

MEASUREMENT

Energy metabolism in relation to body composition and gender in adolescents

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Abstract

Objective—To study the effect of body composition on average daily metabolic rate (ADMR) and basal metabolic rate (BMR) in adolescence, and to examine current BMR prediction equations.

Study—Dutch adolescents were pooled with previously reported American and British subjects (n = 90 overall). BMR and ADMR were analysed by multiple regression.

Results—Fat-free mass, BMR, and ADMR were higher in the obese than in the non-obese group (mean (SD): 53.2 (10.7) kg, 8.35 (1.57) MJ/d, and 13.64 (2.78) MJ/d, compared with 41.0 (8.1) kg, 6.42 (0.94) MJ/d, and 11.16 (2.21) MJ/d, respectively). BMR remained higher when adjusted for fat-free mass, age, and sex. ADMR adjusted for BMR was similar in the two groups. WHO equations overestimated BMR in obese boys and underestimated BMR in non-obese boys.

Conclusions—BMR, but not activity, is increased in obese adolescents and in male adolescents. The WHO BMR equations for adults are recommended for obese adolescents.

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Keywords: energy metabolism; obesity; doubly labelled water

The prevalence of overweight and obesity in children and adolescents is rapidly increasing in Western societies.¹⁻⁴ Obesity during adolescence is associated with raised blood pressure and lipid profiles, which increase the risk of obesity related disease and mortality.⁵⁻⁸ Awareness is growing that the long term cardiovascular health of the next generation of adults is an issue of concern.⁹⁻¹¹ Moreover, the obese adolescent has the highest risk of becoming an obese adult,¹² regardless of parental obesity.¹³ Because obesity in adult life remains difficult to treat,¹⁴ the adolescent age group is of increasing interest as a target for obesity treatment.¹⁵ Knowledge of energy metabolism in adolescents is thus of vital importance for future obesity interventions.

Obesity is characterised by excess adipose tissue. The extra weight that results consists not only of fat mass but also of fat-free mass.

Generally, energy expenditure is increased not only because the increased fat-free mass results in a rise in basal metabolic rate (BMR), but also because of the higher energy cost of weight bearing activities.¹⁶ During adolescence, however, growth spurts and biological maturation may have additional effects on body composition and energy expenditure.^{17,18} Because of these potential confounding factors, several studies measuring basal metabolism in obese adolescents¹⁹⁻²⁵ have tested the validity of existing BMR prediction equations,²⁶ often generating new equations.^{25,26} Only one study has addressed the effect of obesity on BMR as well as on total energy expenditure—or average daily metabolic rate (ADMR)—in this age group.²⁷

Our aim in the study was to examine the relation between ADMR, BMR, and body composition in obese and non-obese male and female adolescents. Because of economic constraints, our objectives were achieved by using results from our own study centre pooled with previously published data. The specific objectives were first, to examine the nature of the relation between ADMR, BMR, and fat-free mass in adolescents, using recommended laboratory techniques; second, to determine the effects of fat mass and sex on ADMR and BMR in this age group; and third, to assess whether existing FAO/WHO/UNU equations can be used to predict BMR in lean and obese adolescents, defining obesity according to current recommendations.²⁸

Methods

A Medline and cross reference search was performed for existing datasets on ADMR and BMR in adolescents. Inclusion criteria were:

- individually reported measures of fat-free mass, BMR, and ADMR from peer reviewed journal articles;
- subjects to be between 12 and 18 years of age and with no disease state other than obesity;
- total body water and ADMR had to be measured by doubly labelled water (free living) and BMR by ventilated hood. Fat-free mass had to be calculated by total body water.

The results were extracted from each report and pooled. For each individual, information about centre localisation, sex, body weight,

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Table 1 Characteristics of obese and non-obese adolescent subjects

Variable	NL-O	US-O	Obese (all)	UK-N	US-N	Non-obese (all)
Sex (F:M)	11:13	12:15	23:28	8:8	10:13	18:21
Age (years)	13.9 (1.3)*	15.0 (1.9)	14.5 (1.7)	13.5 (1.6)	14.3 (1.3)	14.0 (1.5)
Height (cm)	163.4 (6.4)	166.8 (7.9)	165.2 (7.4)	158.6 (10.9)	164.2 (8.6)	161.9 (9.9)
Weight (kg)	85.0 (16.2)**	101.4 (23.2)	93.7 (21.7)†	47.7 (8.3)‡	55.3 (9.5)	52.2 (9.7)
BMI (kg/m ²)	31.7 (4.9)*	36.3 (7.7)	34.1 (6.9)†	19.0 (2.9)	20.5 (2.8)	19.9 (2.9)

Values are mean (SD) or n.

* $p < 0.05$, ** $p < 0.01$ *v* US-O.

† $p < 0.001$ *v* non-obese.

‡ $p < 0.05$ *v* US-N.

NL-O, obese group from the Maastricht area; UK-N, non-obese group from the Belfast area; US-N, non-obese group from the Boston area; US-O, obese group from the Boston area.

height, fat-free mass, fat mass, BMR, and ADMR was extracted into the database. Subject characteristics are shown in table 1.

SUBJECTS AND PROTOCOL OF STUDY CENTRE MAASTRICHT

Twenty four obese subjects (age 12.0 to 17.4 years) with a body mass index (BMI) and triceps skinfold thickness greater than or equal to the 97th centile for age and sex²⁹ were recruited from the regional public health department and paediatric outpatient clinic of the university hospital Maastricht. Subjects with endocrine causes or other secondary causes of obesity were excluded. Before the start of the study the parents gave written informed consent, confirmed by the oral approval of the child. The study was approved by the medical ethics committee of Maastricht University.

Height, weight, and BMR measurements have been described in detail previously,^{30,31} and total body water and ADMR were measured according to the Maastricht protocol for the measurement of body composition and energy expenditure with labelled water.³² In summary, the subject received an oral dose of ²H₂O and H₂¹⁸O as the last drink before bedtime. A urine sample was taken 10 hours after this dose from the second voiding the next morning (day 1). Isotope abundance in the urine was determined using an isotope ratio mass spectrometer (Aqua Sira, VG Isogas, Micromass, Manchester, UK). Total body water was calculated as the ²H dilution space divided by 1.04, correcting for exchange of the ²H label with non-aqueous H of body solids.³³ Fat-free mass was assessed on the assumption that the fat-free mass contains all the body water, using a hydration factor of 0.73. Isotope disappearance rates in the urine from the samples taken on days 1, 8, and 14 from the subsequent 14 days were used to calculate carbon dioxide production. Carbon dioxide production was converted to average daily metabolic rate (total energy expenditure), with a respiratory exchange ratio equal to the food quotient that was derived from a one week food diary.

On day 1, BMR measurement was started after the subject had been lying supine for 10 minutes. Oxygen consumption and carbon dioxide production were measured over 40–50 minutes—using a computerised open circuit ventilated hood system—while the subject was watching television. Gas analyses were performed using a paramagnetic oxygen analyser (Servomex, Crowborough, UK) and an infrared carbon dioxide analyser (Uras 3G, Hartmann and Braun, Frankfurt, Germany). BMR was calculated according to Weir³⁴ over the 14 minute interval with the lowest standard deviation.

BMR PREDICTION EQUATIONS

BMR was calculated according to the prediction equations of the Food and Agriculture Organisation (FAO), the World Health Organisation (WHO), and United Nations University (UNU)¹⁸ on the basis of weight (WHO-1), and weight in combination with height (WHO-2) for ages 10–18 years, as well as for ages 18–30 years (WHO-1a and WHO-2a, respectively) (table 2).

STATISTICAL ANALYSIS

All subjects included in the study (from the Maastricht centre as well as from the other centres that met the inclusion criteria) were pooled. According to the current recommendations,²⁸ the common criterion for obesity was a BMI above the 95th centile for age and sex. Differences in independent variables between the obese and non-obese groups and between the centres—as well as sex differences within the pooled groups—were analysed by the two sample *t* test. Differences in the mean of the measured and predicted BMR in male and female subjects were determined with a paired *t* test as a measure of accuracy. To measure the precision of the BMR predictions, the mean absolute error for each subgroup was calculated.

Second, a multiple linear regression model with BMR as the dependent variable and fat-free mass, age, and sex as independent variables was used to analyse the difference in BMR between the obese and non-obese adolescents, defined by the binary variable group. The difference in regression slope of the influence of fat-free mass on BMR was tested using interaction variables of group and fat-free mass and group and sex, after correction for the variables in the equation. The difference between groups, corrected for these independent variables, was then estimated and tested for significance using linear regression, assuming

Table 2 FAO/WHO/UNU calculations of BMR

WHO-1	10–18 years	Male	0.0732 * weight + 2.72 (MJ/d)
		Female	0.0510 * weight + 3.12 (MJ/d)
WHO-2	10–18 years	Male	69.4 * weight + 322.2 * height + 2392 (kJ/d)
		Female	30.9 * weight + 2016.6 * height + 907 (kJ/d)
WHO-1a	18–30 years	Male	0.0640 * weight + 2.84 (MJ/d)
		Female	0.0615 * weight + 2.08 (MJ/d)
WHO-2a	18–30 years	Male	64.4 * weight - 113.0 * height + 3000 (kJ/d)
		Female	55.6 * weight + 1397.4 * height + 146 (kJ/d)

Table 3 Energy expenditure and body composition of obese and non-obese adolescents

Variable	NL-O	US-O	Obese (all)	UK-N	US-N	Non-obese (all)
FFM (kg)	49.0 (8.5)**	56.8 (11.4)	53.2 (10.7)†††	36.6 (6.4)‡‡	44.1 (7.8)	41.0 (8.1)
FM (kg)	35.9 (9.6) *	44.6 (15.1)	40.5 (13.4)†††	11.0 (5.4)	11.2 (5.0)	11.1 (5.1)
%FM (%)	42.0 (4.9)	43.1 (6.8)	42.6 (6.0)†††	22.8 (7.9)	20.0 (7.2)	21.2 (7.6)
BMR (MJ/d)	7.81 (1.32) *	8.83 (1.65)	8.35 (1.57)†††	6.02 (0.86)‡	6.71 (0.91)	6.42 (0.94)
ADMR (MJ/d)	12.14 (2.19) ***	14.98 (2.58)	13.64 (2.78)†††	10.28 (1.38)‡	11.77 (2.49)	11.16 (2.21)
PAL	1.56 (0.18) **	1.71 (0.18)	1.64 (0.19)†	1.72 (0.18)	1.75 (0.24)	1.73 (0.21)

Values are mean (SD).

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ *v* US-O.

† $p < 0.05$, ††† $p < 0.001$ *v* non-obese.

‡ $p < 0.05$, ‡‡ $p < 0.01$ *v* US-N.

NL-O, obese group from the Maastricht area; UK-N, non-obese group from the Belfast area; US-N, non-obese group from the Boston area; US-O, obese group from the Boston area; PAL, physical activity level (ADMR/BMR).

equal slopes. The same procedure was done with ADMR as the dependent variable, again with fat-free mass, age, and sex as independent variables, and obesity as the grouping variable. This analysis was repeated with BMR instead of fat-free mass as covariate.

Finally, to detect differences between centres, these procedures were repeated within the complete study sample with the study centre as the grouping variable.

The significance level was chosen as 5%. Data are expressed as mean (SD). SPSS release 6.1 for Macintosh (SPSS Inc, Chicago, Illinois, USA) was used as the statistical package.

Results

Of the five BMR and ADMR studies in adolescents²⁷⁻³⁸ that were found in published reports, two met the inclusion criteria: that of Bandini *et al.*,²⁷ who measured obese as well as non-obese adolescents in the Boston region (Massachusetts, USA), and that of Livingstone *et al.*,³⁶ who measured children and adolescents of age 7, 9, 12, and 15 years in the Belfast area (Northern Ireland, United Kingdom). For the present study, based on subjects between 12 and 18 years of age, only the adolescent groups (12 and 15 years) in Livingstone's report are included. All the obese American and Dutch subjects met the common obesity criterion of BMI > 95th centile for age and sex, whereas the other American and British subjects did not. Thus there were two groups of obese adolescents (American and Dutch: US-O and NL-O) and two groups of non-obese adolescents (American and British: US-N and UK-N). When combined, these formed a pooled group of 90 subjects. There were no statistically significant differences between the

groups for sex and height. However, in the obese group as well as in the non-obese group the Americans were heavier than their European counterparts. The US-O group was also older than the NL-O group (table 1). Fat-free mass, fat mass, % fat mass, BMR, ADMR, and physical activity level (ADMR/BMR) were all higher in the obese adolescents. Within the obese group, fat-free mass and fat mass were higher in the US-O group than in the NL-O group, while % fat mass was similar. BMR, ADMR, and physical activity level were also higher in US-O. Within the non-obese group, there was a higher fat-free mass, BMR, and ADMR in the US-N group than in the British adolescents (table 3).

There were no differences between male and female subjects in age, height, weight, or BMI within the obese and non-obese groups (not shown). In addition, fat-free mass was similar, whereas % fat mass was lower in male than in female subjects, but only in the non-obese group (mean (SD): 17.1 (5.4)% *v* 25.9 (7.0)% ($p < 0.0001$)). BMR was higher in male than in female subjects in both the obese and non-obese groups (8.90 (1.58) *v* 7.69 (1.31) MJ/d ($p < 0.01$), and 6.95 (0.84) *v* 5.81 (0.64) MJ/d ($p < 0.001$), respectively). A significant difference between male and female subjects was also found in ADMR for both the obese and the non-obese groups (14.45 (2.69) *v* 12.67 (2.63) MJ/d ($p < 0.05$), and 12.17 (2.02) *v* 9.98 (1.83) MJ/d ($p < 0.01$), respectively). There were no sex differences in physical activity level.

BMR adjusted for fat-free mass resulted in a higher BMR in the obese group than in the non-obese group, even when also adjusted for age and sex. For the complete study sample,

Table 4 FAO/WHO/UNU prediction equations for basal metabolic rate (BMR) of male and female subjects in the obese and non-obese groups

Group	Sex	BMR (MJ/d)	WHO-1 (MJ/d)	WHO-2 (MJ/d)	WHO-1a (MJ/d)	WHO-2a (MJ/d)
Obese	Male	8.90 (1.58)	9.62 (1.63)***	9.46 (1.56)**	8.86 (1.42)	8.87 (1.43)
	Female	7.69 (1.31)	7.88 (1.10)	7.10 (0.72)§§	7.81 (1.32)	6.73 (1.19)§
	Total	8.35 (1.57)	8.84 (1.65)†††	8.40 (1.72)	8.39 (1.46)	7.91 (1.70)††
Non-obese	Male	6.95 (0.84)	6.55 (0.75)‡‡	6.54 (0.74)‡‡	6.18 (0.66)‡‡‡	6.18 (0.65)‡‡‡
	Female	5.81 (0.64)	5.79 (0.48)	5.74 (0.38)	5.29 (0.58)§§	4.45 (0.52)§§§
	Total	6.42 (0.94)	6.19 (0.74)¶	6.17 (0.72)¶	5.77 (0.76)¶¶¶	5.38 (1.05)¶¶¶

Values are mean (SD).

** $p < 0.01$, *** $p < 0.001$ *v* BMR of obese male subjects.

§ $p < 0.05$, §§ $p < 0.01$ *v* BMR of obese female subjects.

†† $p < 0.01$, ††† $p < 0.001$ *v* BMR of obese group.

‡‡ $p < 0.01$, ‡‡‡ $p < 0.001$ *v* BMR of non-obese male subjects.

§§ $p < 0.01$, §§§ $p < 0.001$ *v* BMR of non-obese female subjects.

¶ $p < 0.05$, ¶¶ $p < 0.001$ *v* BMR of non-obese group.

FAO/WHO/UNU, Food and Agriculture Organisation/World Health Organisation/United Nations University; WHO-1: equations based on weight for age 10-18 years; WHO-2: equations based on weight and height for age 10-18 years; WHO-1a: equations based on weight for age 18-30 years; WHO-2a: equations based on weight and height for age 18-30 years.

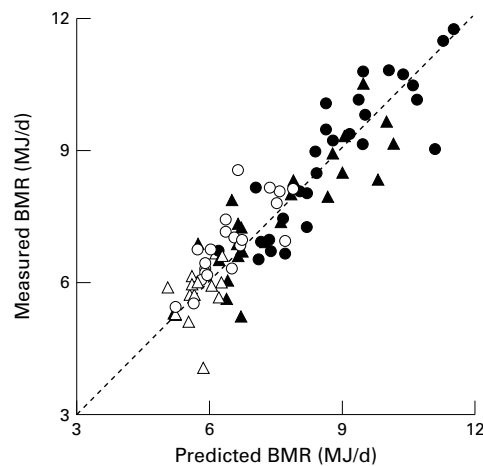


Figure 1 Measured basal metabolic rate (BMR, in MJ/d) as a function of predicted BMR by FAO/WHO/UNU equations (in MJ/d). The obese group (filled symbols) is predicted by adult BMR equations based on weight, and the non-obese group (empty symbols) is predicted by adolescent equations based on height and weight. Female subjects are represented by triangles, male subjects by circles. The dotted line represent the line of identity.

fat-free mass accounted for 80% of the observed variance. Other significant determinants in the prediction of BMR were age and sex.

Both WHO-1 and WHO-2 overestimated the measured BMR in obese male subjects (mean absolute error (MAE) = 723 and 562 kJ, respectively); however, they underestimated BMR in the non-obese male subjects (MAE = 405 and 412 kJ), as demonstrated by the differences in the means shown in table 4. Conversely, WHO-2 underestimated BMR in obese female subjects (MAE = 591 kJ), while the BMR of both obese and non-obese females was adequately predicted by WHO-1 (MAE = 189 and 19 kJ, respectively). WHO-1a and WHO-2a underestimated BMR in non-obese male and female subjects (MAE = 773 and 778 kJ, and 517 and 136 kJ, respectively); however, the measured BMR in obese male and obese female subjects was best predicted by WHO-1a (MAE = 33 and 119 kJ). Thus WHO-2 had the lowest MAE for the non-obese male and female subjects, while WHO-1a had the lowest MAE in the obese male and female subjects. In fig 1, BMR is a function of the BMR prediction of the WHO-2 for the non-obese adolescents and WHO-1a for the obese adolescents, as these prediction equations had the smallest MAE in each group.

ADMR adjusted for fat-free mass resulted in equal outcomes for the obese and the non-obese group even when adjusted for age and sex, the latter negatively influencing ADMR. Fat-free mass accounted for 66% of the observed variance, which could be increased by including age and sex in the equation, adding 5% to the explained variance. For the complete study sample, BMR accounted for 71% of the observed variance, while age—as the only other significant predictor for ADMR—increased the explained variance to 72%.

Discussion

Because there is a scarcity of studies on total energy expenditure in obese as well as non-obese adolescents, our aim in the present study was to combine energy expenditure and body composition data from obese adolescents from the Maastricht region with individual data from the USA (Boston area)²⁷ and the United Kingdom (Belfast area)³⁶ to determine the effect of obesity and sex on energy metabolism in this age group.

BMR adjusted for fat-free mass was higher in the obese group. Although sex and age, as known predictors of BMR, were significant variables in the regression, the statistical difference between the obese and non-obese group remained. These findings therefore confirm the conclusions of some earlier reports,^{19 27 39} although not all found a difference between obese and non-obese adolescents.⁴⁰ When fat mass was included in the analysis, the difference between obese and non-obese subjects was lost. However, this does not imply that in obese adolescents fat mass is (more) metabolically active. One explanation is that obesity causes changes in chemical composition of fat-free mass.^{41 42} Using theoretical calculations it has been shown that, owing to a relative increase in total body water, the density of fat-free mass is decreased in the obese state, leading to an overestimation of fat mass when measured by underwater weighing.⁴³ However, in the present study total body water was measured directly by deuterium dilution, so this variable cannot therefore account for the increased BMR. Another explanation is that the increased BMR adjusted for fat-free mass is not based on an underestimation of fat-free mass but on an increase in the mass of metabolically active organs. Obesity could be associated with a relative increase in internal organ mass compared with muscle mass. As the major organs of the body (the brain, heart, kidney, and liver, including the splanchnic bed) have similar high levels of basal metabolism compared with skeletal muscle,⁴⁴ a higher proportion of these organs in the fat-free mass would be reflected by an increase in BMR, even when the result is adjusted for fat-free mass.

In contrast to the findings of Katch *et al*,¹⁹ our study showed a higher BMR in male subjects, independently of body composition. As for obesity, one could speculate that the relative organ mass in female subjects is smaller than in male subjects or—as has been shown in adults—that Na/K-ATPase activity is reduced in females.⁴⁵ This latter is also related to a lower BMR.⁴⁶

Recently, existing equations to estimate BMR in non-obese children aged 10–15 years have been thoroughly evaluated.²⁶ The investigators concluded that weight was the single most important factor in the equations for either sex, and that the FAO/WHO/UNU equations performed best in predicting BMR in this specific age group. In our present data, however, not all subgroups were well predicted by FAO/WHO/UNU equations. Both WHO-1 and WHO-2 were good predictors of BMR in non-obese female subjects but underestimated

the BMR in non-obese male subjects, resulting in a general underestimation of energy expenditure in the non-obese group as a whole. The underestimation of energy requirements was anticipated by the FAO expert committee, because their database included subjects who may have been on limited energy intakes before the BMR measurement, as well as Indian subjects who were found to have BMR values that were approximately 10% below the average.¹⁸ However, in the present obese group, the BMR in male subjects was overestimated by WHO-1 as well as by WHO-2, resulting in a general overestimation of BMR by FAO/WHO/UNU equations for obese male subjects. Estimation by WHO-2 seemed similar to the measured BMR; however, this was merely the result of a compensating effect of the underestimated BMR in female subjects.

The overestimation of BMR by WHO standards in 10–16 year old healthy children has been reported before, in both obese and non-obese subjects.²⁴ We do not have an explanation for these conflicting findings other than that the measurement of BMR is known to be subject of much error. One may conclude from these data that WHO-1a provides the best BMR prediction for the obese adolescents, while WHO-1 adequately predicts BMR in obese as well as non-obese female subjects, but gives the worst prediction in obese male subjects. Thus a combination of the use of WHO-2 for non-obese adolescents and WHO-1a for obese adolescents results in the best fit along the line of identity (fig 1), although the amount of variation around this line shows—as already the FAO expert committee already concluded—that equations cannot substitute for direct BMR measurements.

The sex effect on ADMR is actually based on BMR differences, as sex only has a negative effect on ADMR when corrected for age and fat-free mass and not when adjusted for BMR. Therefore, in concordance with data on 4–10 year old children,⁴⁷ our present study showed no effect of gender on activity related energy expenditure. Conversely, in a meta-analysis of adult data,⁴⁸ the sex difference was also demonstrated for ADMR when adjusted for BMR, and it was independent of fat mass. This may indicate that the sex effect on activity related energy expenditure does not appear before adulthood.

In contrast to the effect of obesity on BMR, ADMR is not directly influenced by an excess of fat mass when adjustment is made for fat-free mass. Accordingly, one would expect the energy expenditure of physical activity to be lower in obese individuals, as physical activity and BMR account for about 90% of ADMR. The ratio of ADMR to BMR (physical activity level) provides a measure of activity related energy expenditure corrected for BMR, assuming that diet induced energy expenditure is a constant proportion of ADMR.¹⁸ In the present study, the physical activity level of male adolescents was within the range of 1.6–1.75, as suggested by FAO/WHO/UNU. The average physical activity level of female adolescents was higher than suggested (1.5–1.65),¹⁸ resulting in

an underestimation of the calculated ADMR in this subgroup by FAO/WHO/UNU, as was reported earlier.³⁷

The obese group had a lower physical activity level, indicating a lower activity level overall—which contrasts with other published reports. These have generally been in agreement that obese and non-obese subjects have similar total energy expenditure levels after adjusting for differences in body composition.⁴⁸ In this context, an alternative way of measuring differences in activity related energy expenditure is by analysis of covariance based on multiple regression.⁴⁹ Using this technique—which is most valuable in adjusting data with non-zero intercepts, such as the present data—the relation of ADMR with BMR in obese and non-obese male and female subjects was compared using BMR as a covariate. This analysis showed that activity related energy expenditure is indeed similar in the two groups. It also demonstrates that in this age group physical activity increases with age. Although the positive effect of age on ADMR—after adjustment for BMR—was marginal, it might in part explain the low physical activity level in the younger NL-O group and the high physical activity level found in 15 year old Swedish adolescents.³⁸ On the other hand it is striking that physical activity decreases both in boys⁵⁰ and girls⁵¹ just before puberty, while in this study we have shown that activity, adjusted for sex and body composition, further increases during adolescence towards adulthood.

As the data in this study were pooled from three different centres, it is important to test the assumption that the protocols for the measurement of ADMR, BMR, and fat-free mass were comparable. In multiple linear regression models with BMR or ADMR as the dependent variables, and fat-free mass, fat mass, age, and sex as independent variables, the dummy variables for centre localisation were not significant, indicating that there were no differences that could be accounted for by centre when correction was made for body composition, sex, and age. The assumption of comparable protocols is therefore allowed.

Another point of discussion might be the use of a hydration constant of 0.73 for the calculation of fat-free mass. The hydration factor of fat-free mass changes during growth, ranging from 82% in the newborn to 72% in adult life.^{52–54} Indeed, in previous studies^{30–31} describing young children through to adulthood, hydration factors were used that were based on maturation,⁵⁵ assessed according to Tanner's puberty ratings.⁵⁶ In the present study, however, not all centres collected maturation data. Thus an average adolescent hydration factor was used.

CONCLUSIONS

An attempt to combine the sparse data on energy metabolism in obese and non-obese adolescents has been made. Our study combined energy expenditure and body composition data from different centres, and suggests that during adolescence BMR is increased in the obese state and in male

subjects, independently of differences in body composition. The FAO/WHO/UNU equations underestimate BMR in non-obese adolescents and overestimate BMR in obese male adolescents. For the obese subgroup, we recommend the adult FAO/WHO/UNU BMR prediction equations, based on weight. The ADMR of obese adolescents, adjusted for body composition or BMR, is comparable to that of their non-obese peers, indicating that activity related energy expenditure does not differ between obese and non-obese adolescents.

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