

## Twenty-four-hour energy expenditure and substrate utilization in body builders<sup>1-3</sup>

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**ABSTRACT** Twenty-four-hour energy expenditure (EE) was measured by indirect calorimetry in 10 body builders and 10 lean control subjects of the same sex with similar age, height, and percent body fat. The study was performed to elucidate possible effects of strength training on energy metabolism and substrate utilization. Twenty-four-hour EE was higher in the body builders than in control subjects but was similar when adjusted for differences in fat-free mass. A higher 24-h nonprotein respiratory quotient (RQ) was found in the body builders. Because both groups were in energy balance, the higher RQ in the body builders can be attributed to a different habitual diet or may be explained by physiological differences. *Am J Clin Nutr* 1994;59:10-2.

**KEY WORDS** Energy metabolism, fat-free mass, indirect calorimetry, respiratory quotient, strength training

### Introduction

During rest, skeletal muscle mass has an oxygen uptake per kilogram tissue of only  $\approx 2.5\%$  of that seen in some of the internal organs (1). However, skeletal muscle mass comprises a substantial part of the total fat-free mass (FFM) and its contribution to whole-body energy metabolism is therefore important even under sedentary conditions. Zurlo et al (2) found that variation in oxygen uptake per volume of forearm tissue explained 40-50% of the variation in basal metabolic rate (BMR) adjusted for differences in FFM, body fat mass (FM), age, and sex. Skeletal muscle may play the most important role in the thermic response to meals; Astrup et al (3) suggested that  $\approx 60\%$  may be localized to muscles.

In the present study we investigated the effect of strength training, which normally causes an enlargement of the skeletal muscle mass, on 24-h energy expenditure (EE) and substrate utilization.

### Subjects and methods

#### Subjects

Twenty lean subjects, 18 males and 2 females, took part in the study. Ten of them, nine males and one female, participated regularly in strength training, such as body building and power lifting (hereafter referred to as body builders). The physical char-

acteristics of the subjects are given in **Table 1**. None of the subjects reported a history of obesity, any metabolic diseases or other chronic diseases, or food intolerance. All body builders reported that they had not taken anabolic steroids within the 2 mo immediately preceding the study.

#### Experimental design

The study was approved by the Municipal Ethical Committee of Frederiksberg and Copenhagen and the subjects gave informed consent according to the declaration of Helsinki II. Twenty-four-hour EE was measured by indirect calorimetry in a respiration chamber described in detail elsewhere (4). The body builders were told to maintain their habitual training routine during the days before the experiment but both groups were instructed not to perform prolonged aerobic exercise the 2 antecedent days. A predetermined program simulating ordinary daily activities was followed during the experiment. The 24-h period was subdivided into a daytime period (0930-0000), a sleeping period (0000-0830), and a postprandial period—4 h after the largest meal (1900-2300). To accustom the subjects to the environment, the night preceding the experiment was spent in the chamber.

The experimental diet provided  $180 \text{ kJ} \cdot \text{kg FFM}^{-1} \cdot \text{d}^{-1}$ . The energy composition was 51% from carbohydrate, 32% from fat, and 17% from protein. Dietary energy content and composition were calculated by *DANKOST* dietary-assessment software (National Food Agency, Søborg, Denmark), which is based on the factors of Atwater. Food left by the subjects was reweighed item by item for inclusion in the calculations of food intake. At the end of the 24-h calorimetry measurement each subject was weighed on an electronic scale (model 707; Seca, Copenhagen) after voiding the bladder. Bioelectrical impedance was measured by ANIMETER (HTS-Engineering Inc, Odense, Denmark). FFM was calculated according to the equations of Segal et al (5) for lean men and lean women. FM was calculated as body weight minus FFM.

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<sup>2</sup> Supported by the Danish Medical Research Council (12-9537).

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Received September 23, 1992.

Accepted for publication June 15, 1993.

TABLE 1  
Physical characteristics\*

	Body builders (n = 10)	Control subjects (n = 10)
Age (y)	26 ± 2.3	28 ± 1.9
Height (cm)	176 ± 2.5	178 ± 2.9
Weight (kg)	82 ± 4.1	71 ± 2.6†
Fat-free mass (kg)	69 ± 3.4	60 ± 2.6
Body fat mass		
(kg)	13 ± 1.3	10 ± 0.5
(%)	15.5 ± 1.0	14.9 ± 0.8
BMI‡	27 ± 1.4	22 ± 0.6§

\*  $\bar{x} \pm SE$ .

†§ Significantly different from body builders (two-sided *t* test):

†*P* = 0.03, §*P* = 0.01.

‡ In kg/m<sup>2</sup>.

### Calculations and statistics

Nonprotein respiratory quotient (RQ) was calculated as the ratio between carbon dioxide production and oxygen uptake, which did not arise from protein combustion. When substrate utilization and nonprotein RQ for each of the periods was calculated, a constant protein oxidation rate was assumed throughout the entire experiment and nitrogen excretion was only determined for the total 24 h.

Statistical analyses were performed with *STATGRAPHICS* software (Graphic Software Systems Inc, Rockville, MD). To test group differences, analyses of covariances (ANCOVA) were performed including FFM, FM, and age when EE was analyzed, or including energy balance when nonprotein RQ was tested. Statistical significance was set at *P* < 0.05. EE is expressed in kJ/24 h for all the experimental periods. EE values are presented unadjusted and adjusted for differences in FFM as described by Ravussin and Borgardus (6). All results are given as mean ± SE.

### Results

Twenty-four-hour and daytime EE were higher in the body builders than in the control subjects; however, no group differ-

TABLE 2  
Twenty-four-hour energy expenditure (24-h EE) and its components before and after adjustment for differences in fat-free mass\*

	Body builders	Control subjects
	MJ/d	
24-h EE	11.82 ± 0.51 (11.24 ± 0.28)	10.34 ± 0.36† (10.91 ± 0.16)
Daytime	14.01 ± 0.60 (13.35 ± 0.37)	12.12 ± 0.41† (12.79 ± 0.20)
Sleeping	8.38 ± 0.37 (8.0 ± 0.16)	7.55 ± 0.29‡ (8.0 ± 0.13)
Postprandial	12.20 ± 0.64 (11.51 ± 0.36)	10.61 ± 0.45‡ (11.30 ± 0.22)

\*  $\bar{x} \pm SE$ . Values adjusted for differences in fat-free mass are in parentheses. No group differences were found by analyses of covariance including fat-free mass, body fat mass, and age.

† Significantly different from body builders, *P* < 0.05 (two-sided *t* test).

‡ *P* < 0.10 (body builders vs control subjects, two-sided *t* test).

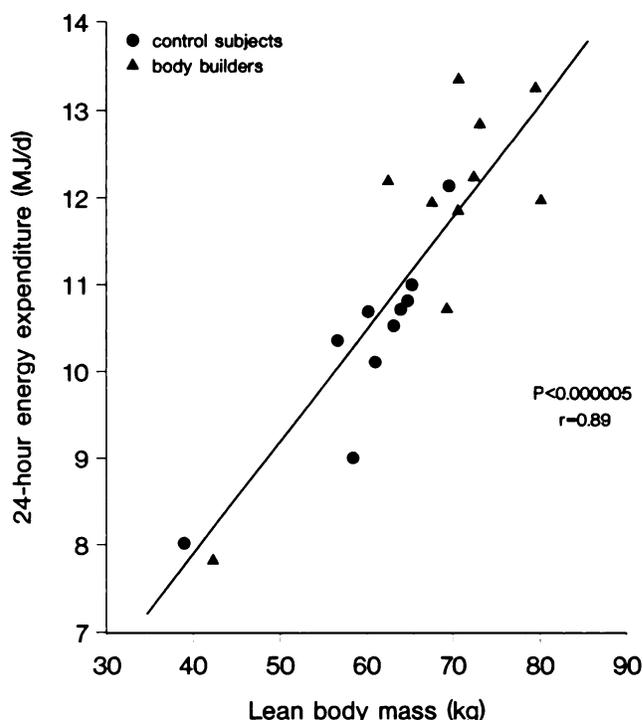


FIG 1. Relationship between 24-h energy expenditure and fat-free body mass (FFM) in 10 body builders and 10 lean control subjects.

ences were seen when 24-h, daytime, sleeping, and postprandial EE were tested by ANCOVA, which included FFM, FM, and age (Table 2). FFM was the only factor showing a significant relationship with EE (*P* < 0.001 for all the periods). Figure 1 illustrates the association between 24-h EE and FFM.

Twenty-four-hour nonprotein RQ was higher in the body builders than in the control group. During sleep no difference in nonprotein RQ was seen between the two groups whereas daytime nonprotein RQ tended to be higher in the body builders (Table 3). The higher nonprotein RQ in the body builders could not be related to a difference in energy balance because 24-h energy intake minus EE was similar in the two groups (body builders vs control subjects: 568 ± 290 vs 441 ± 244 kJ, *P* = 0.74). Furthermore, nonprotein RQ remained higher in body builders after energy balance was included as a covariate.

TABLE 3  
Twenty-four-hour nonprotein respiratory quotient (RQ) and its components\*

	Body builders	Control subjects
24 h	0.882 ± 0.013	0.850 ± 0.003†
Daytime	0.889 ± 0.014	0.861 ± 0.036‡
Sleeping	0.844 ± 0.018	0.835 ± 0.006
Postprandial	0.889 ± 0.012	0.880 ± 0.007

\*  $\bar{x} \pm SE$ . *P* values attained by ANCOVA, including 24-h energy intake - 24-h EE as a covariate. Nonprotein RQ calculated as  $\dot{V}CO_2/\dot{V}O_2$  after subtraction of estimated gas exchange arising from protein oxidation.

† Significantly different from body builders, *P* < 0.05.

‡ *P* < 0.10 (body builders vs control subjects).

**Table 4** presents 24-h oxidation rates of the three macronutrients and the calculated macronutrient intakes for each group. The body builders had a higher 24-h carbohydrate oxidation rate, which entirely covered the higher EE of this group. No differences appeared between intake and oxidation of any of the macronutrients in the body builders whereas the control subjects were in positive carbohydrate balance and negative fat balance.

## Discussion

No differences in EE were found between body builders and control subjects when differences in FFM were taken into account. This result agrees with the findings in a study performed by Broeder et al (7), in which 12 wk of intensive strength training had no impact on resting metabolic rate (RMR), but disagrees with a cross-sectional study in which a higher RMR was observed in body builders than in nontrained individuals after differences in FFM were accounted for (8). However, the comparison between resistance-trained and nontrained individuals may be biased by differences in the composition of FFM. The higher FFM in body builders is probably mostly accounted for by a greater muscle mass. Resting skeletal muscle mass has a lower metabolic rate than the rest of the FFM, eg, internal organs (1). When FFM is considered as a single entity when adjusted for, there may be an underestimation of the effect of strength training on resting EE.

A comparison between the composition of the 24-h diet and 24-h substrate utilization reveals that the control subjects oxidated more lipid than was provided by the diet. Provided a zero

energy balance in both groups, the observation of a higher 24-h nonprotein RQ in the body builders may reflect a carryover effect in the control group from a habitual diet with a higher lipid content. A lower percent fat in the habitual diet of resistance-training males compared with untrained males was found in a study including 3-d self-recorded food diaries (8). Alternatively, the composition of the experimental diet might deviate similarly from the composition of the habitual diet in both groups. The higher nonprotein RQ in the body builders would then be due to biological mechanisms giving rise to different dynamics in the adaptation of the oxidation to the experimental diet. Although single bouts of aerobic exercise result in a higher lipid oxidation during the subsequent 18 h (9), studies involving endurance training (7, 10) indicate that physical training may have a chronic promoting effect on sedentary postabsorptive carbohydrate oxidation. One explanation may be that carbohydrate availability may be higher during postabsorptive periods because of an improved capacity for carbohydrate storage. 

We thank John Lind, Inge Timmermann, Lene Kromann-Larsen, Christina Cuthbertson, and Inger-Lise Grønfeldt for their contributions to the study. Irene Bosseleers was an exchange student in Human Nutrition from the Agricultural University in Wageningen, Holland.

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**TABLE 4**  
Twenty-four-hour macronutrient intake and oxidation\*

	Body builders	Control subjects
	<i>MJ/d</i>	
Carbohydrate oxidation	5.75 ± 0.42	4.34 ± 0.17†‡
Carbohydrate intake	6.22 ± 0.27	5.60 ± 0.26
Fat oxidation	3.83 ± 0.52	4.34 ± 0.17§
Fat intake	3.97 ± 0.16	3.41 ± 0.20†
Protein oxidation	2.24 ± 0.27	1.66 ± 0.13
Protein intake	2.20 ± 0.16	1.78 ± 0.06†

\*  $\bar{x} \pm SE$ . Macronutrient intake was calculated from *DANKOST* dietary-assessment software (National Food Agency, Søborg, Denmark).

† Significantly different from body builders,  $P < 0.05$  (two-sided  $t$  test).

‡ Significantly different from carbohydrate intake,  $P < 0.05$  (two-sided  $t$  test for paired observations).

§ Significantly different from fat intake,  $P < 0.05$  (two-sided  $t$  test for paired observations).

||  $P < 0.10$  (body builders vs control subjects, two-sided  $t$  test).