

Dietary fat oxidation as a function of body fat^{1,2}

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ABSTRACT

Background: It is hypothesized that low dietary fat oxidation makes subjects prone to weight gain.

Objective: The aim of the study was to determine dietary fat oxidation in normal, overweight, and obese subjects.

Design: The subjects were 38 women and 18 men with a mean (\pm SD) age of 30 ± 12 y and a body mass index (in kg/m^2) of 25 ± 4 (range: 18–39). Dietary fat oxidation was measured with deuterated palmitic acid, given simultaneously with breakfast, while the subjects were fed under controlled conditions in a respiration chamber. Body composition was measured by hydrodensitometry and deuterium dilution.

Results: Dietary fat oxidation, measured over 12 h after breakfast, ranged from 4% to 28% with a mean (\pm SD) of $16 \pm 6\%$. Dietary fat oxidation was negatively related to percentage body fat, and lean subjects had the highest and obese subjects the lowest values ($r = -0.65$, $P < 0.001$).

Conclusion: The observed reduction in dietary fat oxidation in subjects with a higher percentage body fat may play a role in human obesity. *Am J Clin Nutr* 2008;87:132–5.

KEY WORDS Obesity, respiration chamber, energy expenditure, substrate utilization, deuterated palmitic acid

INTRODUCTION

Obesity is a major health problem as a risk factor for the development of coronary heart disease, type 2 diabetes, hypertension, dyslipidemias, stroke, and cancer (1–3). Obesity is the result of energy intake in excess of energy requirements and for which alterations in the routing of dietary nutrients may also play a role. Maggio and Greenwood (4) hypothesized that excessive storage of dietary fat relative to its oxidation might predispose to fat accretion. A suggested mediator in partitioning absorbed fat between storage and oxidation is lipoprotein lipase (LPL). A low muscle LPL activity was related to a low ratio of fat to carbohydrate oxidation as measured in subjects fed a weight-maintenance diet in a respiration chamber (5). Subsequently, a low ratio of fat to carbohydrate oxidation is a predictor of weight gain and thus contributes to the development of obesity (6). Normal-weight subjects with a strong family history of obesity have reduced lipid oxidation in the postprandial period as an early predictor of weight gain (7).

Fat metabolism can be traced with isotope-labeled fatty acids. Oxidation and adipose tissue uptake of dietary fat can be measured by adding fatty acid tracers to meals. Thus, it was shown in

nonobese humans that women and men oxidize a similar proportion of dietary fat over 24 h after a test meal; women stored a greater portion in subcutaneous adipose tissue (8). The missing meal fat, calculated as total intake minus oxidation and subcutaneous storage, was related to visceral fat mass. In another study, in which nonobese and obese subjects were followed for 6 h after an oral fat load, it was suggested that obesity is associated with a defect in the oxidation of dietary fat, probably related to an excessive uptake by the adipose tissue of meal-derived fatty acids (9). Recently, a difference in trafficking of dietary fat was shown in obesity-prone and obesity-resistant rats (10). The obesity-resistant phenotype was associated with greater oxidation and less storage of dietary fat than was the obesity prone phenotype.

The following study presents results of observations in the human model where dietary fat oxidation was measured in normal, overweight, and obese subjects for 24 h in a respiration chamber.

SUBJECTS AND METHODS

Data were collected through 3 different experiments that studied the effect of dietary intake on energy expenditure and substrate utilization measured with the same technique. The data presented are from the placebo observations in these experiments. The Ethics Committee of Maastricht University approved the studies. All subjects received verbal and written information and signed a written consent form.

Subjects

The subjects were 38 women and 18 men aged 30 ± 12 y with a mean (\pm SD) body mass index (in kg/m^2) of 25 ± 4 (range: 18–39) (**Table 1**). The subjects were in good health as assessed by medical history and physical examination. Body composition was estimated by using hydrodensitometry and isotope dilution. Body density was determined by underwater weighing with simultaneous measurement of residual lung volume with the helium dilution technique. Total body water (TBW) was determined with deuterium dilution following the Maastricht protocol (11). Body composition was calculated from body density and

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TABLE 1
Subject characteristics¹

	Women (n = 38)	Men (n = 18)
Age (y)	28 ± 11 (19–53)	34 ± 13 (18–54)
Height (m)	1.68 ± 0.08 (1.50–1.81)	1.77 ± 0.10 (1.63–2.07) ²
Weight (kg)	67.4 ± 10.7 (49.4–94.1)	85.1 ± 16.0 (63.1–113.4) ²
Body fat (%)	29.8 ± 7.8 (10.4–43.6)	24.3 ± 7.9 (5.5–34.8) ³
BMI (kg/m ²)	24.0 ± 3.5 (17.5–31.9)	27.2 ± 4.8 (20.4–39.2) ²
SMR (MJ/d)	6.12 ± 0.56 (4.79–7.17)	7.61 ± 1.03 (5.59–9.63)
PAL	1.43 ± 0.08 (1.14–1.58)	1.41 ± 0.08 (1.30–1.56)

¹ All values are $\bar{x} \pm$ SD; range in parentheses. SMR, sleeping metabolic rate; PAL, physical activity level (ie, total energy expenditure as a multiple of SMR as measured in a respiration chamber).

^{2,3} Significantly different from women (unpaired *t* test): ²*P* < 0.01, ³*P* < 0.05.

TBW with the 3-compartment model of Siri (12). TBW was measured after measurement of dietary fat oxidation, and baseline values were corrected for the increase in body water deuterium from the oxidation of deuterated fat (*see below*).

Diet and dietary fat oxidation

Dietary fat oxidation was measured with deuterated palmitic acid (13), given simultaneously with breakfast, while the subjects were fed in energy balance in a respiration chamber. Three days before the test day, the subjects were provided with a diet of the same composition to consume at home. The diets provided 30%, 30%, and 40% of energy from fat, protein, and carbohydrate, respectively (*n* = 12); 35%, 15%, and 50% of energy from fat, protein, and carbohydrate, respectively (*n* = 14); 35%, 10%, and 55% of energy from fat, protein, and carbohydrate, respectively (*n* = 6); or 30%, 15%, and 55% of energy from fat, protein, and carbohydrate, respectively (*n* = 24). The energy content of the diet that the subjects consumed at home was based on basal metabolic rate, which was calculated with the equation of Harris-Benedict (14) and multiplied by an activity index of 1.7 (15). To attain energy balance in the respiration chamber, we adopted an activity index of 1.4. Energy intake in the respiration chamber was divided over 3 meals; breakfast provided 20% of the daily total. Palmitic acid, d₃₁-palmitic acid (98 atom%; Cambridge Isotope, Andover, MA) at a dose of 20 mg/kg, was supplied in 150 mL hot chocolate milk. ²H was measured in a urine sample collected before dosing and samples were collected every 2 h for 12 h after dosing. In 20 subjects, an additional measurement was performed 24 h after dosing. Urine samples were analyzed for deuterium content with an isotope ratio mass spectrometer (Optima, VG, Manchester, United Kingdom) after preparation with the platinum-equilibration methodology (16). Urine samples of 300 μL were placed in the bottom of 3-mL glass containers with 4 mg catalyst (5% platinum-on alumina, 325 mesh; Aldrich Chemical Company Ltd, Dorset, United Kingdom) in an insert, filled with hydrogen from a cylinder to 60 kPa above atmospheric pressure, and left for 3 d at room temperature before analysis. Recovery of deuterium from palmitic acid oxidation was calculated as excess ²H times dilution space divided by the dose of ²H administered (13).

Substrate oxidation and energy expenditure

Subjects entered the respiration chamber in the evening or the early morning before the 24-h measurement started. The respiration chamber is a 14-m³ room furnished with a bed, chair,

computer, television, radio cassette player, telephone, intercom, sink, and toilet (17). During the day, the subjects were allowed to move freely, sit, lie down, study, telephone, listen to the radio, watch television, and use the computer; only sleeping and strenuous exercise were not allowed. Fat, protein, and carbohydrate oxidation and energy expenditure were calculated from measurements of oxygen consumption, carbon dioxide production, and urinary nitrogen excretion by using the formulas of Brouwer (18).

Statistical analysis

Data are presented as means ± SDs unless otherwise indicated. Regression analysis was performed to determine relations between selected variables. Significance was defined as *P* < 0.05. All statistical tests were performed by using the STATVIEW program (1992–1998; SAS Institute Inc, Cary, NC).

RESULTS

The subjects were in a slightly positive energy balance and fat balance (**Table 2**). Protein and carbohydrate balances were not significantly different from zero. Dietary fat oxidation, as calculated from cumulative recovery of deuterium from palmitic acid oxidation over 12 h after breakfast, ranged from 4% to 28% with a mean value of 16 ± 6%. In a stepwise regression analysis with energy balance or fat balance, diet composition or study, subject age, and body mass index as independent variables, dietary fat oxidation was negatively related to body mass index (*r* = −0.58, *P* < 0.001; **Figure 1A**). On average, dietary fat oxidation in a subject with a body mass index of 20 was twice that in a subject with a body mass index of 30.

Dietary fat oxidation showed a steep increase from 2 h after consumption to plateau at ≈12 h after consumption (**Figure 2**). In the 20 subjects in whom an additional measurement was performed 24 h after consumption, label recovery showed a further increase of 0.9 ± 1.1% (*P* < 0.01). The negative relation between dietary fat oxidation and body mass index already existed at 2 h (*r* = −0.36, *P* < 0.01), 4 h (*r* = −0.52, *P* < 0.001), 6 h (*r* = −0.64, *P* < 0.001), 8 h (*r* = −0.61, *P* < 0.001), and 10 h (*r* = −0.59, *P* < 0.001).

In a multiple regression analysis with sex and percentage body fat as independent variables and 12-h dietary fat oxidation as the dependent variable, dietary fat oxidation was negatively related to percentage body fat (*r* = −0.65, *P* < 0.001); values for women were higher than for men (**Figure 1B**). Energy balance or fat balance, diet composition or study, physical activity level in the chamber, and subject age did not explain any additional variation.

TABLE 2

Energy and substrate balances measured over 24 h in a respiration chamber (*n* = 56)¹

	Intake	Expenditure	Balance
	MJ/d		
Energy	9.76 ± 1.33	9.34 ± 0.34	0.41 ± 0.60 ²
Fat	3.35 ± 0.36	3.03 ± 1.05	0.30 ± 0.94 ²
Protein	1.34 ± 0.21	1.38 ± 0.48	−0.03 ± 0.43
Carbohydrate	5.07 ± 0.62	4.93 ± 1.05	0.14 ± 0.95

¹ All values are $\bar{x} \pm$ SD.

² Significantly different from zero, *P* < 0.01.

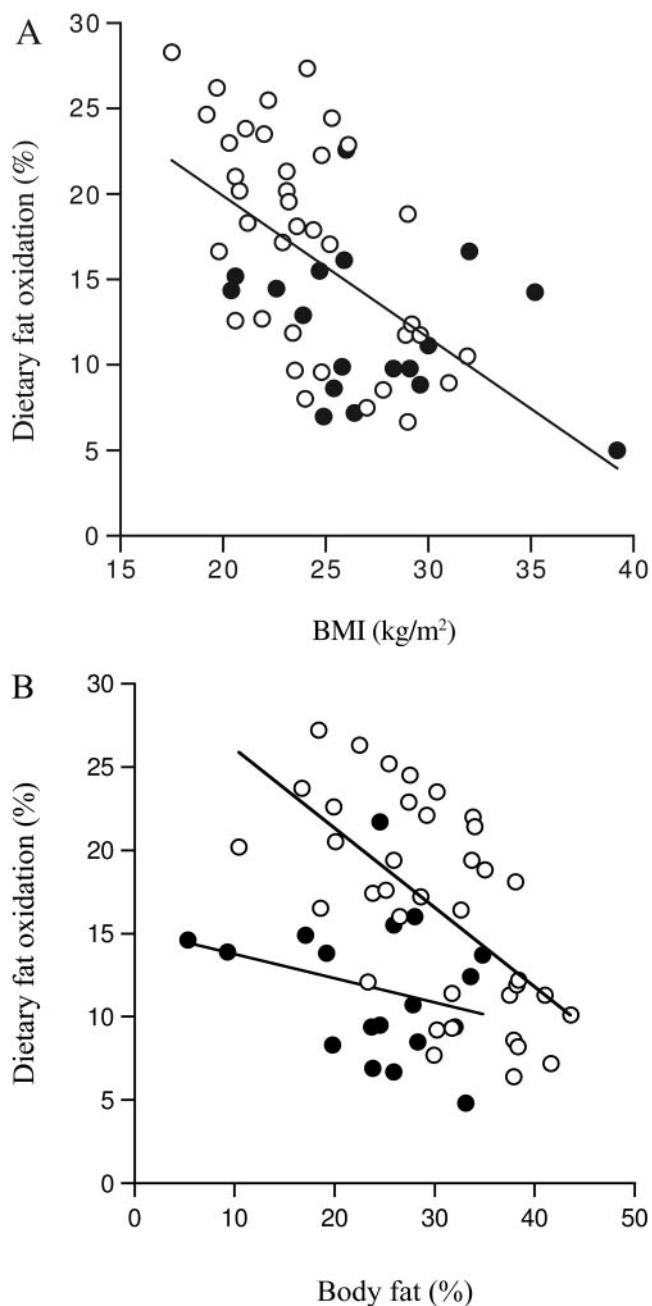


FIGURE 1. Dietary fat oxidation calculated by linear regression 12 h after consumption of deuterated palmitic acid as a function of BMI for women (○) and men (●) combined ($r = -0.58$, $P < 0.001$) (A) and as a function of body fat for women (○; $r = -0.65$, $P < 0.001$) and men (●; $r = -0.27$, NS) (B).

DISCUSSION

Dietary fat is often considered a factor in the development of obesity (19). Fat, as a substrate for energy metabolism, is at the bottom of the oxidative hierarchy that determines fuel selection (20). Here, we showed that dietary fat oxidation, as measured over 12 h after a breakfast containing deuterated palmitic acid, was negatively related to body fatness, and lean subjects had the highest and obese subjects the lowest values. All subjects were observed under similar sedentary conditions in a respiration chamber without activity equipment or a imposed activity protocol.

Dietary fat oxidation is often measured with ¹³C- or ¹⁴C-labeled fatty acids. Votruba et al (13) showed that results of the deuterated palmitic acid method are equivalent to results of the traditional [¹³C]palmitic acid method. An advantage of the deuterated palmitic acid method is that there is no need for a recovery correction due to exchange, ie, the [¹³C]acetate correction. The deuterium label, after oxidation of the labeled fat, accumulates in the body water and subsequent loss is negligible over the adopted study interval of 12 h.

The observed level of dietary fat oxidation is comparable with that observed in earlier studies. Votruba et al (13) calculated the recovery of deuterated palmitic acid to be $13 \pm 8\%$ 10 h after dosing. Recovery values from [¹³C]palmitic acid were $16 \pm 3\%$ over an interval of 9 h during which subjects were not allowed to eat, after a test meal of 3.00 MJ containing 38% of energy as fat (21). The oxidation of dietary fat decreases with increasing carbon number (22). Cumulative oxidation over 9 h ranged from a high of $34 \pm 10\%$ for laurate (12:0) to $14 \pm 3\%$ for palmitate (16:0) and to a low of $11 \pm 4\%$ for stearate (18:0). Sonko et al (23) estimated ingested fat oxidation over 24 h by providing subjects with $\approx 70\%$ of total fat intake over the 24-h interval from naturally ¹³C-enriched corn oil and from test meals supplemented with [¹³C]palmitic acid. They calculated that $28 \pm 3\%$ of ingested fat was oxidized over 24 h, which provided $8 \pm 1\%$ of total energy expenditure when the diet contained 30% of energy as fat.

The cumulative oxidation of dietary fat in time, as shown in Figure 2, corresponds to earlier observations with ¹³C-labeled fatty acids (24, 25). Peaks in ¹³C enrichment in breath were reached 3–5 h after intake of [¹³C]linoleic acid or [¹³C]palmitic acid. The 12-h recovery of 17% to 25% in subjects with a body mass index of 22.2 ± 1.3 also corresponded to the range observed for similar subjects in the current study (Figure 1). Thus, in the postprandial state, most of the dietary fat is channeled into adipose tissue (25).

The observed sex difference in dietary fat oxidation, ie, higher values in women than in men (Figure 1B), requires further study. Burdge et al (26, 27) observed the opposite, ie, lower dietary fat oxidation in women than in men. However, they gave women and men the same sized meal with the tracer; thus, the lower dietary

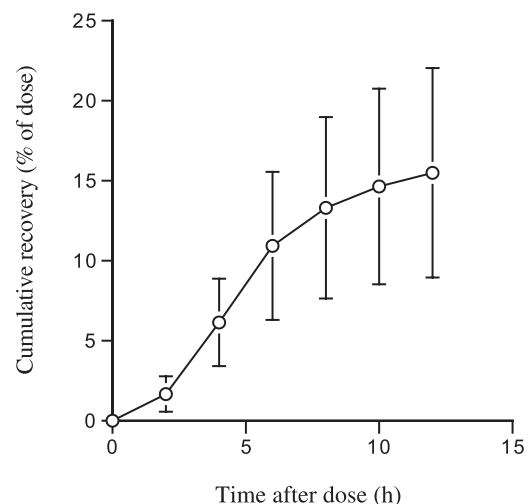


FIGURE 2. Mean (\pm SD) cumulative oxidation of dietary fat as a percentage of dose over time. $n = 56$.



fat oxidation in women possibly reflected the lower rate of energy metabolism in women than in men. Goyens (28) observed no sex difference in ^{13}C recovery as $^{13}\text{CO}_2$ in expired breath from ^{13}C -labeled fatty acids included in a standardized breakfast, without further information on breakfast size in relation to individual energy requirement. In the current study, the label was included in a breakfast consisting of a fixed fraction of 20% of the total individual daily energy requirement. The 4 studies cited above used a diet that provided 30–38% of energy from fat, which is similar to the diets used in the current study, which provided 30–35% of energy from fat.

In an animal model, differences in the partitioning of dietary fat between oxidation and storage were associated with obesity (10). Obesity-prone rats showed less oxidation and more storage of dietary fat than did obesity-resistant rats; the obesity-prone rats were only slightly heavier than the lean phenotype. In the current study the differences in body weight, and consequent differences in body fat, were much larger. The lower dietary fat oxidation in overweight and obese subjects could have been a cause or a result of the difference in body fatness. Indeed, increased fatty acid trapping by adipose tissue was observed in obese women (29).

Whatever the reason, the aim should be a reduction in the storage of dietary fat in obesity-prone and obese subjects. Further research on the effect of a reduction in energy intake, especially fat, and an increase in physical activity is required when accumulation of dietary fat is to be prevented. For physical activity, evidence suggests that moderate-intensity exercise yields the most grams of fat used for oxidation in the average individual (30), inactivity reduces the oxidation of saturated but not monounsaturated dietary fat (31), and exercise increases monounsaturated fat oxidation more than saturated fat oxidation regardless of exercise intensity (32). In conclusion, dietary fat oxidation is negatively related to percentage body fat and thus may play a role in human obesity.

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