical Research of Burgundy and written, informed consent was obtained from all subjects.

### Study design

The experiment was composed of 4 sessions, each lasting 10 h (from 1200 to 2200). The subjects arrived in the laboratory at 1200 and were isolated until 2200 in an individual, sound-attenuated medical suite in a residential metabolic ward at the Dijon University Hospital. The ambient temperature was kept constant at  $21 \pm 1^\circ\text{C}$ . The subjects were kept under artificial light and all references to time cues or intervals were eliminated. The subjects were instructed to not read, to listen only to classical music, and to rest but remain awake. Under these such conditions, the subjects lost track of time. When the subjects were asked at the end of each session to estimate the time, they were consistently mistaken with an average error of 40 min. Two subjects were examined at the same time and the 4 experimental days were scheduled 1 wk apart on a Tuesday, Wednesday, or Thursday. A breakfast was selected by the subjects and this same breakfast was consumed on each morning of the experimental days at 0800.

### Meals

The lunch meals differed by energy content and in the nature of the fat, carbohydrate, and fat substitute added. The 695-g

lunch was composed of 60 g dehydrated potato flakes plus water, 60 g mashed carrots, 100 g minced chicken, and 200 g apple sauce (99 g carbohydrate, 35 g protein, 2 g fat, and 2310 kJ). The lunch was supplemented with 1) 15 g fat substitute (the polydextrose Litesse; Pfizer, Orsay, France) (40 kJ; Sub lunch), 2) 35 g MCTs (Ceres margarine; Astra Calve, Paris) (1200 kJ; MCT lunch), 3) 32 g LCTs (40% monounsaturated, 22.5% saturated, and 17.5% polyunsaturated; Primevère margarine; CEMA, Bondues, France) (1200 kJ; LCT lunch), or 4) 50 g maltodextrin (D17; Roquette, Lesterm, France), 8 g LCTs (Primevère), and 15 g fat substitute (Litesse) (1200 kJ; Cho lunch). The Sub lunch was chosen as a basic hypoenergetic meal supplemented with Litesse (fat substitute) and was sensorially equivalent to the MCT and LCT lunches but without added energy.

A preliminary sensorial evaluation indicated that the subjects were unable to distinguish between these 4 different lunches on the basis of their sensorial cues. The effects of the 4 lunches on the control of food intake and on satiety duration were compared. The foods composing the lunch meals were chosen to correspond, as much as possible, to foods usually eaten by the subjects. The energy contents of the LCT, MCT, and Cho lunches (3510 kJ) were similar to the energy contents of the subjects' usual lunches, as indicated by the 7-d food records ( $3975 \pm 305$  kJ;  $\approx 32\%$  of the daily energy intake). The lunches were served at 1300 and the subjects were allowed 20 min to consume them. The order of the experimental sessions was randomized according to a Latin-square design.

The dinner meal was provided ad libitum as a buffet of 30 different palatable foods (**Appendix A**), including meats, vegetables, cheeses, desserts, bread, sweets, and drinking water. As indicated by the 7-d food records, no subject reported disliking any of these foods. There was no time limit for consuming the dinner meal.

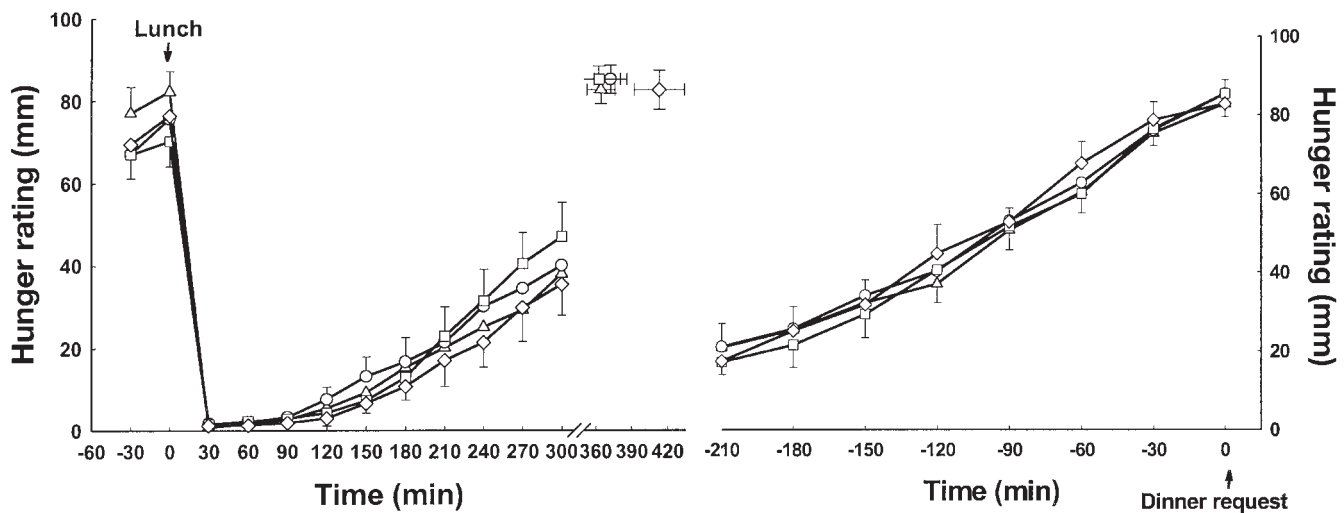
### Hunger and food intake

The following measurements related to food intake were made: 1) the hedonic value of lunch evaluated on a 100-mm visual analogue scale, 2) the time elapsed between the lunch and the spontaneous dinner request, 3) the total energy content and macronutrient composition of the food ingested for dinner, and 4) the temporal pattern of the subjects' hunger sensations, which were evaluated every 30 min throughout the experimental session on the basis of a 100-mm visual analogue scale.

### Substrate oxidation and balance

The rate of substrate oxidation was continuously measured by indirect calorimetry according to Rigaud and Melchior (28), beginning 15 min before the lunches until the time of the dinner request. Expired gases were collected via a 3-way nasobuccal mask and were stored in Tissot spirometers (Gauthier, Paris). The total expired volume was measured every 15 min and the carbon dioxide (an infrared method) and oxygen (paramagnetic method) fractions were measured with gas analyzers (Analyser Series 1400; Servomex, Paris). Total energy expenditure was calculated as the sum of energy expenditure measured during the 15-min periods from lunch until the time of the dinner request. To determine the net protein oxidation rate, all urine produced during the sessions was regularly collected and aliquots were frozen for the measurement of urea excretion with a kinetic colorimetric enzymatic method ( $<5\%$  accuracy, urea kit; Hycel Diagnostic, Lisabio Group, Pouilly en Auxois, France) in the Lisa 200 automatic analyzer (Hycel Diagnostic). From these





**FIGURE 1.** Mean ( $\pm$ SEM) temporal hunger ratings after 4 lunch meals from before lunch to the time of the first dinner request (left panel) and during the 195 min preceding the time of the dinner request (right panel), the values for which were synchronized to the time of the dinner request. There was a significant time  $\times$  lunch interaction in the left panel,  $P < 0.001$ .  $\square$ , basic meal with 40 kJ fat substitute (Sub lunch);  $\diamond$ , basic meal plus 900 kJ as carbohydrate and 300 kJ as long-chain triacylglycerols (CHO lunch);  $\circ$ , basic meal plus 1200 kJ as medium-chain triacylglycerols (MCT lunch);  $\triangle$ , basic meal plus 1200 kJ as LCTs (LCT lunch). For the sake of clarity, error bars are only given for the maximum and minimum values at each time point.  $n = 9$ .

calorimetric measurements, we calculated the net oxidation of fat, protein, and carbohydrate.

#### Blood and hormone variables

A 3-mL blood sample was collected every 10 min continuously, from 20 min before lunch until the spontaneous dinner request. At 1240 we slid a double cannula (Medical Technique Bioengineering, Amstetten, Germany) into an 18-gauge catheter (Adsyte 18 ga, 13/4 in; Becton Dickinson, Grenoble, France) that had been previously inserted in the forearm vein by a registered nurse. One cannula was used to continuously perfuse a heparin-containing saline solution (0.03 mL/min) that mixed in the catheter with blood continuously collected by another cannula (0.3 mL/min) without heparin infusion to prevent coagulation (29).

Blood was immediately centrifuged ( $3000 \times g$ ,  $4^{\circ}\text{C}$ , 10 min) and plasma samples were rapidly separated and stored at  $-40^{\circ}\text{C}$  for subsequent assay of glucose, insulin, triacylglycerols, and fatty acids;  $\beta$ -hydroxybutyrate was assayed at  $-70^{\circ}\text{C}$ . Glucose, triacylglycerols, fatty acids, and  $\beta$ -hydroxybutyrate concentrations were measured with an automatic analyzer (Lisa 200; Hycel Diagnostic). Glucose concentrations were measured in  $4 \mu\text{L}$  plasma with a colorimetric enzymatic assay with use of a glucose oxidase method ( $<5\%$  accuracy; Hycel Diagnostic). Triacylglycerols ( $<5\%$  accuracy; Hycel Diagnostic) and fatty acids ( $<5\%$  accuracy, NEFA-C Wako kit; Unipath, Dardilly, France) were measured with a colorimetric enzymatic method; both MCTs and LCTs were measured.  $\beta$ -Hydroxybutyrate was measured with a dehydrogenase method (5% accuracy, RB 1007 kit; Randox Laboratory, Antrim, United Kingdom). Insulin was measured with use of a radioimmunologic assay (5% accuracy; Bi insulin IRMA kit; Sanofi Diagnostics Pasteur, Marnes la Coquette, France).

#### Statistical analysis

The results from only 9 subjects were included in the analysis because 1 subject withdrew from the study after experiencing adverse effects after the MCT lunch. Because the subjects requested their dinners at different times, data were expressed as

means ( $\pm$ SEMs) until the time at which the first individual requested a meal (ie, 300 min). To examine the possible temporal influence of metabolic variables on the time that the dinner request was made, we computed the temporal patterns of the subjects during the 195 min preceding the time of the dinner request and synchronized the values for the different subjects to the time of their dinner request. Food intakes at dinner and the temporal pattern of substrate oxidation and blood variables were compared by repeated-measures analysis of variance (ANOVA) with the time and type of lunch meal as main factors. The ANOVA was followed by a post hoc multiple-comparison Student's  $t$  test with Bonferroni correction when appropriate ( $P < 0.05$ ). All statistical analyses were conducted with use of the NCSS 2000 statistical package (Statistical System for WINDOWS; Number Cruncher Statistical Systems, Kaysville, UT). Blood glucose and insulin concentrations were reported as areas under the curve (AUCs). Incremental AUCs were calculated by the trapezoidal method as the total AUC minus the mean baseline value from lunch until the time of the first dinner request.

## RESULTS

### Hunger and food intake

No significant differences were found in the hedonic ratings of the lunch meal:  $57 \pm 4.2$  mm for the LCT lunch,  $64 \pm 2.5$  mm for the MCT lunch,  $54 \pm 3$  mm for the Sub lunch, and  $60 \pm 4.4$  mm for the Cho lunch. Hunger ratings followed a temporal pattern and were not significantly different after the lunch meals or at the time of the dinner request (**Figure 1**). However, the time to the dinner request was significantly longer after the Cho lunch than after the Sub and LCT lunches ( $P = 0.05$ ; **Table 1**). Although the time that subjects were allotted to eat dinner was not limited, we noted that all subjects finished the dinner meal within 20 min. Energy intake was significantly lower after the MCT lunch than after the Sub and Cho lunches but there was no significant difference in the macronutrient composition of the

TABLE 1

Food intake at dinner after consumption of the 4 lunches and the time elapsed from lunch to the time of the spontaneous dinner request<sup>1</sup>

Lunch	Energy	Carbohydrate	Fat	Protein	Time of the dinner request
	<i>kJ</i>	% of energy	% of energy	% of energy	<i>min</i>
LCT	4142.8 ± 390 <sup>a,b</sup>	59.1 ± 4	21.5 ± 3	19.5 ± 2	364.3 ± 11 <sup>a</sup>
MCT	3601.9 ± 258 <sup>b</sup>	56.6 ± 4	19.7 ± 2	23.7 ± 4	372.4 ± 13 <sup>a,b</sup>
Sub	4375.4 ± 262 <sup>a</sup>	56.2 ± 5	25 ± 4	18.8 ± 2	362.6 ± 18 <sup>a</sup>
Cho	4351.3 ± 373 <sup>a</sup>	60.5 ± 4	20.1 ± 3	19.4 ± 2	413 ± 22 <sup>b</sup>
<i>P</i> <sup>2</sup>	<0.05	NS	NS	NS	0.05

<sup>1</sup> $\bar{x} \pm \text{SEM}$ ; *n* = 9. Means within columns with different superscript letters are significantly different, *P* < 0.01 (Student's *t* test with use of the error term with Bonferroni correction). LCT, long-chain triacylglycerol; MCT medium-chain triacylglycerol; Sub, fat substitute; Cho, carbohydrate.

<sup>2</sup>The 4 means were compared with use of repeated-measures analysis of variance. If the means differed significantly, they were compared 2 by 2 with Student's *t* test (with use of the error term) with Bonferroni correction of the type I error.

food ingested. The only adverse side effect reported was vomiting by one subject after the MCT lunch.

### Substrate oxidation and balance

The rate of energy expenditure was not significantly different after the 4 lunch meals or during the 195 min preceding the time of the dinner request, and total energy expenditure was not significantly different at the time of the dinner request regardless of the lunch type (Figure 2). However, the RQ was significantly lower after the LCT lunch and even lower after the MCT lunch than after Sub and Cho lunches (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.001). During the 195 min preceding the time of the dinner request, the RQ remained significantly higher after the Cho lunch than after the 3 other lunches, except during the 15 min preceding the time of the dinner request (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.001). This finding reflected the significant differences in the rate of fat oxidation (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.001) due to significantly higher amounts of lipid oxidized after the LCT and MCT lunches (Figure 3). Note that fat oxidation increased more quickly after the MCT than after the LCT lunch, being significantly higher from 30 to 60 min after these lunches. Compared with the Sub lunch, fat oxidation was 62% greater after the LCT lunch and 80% greater after the MCT lunch. Compared with the Cho lunch, fat oxidation was 90% greater after the LCT lunch and 110% greater after the MCT lunch (Table 2). Lipid oxidation remained significantly higher after the MCT and LCT lunches than after the other 2 lunches until 120 min before the time of the dinner request (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.001). At the time of the dinner request, the subjects had oxidized almost twice as much lipid after the MCT and LCT lunches than after the other 2 lunches (Figure 3 and Table 2; *P* < 0.001). Conversely, at the same times, carbohydrate oxidation was significantly lower after the MCT lunch than after the 3 other lunches and remained so for ≈3 h.

Throughout the entire experimental period, carbohydrate oxidation was significantly lower after the MCT lunch than after the Cho and Sub lunches (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.001; Figure 3 and Table 2). In our study, compared with the Sub lunch, the added 35 g MCTs decreased carbohydrate oxidation by an equivalent of only 11.9 g at the time of the dinner request compared with 7.7 g with an isoenergetic amount of LCTs (32 g) (Table 2). During the 195 min preceding the time of the dinner request, carbohydrate oxidation was higher after the Cho lunch than after the 3 other meals from -105 to -60 min before

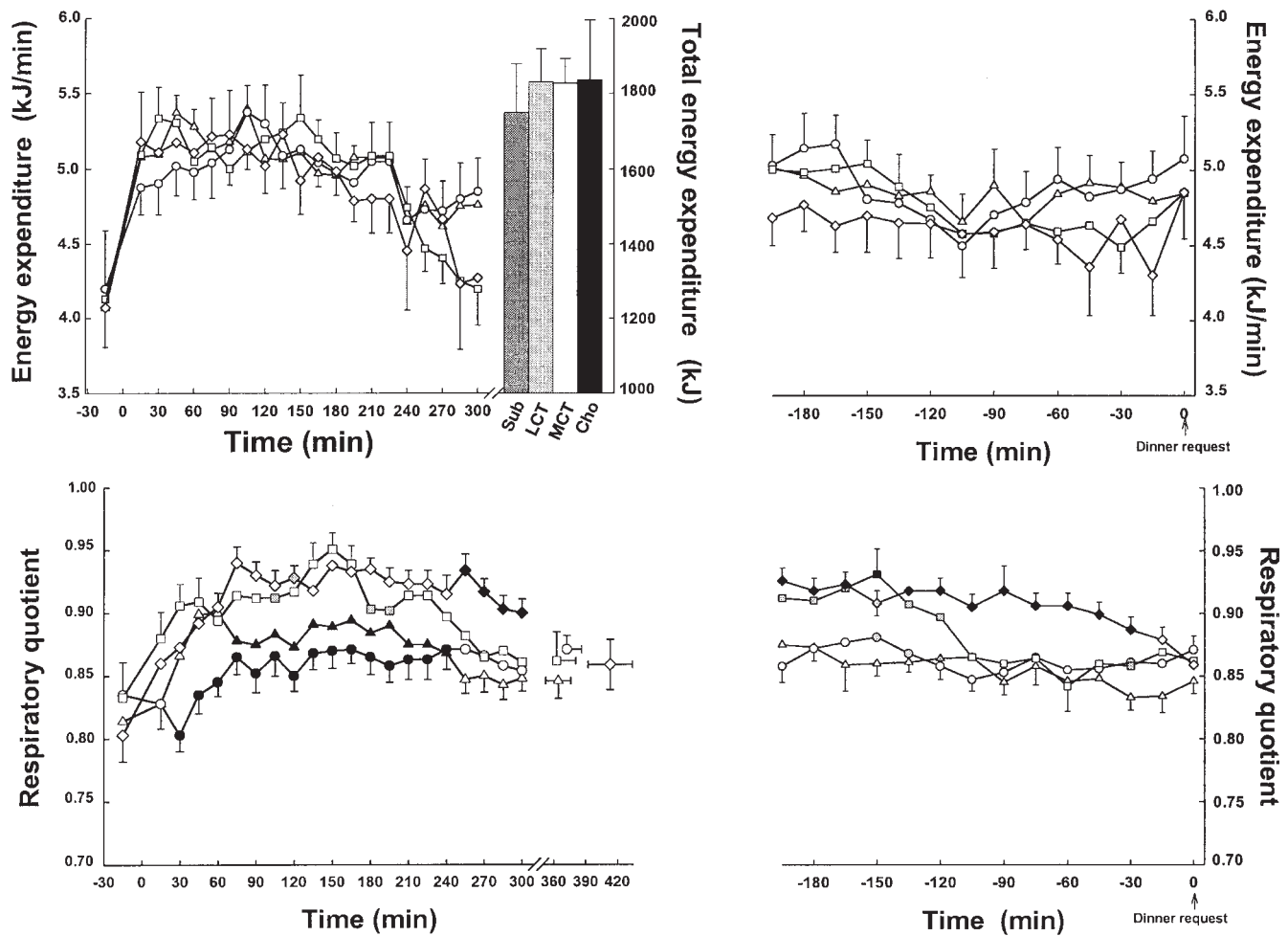
dinner (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.01). No significant differences in protein oxidation were observed (data not shown).

Substrate balance at the time of the dinner request was calculated as the difference between the amount of carbohydrate or fat ingested at lunch and the amount oxidized from the time lunch was consumed until the time of the dinner request. Fat balance was clearly positive after the 2 high-fat lunches (19.4 ± 4 g fat stored after the LCT lunch and 20.6 ± 1 g fat stored after the MCT lunch; *P* < 0.001) but was negative after the Sub lunch (-7 ± 1 g) (Table 2). Carbohydrate balance was positive after all 4 lunches, but was significantly greater (74.6 ± 6 g; *P* < 0.001) after the Cho lunch than after the 3 other lunches.

### Blood and hormone variables

The time courses of blood glucose concentrations were significantly different after the 4 lunches (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.05; Figure 4). The total glycemic response, as expressed as the AUCs, was clearly higher after the Cho lunch than after the 3 other lunches (*P* = 0.01), and plasma glucose concentrations peaked to a significantly greater value after the Cho lunch than after the MCT and LCT lunches (*P* < 0.001). Note that although the Sub, MCT, and LCT lunches provided approximately the same amount of carbohydrate, blood glucose concentrations increased more slowly after the MCT lunch and peaked at a significantly later time than it did after the 3 other lunches (91 ± 7 min after the MCT lunch, 57 ± 5 min after the LCT lunch, 54 ± 4 min after the Sub lunch, and 61 ± 4 min after the Cho lunch; *P* < 0.001, ANOVA). A time effect appeared during the 195 min preceding the time of the dinner request (ANOVA: time effect, *P* < 0.001).

Plasma insulin concentrations followed a similar pattern, with an early peak being significantly greater after the Sub lunch than after the MCT and LCT lunches. Again the difference was larger after the Cho lunch than after the 3 other lunches (ANOVA: time effect, *P* < 0.001; lunch effect, *P* < 0.001; Figure 4). Total insulin secretion, estimated by the AUCs, was also significantly greater after the Cho lunch than after the 3 other lunches (*P* < 0.001), whereas the peak insulin response (Figure 4) was delayed after the MCT lunch relative to the response to the 3 other lunches (97 ± 8 min after the MCT lunch, 56 ± 4 min after the LCT lunch, 62 ± 6 min after the Sub lunch, and 66 ± 4 min after the Cho lunch; *P* < 0.001). During the 195 min preceding the time of the dinner request, the only significant differences in insulin responses were between -10 and 0 min after the MCT lunch



**FIGURE 2.** Mean ( $\pm$ SEM) temporal energy expenditures and respiratory quotients after 4 lunches from before lunch to the time of the first dinner request (left panel) and during the 195 min preceding the time of the dinner request (right panel), the values for which were synchronized to the time of the dinner request. There was a significant time  $\times$  lunch interaction for respiratory quotient in the left ( $P < 0.001$ ) and right ( $P < 0.01$ ) panels. □, basic meal with 40 kJ fat substitute (Sub lunch); ◇, basic meal plus 900 kJ as carbohydrate and 300 kJ as long-chain triacylglycerols (CHO lunch); ○, basic meal plus 1200 kJ as medium-chain triacylglycerols (MCT lunch); △, basic meal plus 1200 kJ as LCTs (LCT lunch). The filled symbols are significantly different from the open symbols at the respective time points; the gray symbols are not significantly different from the open or filled symbols (ANOVA followed by Student's *t* test with Bonferroni correction). For the sake of clarity, error bars are only given for the maximum and minimum values at each time point.  $n = 9$ . The bars represent the total energy expenditure for each experimental condition.

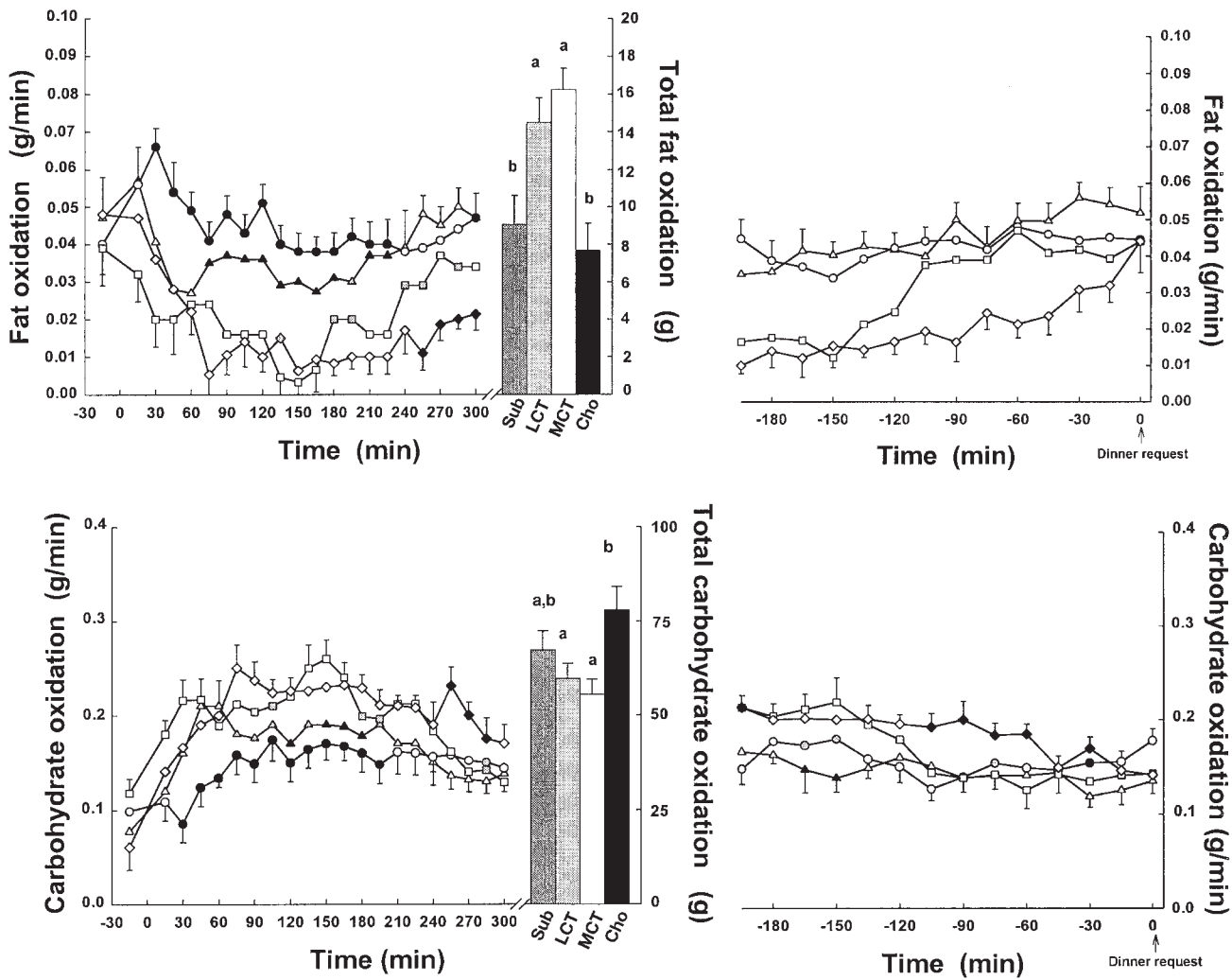
(ANOVA: time effect,  $P < 0.001$ ). Note that at the time of the dinner request, both plasma glucose and insulin concentrations were still significantly higher after the MCT lunch than after the 3 other lunches ( $P < 0.05$  and  $< 0.01$ , respectively).

Because of the inhibition of lipolysis, plasma fatty acid concentrations decreased abruptly from 30 to 90 min after the 4 lunches, ie, when plasma glucose was at its peak (ANOVA: time effect,  $P < 0.001$ ; lunch effect,  $P < 0.001$ ; **Figure 5**). However, after the MCT lunch, plasma fatty acid concentrations remained significantly greater than after the 3 other conditions for  $>4$  h. Before dinner, plasma fatty acid concentrations increased progressively from  $-130$  min until the time of the dinner request (ANOVA: time effect,  $P < 0.001$ ). At the time of the dinner request, plasma fatty acid concentrations did not differ significantly between the 4 lunches.

The course of plasma triacylglycerol concentrations (Figure 5) was significantly different after the 4 lunches. Although triacylglycerol concentrations decreased for  $\approx 3$  h after the Sub, MCT,

and LCT lunches, they increased progressively after the LCT lunch (ANOVA: time effect,  $P < 0.001$ ; lunch effect,  $P = 0.05$ ). As a consequence, plasma triacylglycerol concentrations were significantly higher from 120 to 300 min after the LCT lunch, although this difference had disappeared by the time of the dinner request. During the 195 min preceding the time of the dinner request, plasma triacylglycerol concentrations were higher after the LCT lunch than after the 3 other lunches (ANOVA: lunch effect,  $P < 0.001$ ).

After the MCT lunch, plasma  $\beta$ -hydroxybutyrate concentrations increased and peaked 60 min later. Concentrations then decreased but remained significantly greater by  $\approx 10$ -fold after the MCT lunch than after the other 3 lunches (ANOVA: time effect,  $P < 0.001$ ; lunch effect,  $P < 0.001$ ; **Figure 5**); differences were also noted during the 195 min preceding the time of the dinner request (ANOVA: time effect,  $P < 0.001$ ; lunch effect,  $P < 0.001$ ). However, at the time of the dinner request, plasma  $\beta$ -hydroxybutyrate concentrations were significantly lower only after the Cho lunch ( $P < 0.05$ ).



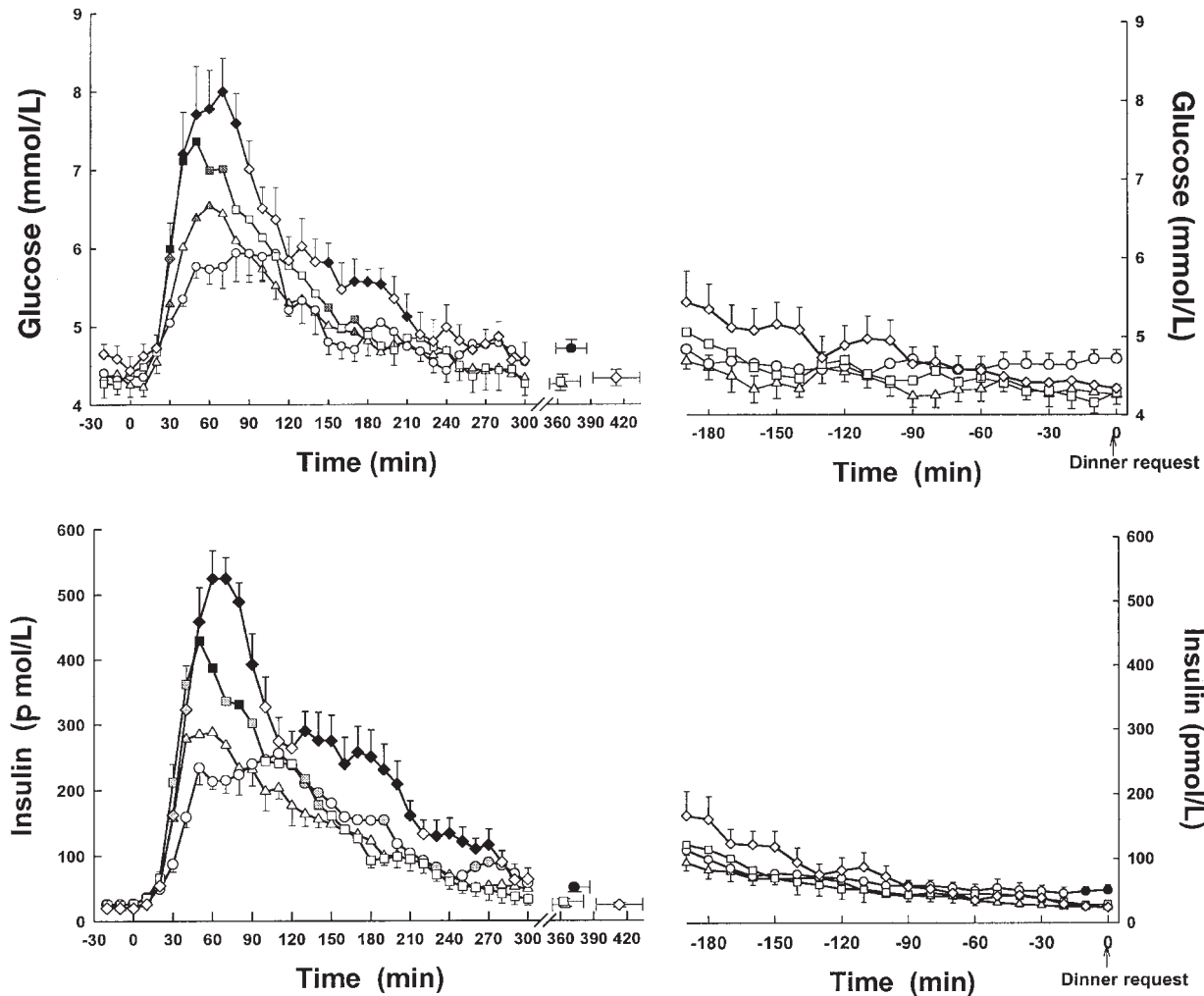
**FIGURE 3.** Mean ( $\pm$ SEM) temporal fat and carbohydrate oxidation after 4 lunch meals from before lunch to the time of the first dinner request (left panel) and during the 195 min preceding the time of the dinner request (right panel), the values for which were synchronized to the time of the dinner request. There was a significant time  $\times$  lunch interaction for fat oxidation in the left panel ( $P < 0.001$ ) and for carbohydrate oxidation in both panels ( $P < 0.001$ ).  $\square$ , basic meal with 40 kJ fat substitute (Sub lunch);  $\diamond$ , basic meal plus 900 kJ as carbohydrate and 300 kJ as long-chain triacylglycerols (CHO lunch);  $\circ$ , basic meal plus 1200 kJ as medium-chain triacylglycerols (MCT lunch);  $\triangle$ , basic meal plus 1200 kJ as LCTs (LCT lunch). The filled symbols are significantly different from the open symbols at the respective time points; the gray symbols are not significantly different from the open or filled symbols (Student's  $t$  test with Bonferroni correction after ANOVA). For the sake of clarity, error bars are only given for the maximum and minimum values at each time point.  $n = 9$ . Bars represent total fat and carbohydrate oxidation: a and b are significantly different (ANOVA followed by Student's  $t$  test with Bonferroni correction).

**TABLE 2**  
Nutrient balance at the time of the dinner request<sup>1</sup>

Lunch	Fat				Carbohydrate			
	Intake	Oxidation	Balance	Oxidation rate	Intake	Oxidation	Balance	Oxidation rate
	g	g	g	mg/min	g	g	g	mg/min
LCT	34	14.6 $\pm$ 1 <sup>a</sup>	19.4 $\pm$ 4 <sup>a</sup>	40.1 $\pm$ 3 <sup>a</sup>	99	59.7 $\pm$ 4 <sup>a</sup>	39.2 $\pm$ 4 <sup>a</sup>	163.3 $\pm$ 9 <sup>b</sup>
MCT	37	16.2 $\pm$ 1 <sup>a</sup>	20.6 $\pm$ 1 <sup>a</sup>	44.5 $\pm$ 4 <sup>a</sup>	99	55.5 $\pm$ 4 <sup>a</sup>	43.4 $\pm$ 4 <sup>a</sup>	148.7 $\pm$ 10 <sup>b</sup>
Sub	2	9 $\pm$ 1 <sup>b</sup>	-7 $\pm$ 1 <sup>c</sup>	24.8 $\pm$ 4 <sup>b</sup>	101.4	67.4 $\pm$ 5 <sup>a,b</sup>	33.9 $\pm$ 5 <sup>a</sup>	184.9 $\pm$ 9 <sup>a</sup>
Cho	10	7.7 $\pm$ 1 <sup>b</sup>	2.3 $\pm$ 1 <sup>b</sup>	19.1 $\pm$ 4 <sup>b</sup>	152.6	78.1 $\pm$ 6 <sup>b</sup>	74.6 $\pm$ 6 <sup>b</sup>	188.8 $\pm$ 11 <sup>a</sup>
$P^2$	—	<0.001	<0.001	<0.001	—	<0.001	<0.001	<0.001

<sup>1</sup> $\bar{x} \pm$  SEM;  $n = 9$ . Means within columns with different superscript letters are significantly different,  $P < 0.01$  (Student's  $t$  test with use of the error term with Bonferroni correction). LCT, long-chain triacylglycerol; MCT medium-chain triacylglycerol; Sub, fat substitute; Cho, carbohydrate.

<sup>2</sup>The 4 means were compared with use of repeated-measures analysis of variance. If the means differed significantly, they were compared 2 by 2 with Student's  $t$  test (with use of the error term) with Bonferroni correction of the type I error.



**FIGURE 4.** Mean ( $\pm$ SEM) temporal glucose and insulin concentrations after 4 lunch meals from before lunch to the time of the first dinner request (left panel) and during the 195 min preceding the time of the dinner request (right panel), the values for which were synchronized to the time of the dinner request. There was a significant time  $\times$  lunch interaction for glucose in the left panel ( $P < 0.001$ ) and for insulin in the left ( $P < 0.001$ ) and right ( $P < 0.05$ ) panels.  $\square$ , basic meal with 40 kJ fat substitute (Sub lunch);  $\diamond$ , basic meal plus 900 kJ as carbohydrate and 300 kJ as long-chain triacylglycerols (CHO lunch);  $\circ$ , basic meal plus 1200 kJ as medium-chain triacylglycerols (MCT lunch);  $\triangle$ , basic meal plus 1200 kJ as LCTs (LCT lunch). The filled symbols are significantly different from the open symbols at the respective time points; the gray symbols are not significantly different from the open or filled symbols (ANOVA followed by Student's  $t$  test with Bonferroni correction). For the sake of clarity, error bars are only given for the maximum and minimum values at each time point.  $n = 9$ .

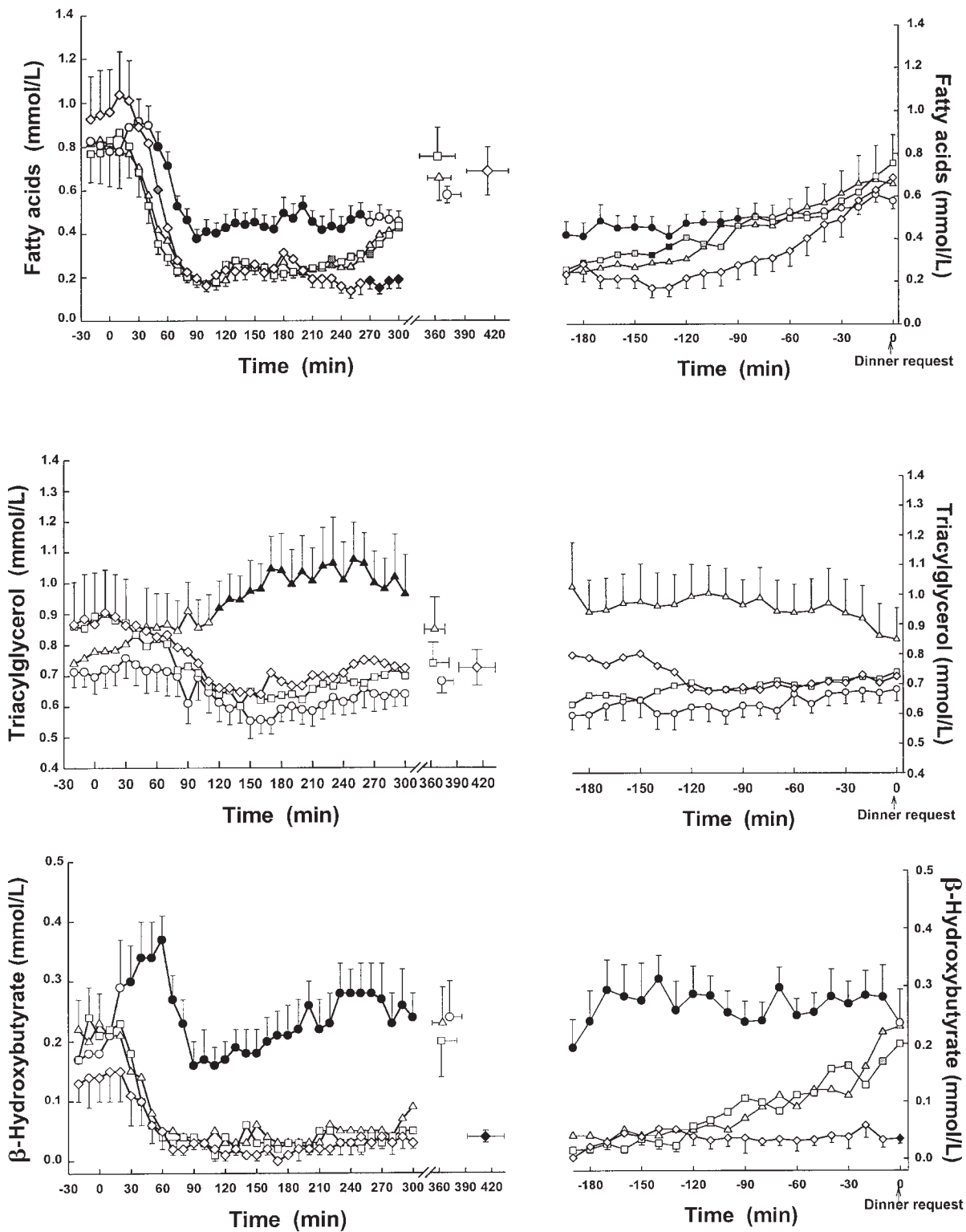
## DISCUSSION

This study was designed to evaluate the role of glucose and its metabolism on the control of food intake in humans. To this end we compared the effects of a basic lunch (Sub lunch) and the same basic lunch supplemented with carbohydrate (Cho lunch) or fat (MCT and LCT lunches). The hypothesis was that carbohydrate oxidation would be lower after the MCT lunch than after the LCT lunch and that the glucose spared would delay the following meal request and modify subsequent food intake.

The finding that carbohydrate oxidation was significantly greater and fat oxidation significantly lower after the Cho lunch meal than after the other lunches is consistent with the results of previous studies (17, 30–32) and with the paradigm that carbohydrate balance is autoregulated (17, 30, 33). The finding in the present study that fat oxidation was significantly greater after the MCT and LCT lunches than after the other 2 lunches differs from

the findings of some of the above-mentioned studies, which indicated that the addition of fat to “usual” meals does not increase fat oxidation (16, 17, 30–33). However, these differences could stem from differences in the methods used, eg, the amount of fat added in some of these studies exceeded usual energy requirements. On the other hand, the possibility that metabolic fat utilization increased as the fat content of the meal increased was also observed by Griffiths et al (15).

The finding that the Cho lunch resulted in a significantly positive carbohydrate balance at the time of the dinner request (30–40 g; Table 2) and significantly prolonged satiety 40–50 min postmeal (Table 1) is consistent with the hypothesis of a predominant role of carbohydrate metabolism and cellular glucose availability on the control of food intake and, more specifically, on the duration of satiety. This finding agrees with the findings of Raben and Astrup (34), ie, that there is a good correlation between the total energy contents of different foods, particularly



**FIGURE 5.** Mean ( $\pm$ SEM) temporal plasma fatty acid, triacylglycerol, and  $\beta$ -hydroxybutyrate concentrations after 4 lunch meals from before lunch to the time of the first dinner request (left panel) and during the 195 min preceding the time of the dinner request (right panel), the values for which were synchronized to the time of the dinner request. There was a significant time  $\times$  lunch interaction for the 3 variables in the left panels ( $P < 0.001$ ) and for fatty acids ( $P < 0.01$ ) and  $\beta$ -hydroxybutyrate ( $P < 0.001$ ) in the right panels.  $\square$ , basic meal with 40 kJ fat substitute (Sub lunch);  $\diamond$ , basic meal plus 900 kJ as carbohydrate and 300 kJ as long-chain triacylglycerols (CHO lunch);  $\triangle$ , basic meal plus 1200 kJ as medium-chain triacylglycerols (MCT lunch);  $\triangle$ , basic meal plus 1200 kJ as LCTs (LCT lunch). The filled symbols are significantly different from the open symbols at the respective time points; the gray symbols are not significantly different from the open or filled symbols (ANOVA followed by Student's  $t$  test with Bonferroni correction). For the sake of clarity, error bars are only given for the maximum and minimum values at each time point.  $n = 9$ .




the carbohydrate content, and their satiation power. Raben et al (35) also noted a positive correlation between satiety and carbohydrate oxidation but an inverse correlation between satiety and fat oxidation.

The positive correlation between glucose utilization and the duration of satiety may stem from the rate of intestinal absorption of glucose. It was suggested that the decrease in blood glucose, which initiates food intake, may be due to a decrease in intestinal metabolite absorption, particularly glucose (36). It is now clear that acute changes in blood glucose concentrations have a major effect on both gastrointestinal motor function and gastric emptying (37–39). There is an inverse relation between the rate of gastric emptying and blood glucose concentrations, ie, gastric emptying is slower during hyperglycemia and faster during hypoglycemia (39). In the present study, the higher blood glucose and insulin concentrations after the Cho lunch may have slowed gastric emptying, which delayed the hunger sensation and promoted satiety. However, the addition of either MCTs or LCTs to the lunches did not allow enough glucose to be spared to delay the time of the dinner request. This finding supports a minor direct role of lipid availability in the duration of satiety. Flatt et al (17) showed that 10 g carbohydrate was spared after the substitution of 40 g MCTs for 50 g LCTs. Preliminary tests in our laboratory indicated that the triacylglycerol content of a meal should not exceed  $\approx 35$  g because of the adverse effects that are associated with higher doses. Because the difference in carbohydrate oxidation between the MCT and LCT lunches was small (ie, 4.2 g), we concluded that carbohydrate oxidation was not spared more with the MCT than with the LCT lunch. A theoretical computation based on the equation proposed by Rigaud and Melchior (29), modified assuming the exclusive oxidation of an equimolar mixture of  $C_8$  and  $C_{10}$  fatty acids after the MCT lunch (corresponding to an RQ of 0.731 instead of 0.711 for the oxidation of typical dietary triacylglycerols), indicates that this difference in carbohydrate oxidation would be  $\leq 7.9$  g, rather than 4.2 g as indicated by our results; however, the difference was insignificant. However, because of type II error, it is possible that a significant difference was not found because of the relatively small number of subjects. The CI indicated that the maximum amount of carbohydrate spared would be 14.2 g. The addition of  $\approx 50$  g carbohydrate to the basic lunch delayed the dinner request by  $\approx 50$  min ( $\approx 1$  min/g) and resulted in a longer duration of satiety (8.1 min; NS) after the MCT than after the LCT lunch, with 4.2 g carbohydrate spared. This finding supports a specific role of glucose availability in the maintenance of satiety.

The main finding that ingestion of the MCT lunch resulted in less food consumed at dinner than did the other meals indicates that MCTs have a higher satiation power than do other fats and carbohydrate (27). However, the reason why the duration of satiety was not longer after the MCT lunch than after the LCT lunch is unclear. There is some evidence that dietary fat structure influences short-term energy intake. Rolls et al (40) showed that the consumption by humans of mixed preloads containing 24% MCTs and 6% LCTs 30 min before lunch resulted in less food consumption at the next meal than did a preload containing 30% LCTs. This immediate effect indicates preabsorptive mechanisms. In contrast, Maggio and Koopmans (41) and Satabin et al (42) showed that gastric loads of MCTs or LCTs in rats had the same suppressant action on short-term food intake.

The lower food intake at dinner after the MCT lunch than after the other meals could also be accounted for by the finding of Fielding et al (43), ie, that after the consumption of a breakfast with a high fat content, the postprandial peak of the major fatty acids is followed by a second peak, which occurs at the beginning of the next meal. In the present study, less food was consumed at the dinner after the MCT lunch possibly because plasma fatty acid concentrations were higher after the MCT lunch than after the other 3 meals.

A third possibility relates to insulin and glucose concentrations at the time of the dinner request, which were the only blood variables that were significantly different between the MCT lunch and the other 3 lunches. Note that the only significant differences in blood variables at the time of the dinner request were plasma glucose and insulin concentrations after the MCT lunch compared with the 3 other lunches. Schwartz et al (44) reported that there is a relation between plasma and cerebrospinal fluid insulin concentrations, ie, a physiologic increase in plasma insulin produces significant elevations in cerebrospinal fluid insulin within 30–60 min. Insulin may pass through the blood-brain barrier in the vicinity of the third ventricle. In addition, intraventricular insulin administration reduces food intake (45–48). The higher satiation power of MCT could thus stem from a specific central action of insulin mobilized in the periphery.

Taken together, the results favor a specific role of glucose cellular availability in the control of food intake and the satiety duration, a potential role of lipids in the satiety duration, and a weak role of lipids in the satiety duration. Further studies are required to determine the relation between eating behavior, metabolic rate (substrate oxidation and blood variables), and gastric emptying to delineate the respective roles of glucose and lipids in the control of food intake. 

We thank J Bouillard, P Noirof, F Poirot, and C Douzi-Varvou for their technical support and help in data collection.

## REFERENCES

1. Le Magnen J. Neurobiology of feeding and nutrition. San Diego: Academic Press, 1992.
2. Bernstein IL, Zimmerman JC, Czeisler CA, Weitzman ED. Meal patterns in "free-running" humans. *Physiol Behav* 1981;27:621–3.
3. Mayer J. Glucostatic mechanism of regulation of food intake. *N Engl J Med* 1953;249:13–4.
4. Mayer J. Regulation of energy intake and the body weight: the glucostatic theory and the lipostatic hypothesis. *Ann N Y Acad Sci* 1955;73:15–42.
5. Oomura Y, Ono T, Ooyama H, Wayner MJ. Glucose and osmosensitive neurones of the rat hypothalamus. *Nature* 1969;222:282–4.
6. Himmi T, Boyer A, Orsini JC. Changes in lateral hypothalamic neuronal activity accompanying hyper- and hypoglycemia. *Physiol Behav* 1988;44:347–54.
7. Louis-Sylvestre J, Le Magnen J. A fall in blood glucose level precedes meal onset in free-feeding rats. *Neurosci Biobehav Rev* 1980;4(suppl):13–5.
8. Campfield LA, Brandon P, Smith FJ. On-line continuous measurement of blood glucose and meal pattern in free-feeding rats: the role of glucose in meal initiation. *Brain Res Bull* 1985;14:605–16.
9. Campfield LA, Smith FJ, Rosenbaum M, Hirsch J. Human eating: evidence for a physiological basis using a modified paradigm. *Neurosci Biobehav Rev* 1996;20:133–7.
10. Melanson KJ, Westterp-Platanga MS, Saris WH, Smith FJ, Campfield LA. Blood glucose patterns and appetite in time-blinded humans: carbohydrate versus fat. *Am J Physiol* 1999;277:R337–45.

11. Randle PJ, Garland PB, Hales CN, Newsholme EA. The glucose fatty acid cycle: its role in insulin sensitivity and the metabolic disturbances of diabetes mellitus. *Lancet* 1963;1:785-98.
12. Kelley DE, Mokan M, Simoneau JA, Mandarino LJ. Interaction between glucose and free fatty acid metabolism in human skeletal muscle. *J Clin Invest* 1993;92:91-8.
13. Vaag A, Skött P, Damsbo P, Gall MA, Richter EA, Beck-Nielsen H. Effect of the antilipolytic nicotinic acid analogue acipimox on whole-body and skeletal muscle glucose metabolism in patients with non-insulin-dependent diabetes mellitus. *J Clin Invest* 1991;88:1282-90.
14. Himaya A, Fantino M, Antoine JM, Brondel L, Louis-Sylvestre J. Satiety power of dietary fat: a new appraisal. *Am J Clin Nutr* 1997;65:1410-8.
15. Griffiths AJ, Humphreys SM, Clark ML, Fielding BA, Frayn KN. Immediate metabolic availability of dietary fat in combination with carbohydrate. *Am J Clin Nutr* 1994;59:53-9.
16. Schutz Y, Flatt JP, Jequier E. Failure of dietary fat intake to promote fat oxidation: a factor favoring the development of obesity. *Am J Clin Nutr* 1989;50:307-14.
17. Flatt JP, Ravussin E, Acheson KJ, Jequier E. Effects of dietary fat on postprandial substrate oxidation and on carbohydrate and fat balances. *J Clin Invest* 1985;76:1019-24.
18. Scharrer E, Langhans W. Control of food intake by fatty acid oxidation. *Am J Physiol* 1986;250:R1003-6.
19. Friedman MI, Tordoff MG. Fatty acid oxidation and glucose utilization interact to control food intake in rats. *Am J Physiol* 1986;251:R840-5.
20. Friedman MI, Harris RB, Ramirez I, Tordoff MG. Fatty acid oxidation affects food intake by altering hepatic energy status. *Am J Physiol* 1999;276:R1046-53.
21. Ritter S, Ritter JB, Cromer L. 2-Deoxy-D-glucose and mercaptoacetate induce different patterns of macronutrient ingestion. *Physiol Behav* 1999;66:709-15.
22. Even P, Nicolaïdis S. Spontaneous and 2-DG induced metabolic changes and feeding: the ischymetric hypothesis. *Brain Res Bull* 1985;15:429-35.
23. Friedman MI, Stricker EM. The physiological psychology of hunger: a physiological perspective. *Psychol Rev* 1976;83:409-31.
24. Bach AC, Ingenbleek Y, Frey A. The usefulness of dietary medium-chain triglycerides in body weight control: fact or fancy? *J Lipid Res* 1996;37:708-26.
25. Cotter R, Taylor CA, Johnson R, Rowe WB. A metabolic comparison of a pure long-chain triglyceride lipid emulsion (LCT) and various medium-chain triglyceride (MCT)-LCT emulsions in dogs. *Am J Clin Nutr* 1987;45:927-39.
26. Metges CC, Wolfram G. Medium- and long-chain triglycerides labeled with <sup>13</sup>C: a comparison of oxidation after oral or parenteral administration in humans. *J Nutr* 1991;121:31-6.
27. Van Wymelbeke V, Himaya A, Louis-Sylvestre J, Fantino M. Influence of medium-chain and long-chain triacylglycerols on the control of food intake in men. *Am J Clin Nutr* 1998;68:226-34.
28. Rigaud D, Melchior JC. Le métabolisme énergétique chez l'homme. (Energetic metabolism in humans.) Cachan, France: Editions Médicales Internationales, 1992:1-143 (in French).
29. Chabert MF, Verger P, Louis-Sylvestre J. A method for long-term and accurate measurement and recording of the blood glucose level in man. *Physiol Behav* 1991;49:827-30.
30. Jequier E. Body weight regulation in humans: the importance of nutrient balance. *Am Physiol Soc* 1993;8:273-6.
31. Horton TJ, Drougas H, Brachey A, Reed GW, Peters JC, Hill JO. Fat and carbohydrate overfeeding in humans: different effects on energy storage. *Am J Clin Nutr* 1995;62:19-29.
32. Jeukendrup AE, Thielen JJHC, Wagenmakers AJM, Brouns F, Saris WHM. Effect of medium-chain triacylglycerol and carbohydrate ingestion during exercise on substrate utilization and subsequent cycling performance. *Am J Clin Nutr* 1998;67:397-404.
33. Hill JO, Peters JC, Reed GW, Schlundt DG, Sharp T, Greene HL. Nutrient balance in humans: effects of diet composition. *Am J Clin Nutr* 1991;54:10-7.
34. Raben A, Astrup A. Manipulating carbohydrate content and sources in obesity prone subjects: effect on energy expenditure and macronutrient balance. *Int J Obes Relat Metab Disord* 1996;20: S24-30.
35. Raben A, Holst JJ, Christensen NJ, Astrup A. Determinants of postprandial appetite sensations: macronutrient intake and glucose metabolism. *Int J Obes Relat Metab Disord* 1996;20:161-9.
36. Louis-Sylvestre J. Glucose utilization dynamics and food intake. *Br J Nutr* 1999;82:427-9.
37. Kong MF, Horowitz M. Gastric emptying in diabetes mellitus: relationship to blood-glucose control. *Clin Geriatr Med* 1999;15:321-38.
38. Samsom M, Smout AJ. Abnormal gastric and small intestinal motor function in diabetes mellitus. *Dig Dis* 1997;15:263-74.
39. Horowitz M, Wishart JM, Jones KL, Hebbard GS. Gastric emptying in diabetes: an overview. *Diabet Med* 1996;13:S16-22.
40. Rolls BJ, Gnizak N, Summerfelt A, Laster LJ. Food intake in dieters and nondieters after a liquid meal containing medium-chain triglycerides. *Am J Clin Nutr* 1988;48:66-71.
41. Maggio CA, Koopmans HS. Satiety effects of intragastric meals containing triglycerides with different chain lengths. *Am J Physiol* 1987;252:R1106-13.
42. Satabin P, Auclair E, Servan E, Larue Aghagiotis C, Guezennec CY. Influence of glucose, medium- and long-chain triglyceride gastric loads and forced exercise on food intake and body weight in rats. *Physiol Behav* 1991;50:147-50.
43. Fielding BA, Callow J, Owen RM, Samra JS, Matthews DR, Frayn KN. Postprandial lipemia: the origin of an early peak studied by specific dietary fatty acid intake during sequential meals. *Am J Clin Nutr* 1996;63:36-41.
44. Schwartz MW, Sipols AJ, Kahn SE, et al. Kinetics and specificity of insulin uptake from plasma into cerebrospinal fluid. *Am J Physiol* 1990;259:E378-83.
45. Ikeda H, West DB, Pustek JJ, et al. Intraventricular insulin reduces food intake and body weight of lean but not obese Zucker rats. *Appetite* 1986;7:381-6.
46. Porte D, Woods SC. Regulation of food intake and body weight in insulin. *Diabetologia* 1981;20(suppl):274-80.
47. Nicolaïdis S, Rowland N. Metering of intravenous versus oral nutrients and regulation of energy balance. *Am J Physiol* 1976;231:661-8.
48. Strubbe JH, Steffens AB. Rapid insulin release after ingestion of a meal in the unanesthetized rat. *Am J Physiol* 1975;229:1019-22.



## APPENDIX A

Food choices provided during the ad libitum dinner

Food items	Energy <sup>1</sup>	Protein	Fat	Carbohydrates
	<i>kJ</i>	%	%	%
Tabouleh <sup>2</sup>	530.86	12.18	14.02	73.80
Eggs (hard boiled) <sup>3</sup>	643.72	50.81	45.12	4.07
Ham <sup>3</sup>	518.32	80.77	15.38	3.85
Turkey breast <sup>4</sup>	509.96	84.31	15.69	0.00
Chicken <sup>3</sup>	522.50	96.67	3.33	0.00
Tuna fish <sup>3</sup>	509.96	93.97	6.03	0.00
White bread	1066.74	11.15	1.27	87.58
Kidney beans <sup>5</sup>	388.74	27.80	2.69	69.51
Green peas <sup>5</sup>	309.32	28.89	2.22	68.89
Green beans <sup>5</sup>	75.24	31.82	2.27	65.91
Carrots <sup>5</sup>	136.69	10.26	3.85	85.90
Lentils <sup>6</sup>	484.88	30.53	1.75	67.72
Stew <sup>5</sup>	167.20	10.13	20.25	69.62
Potatoes <sup>7</sup>	293.44	13.29	1.16	85.55
Butter <sup>3</sup>	3143.36	0.83	98.57	0.59
Mayonnaise <sup>8</sup>	3025.94	2.94	96.40	0.66
Mustard <sup>8</sup>	405.46	35.29	29.41	35.29
Cream cheese kiri <sup>9</sup>	1345.96	20.93	74.42	4.65
Comté cheese <sup>3</sup>	1665.73	48.26	51.74	0.00
Cheese, Camembert 45% <sup>3</sup>	1216.38	48.85	50.69	0.46
Chocolate pudding <sup>10</sup>	512.43	12.89	12.85	74.27
Unflavored yogurt <sup>3</sup>	209.00	39.80	21.43	38.78
Fruit yogurt <sup>3</sup>	388.74	14.00	13.00	73.00
Sugar	1666.98	0.00	0.00	100.00
Bananas	417.16	4.86	0.81	94.33
Apples	230.74	2.26	3.01	94.74
Butter cookies <sup>11</sup>	1954.99	6.25	17.71	76.04
Chocolate cookies <sup>12</sup>	1953.31	7.48	25.96	66.55
Dark chocolate <sup>3</sup>	2528.90	8.33	45.83	45.83
Milk chocolate <sup>13</sup>	2257.20	7.37	32.63	60.00
Fruit sugar <sup>14</sup>	936.32	0.00	0.00	100.00

<sup>1</sup>Per 100 g.<sup>2</sup>Garbit; William Saurin, Lagny sur Marne, France.<sup>3</sup>Carrefour, Evry, France.<sup>4</sup>Les Volailles de Marques; Ronsard, Bignan, France.<sup>5</sup>D'aucy; Compagnie Générale de Conserves, Theix, France.<sup>6</sup>Le Cabanon SA, Camaret, France.<sup>7</sup>Les saveurs du Potager; Lunor, Luneray, France.<sup>8</sup>Moutarde de Dijon; Amora, Dijon, France.<sup>9</sup>Kiri; Fromagère Bel, Paris.<sup>10</sup>Danette; Danone, Levallois-Perret, France.<sup>11</sup>Nantais; Lu, Athis-Mons, France.<sup>12</sup>Pepito; Belin Ris Orangis, France.<sup>13</sup>Lindt; Lindt et Spüngly NV, Oloron-Sainte-Maine, France.<sup>14</sup>Panier quatre saisons; Saint Siffrein, Carpentras, France.